

British Geological Survey



Mineral Reconnaissance Programme

Mineral exploration in the
Cockermouth area, Cumbria.
Part 2: follow-up surveys

Department of Trade and Industry

MRP Report 122
Technical Report WF/92/3

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D C Cooper, D G Cameron, B Young,
B C Chacksfield and J D Cornwell

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BRITISH GEOLOGICAL SURVEY

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SUMMARY

This report describes the results of geochemical, geological and geophysical surveys across three small areas of Carboniferous and Lower Palaeozoic rocks along the northern margin of the English Lake District. The areas were chosen from the appraisal of regional-scale survey data described by Cooper et al. (1991). In two of the areas, Ruthwaite and Tallentire, the objective was to provide more information on the extent and magnitude of fracture-controlled epigenetic baryte and base metal mineralisation. In the third area, at Whitrigg, brief surveys were carried out to aid the interpretation of unexplained geochemical and geophysical anomalies found during two projects carried out under the Mineral Exploration and Investment Grants Act (MEIGA).

At Ruthwaite, where a mine formerly worked baryte from a fault separating Lower Palaeozoic and Carboniferous rocks, surface indications of further baryte mineralisation were found. Soil analyses indicated that mineralisation may be present along the continuation of the faultline worked at Ruthwaite and in the Eycott Volcanic Group rocks to the south of it. In this area relatively small, but in some circumstances perhaps economically attractive, deposits of baryte may be present under drift cover.

In the Tallentire Hill area, geological mapping followed by traverse-based soil sampling showed that fracture-controlled mineralisation is widespread in the Carboniferous (Dinantian and Namurian) rocks. The fracture fillings consist dominantly of baryte, often accompanied by carbonate, with traces of copper and mercury. Where seen at surface the fracture fillings are too small, patchy and low-grade to be of any economic importance. Baryte mineralisation also occurs locally as patchy impregnations in sandstones. These are considered to be epigenetic deposits related to the fracture-controlled mineralisation. Trial geophysical surveys suggested that electrical methods may be useful in determining the extent of the mineralised sandstone. There is a possibility that more extensive baryte deposits may be present in the limestone succession underlying the mineralised sandstones.

In the Whitrigg area, Carboniferous rocks are separated from Lower Palaeozoic rocks of the Eycott Volcanic Group by the easterly-trending Boundary Fault and north-westerly-trending Bothel Fault. Evidence from an old mineral working and the results of a soil survey indicate that patchy, epigenetic, fracture-controlled baryte and base metal mineralisation occurs along the Bothel Fault and, locally, in the adjacent rocks. A feature of this mineralisation is the presence of mercury, which is most abundant in a sample of brecciated and altered rock from the Eycott Volcanic Group. Prominent base metal in soil anomalies discovered by MEIGA-funded projects near Stangerhill are not associated with barium anomalies. It was concluded that these soil anomalies are most likely to be caused by secondary concentration in overburden, and that the source of metals may be a sub-cropping metalliferous horizon within the Carboniferous succession or, more probably, fracture-controlled mineralisation.

Trial geophysical surveys carried out in all three areas indicated that in ground free of artificial sources the VLF(EM) and conductivity mapping methods could be useful for tracing faults beneath drift and providing information on drift thickness. Closely-spaced soil sampling proved effective for detecting mineralisation in areas where the drift cover is thin, and a trial soil-gas survey showed that this technique could also be useful for tracing faults beneath drift.

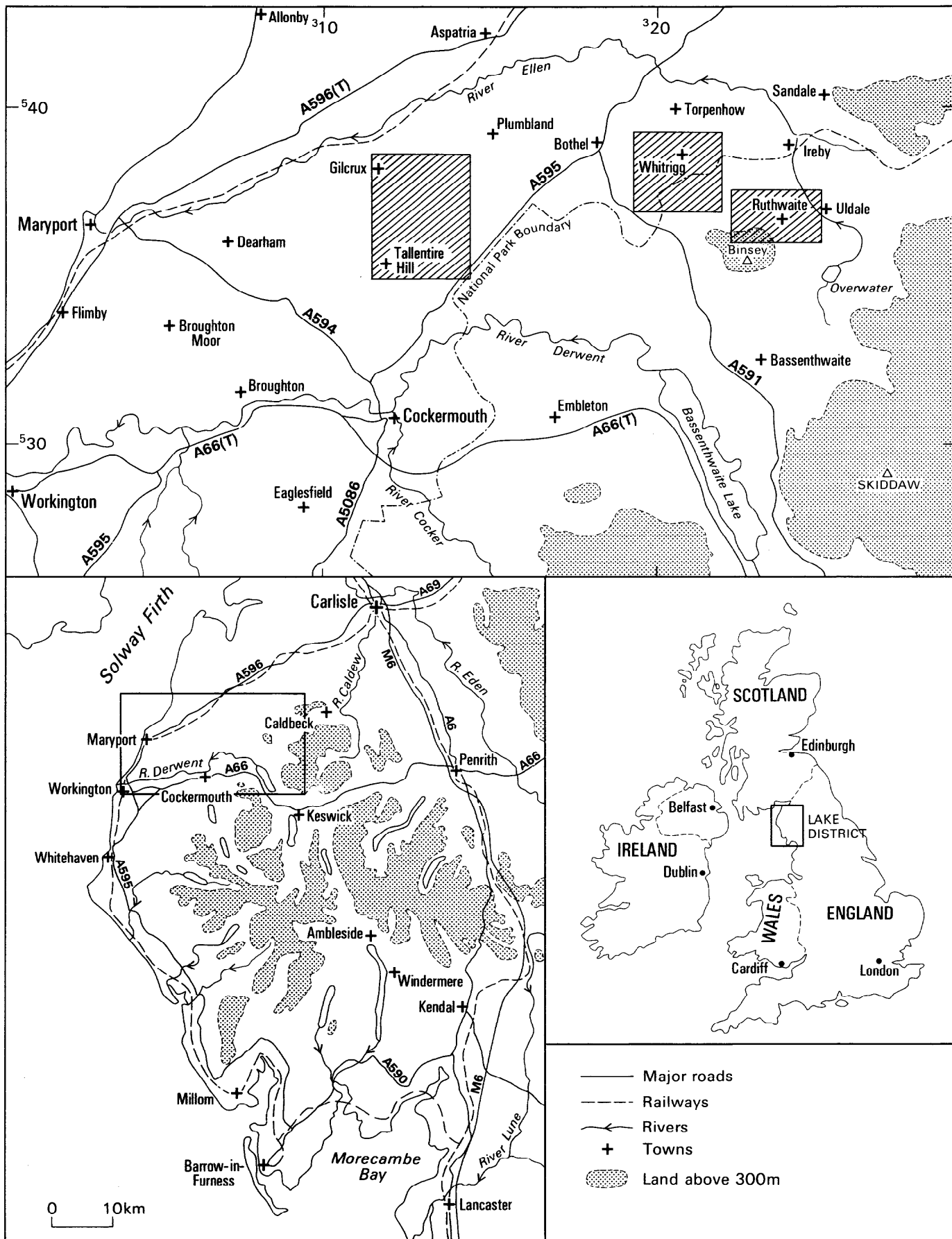


Figure 1 Location of the survey areas

INTRODUCTION

This report describes follow-up investigations across three small areas along the northern margin of the English Lake District. These were selected from the results of regional-scale geological, geochemical and geophysical surveys carried out across the Carboniferous rocks between the village of Caldbeck in the east and the coast at Maryport in the west (Figure 1). The objective of these regional-scale surveys was to assess the mineral potential of the area and the results are described in a previous report (Cooper et al., 1991). It was concluded from this work that baryte mineralisation is far more widespread than had been recognised previously and that locally this mineral might be present in economically significant concentrations. The mineralisation, believed to be Upper Carboniferous in age, shows features in common with ore deposits referred to as "Pennine" and "Irish-style", but distinct differences were also identified, notably the virtual absence of lead-zinc mineralisation. The follow-up investigations reported here were instigated to gather more information in two areas (Ruthwaite and Tallentire) where the reconnaissance surveys suggested that mineralisation is more extensive than previously recorded, but where drift cover (Ruthwaite) or lack of surface drainage (Tallentire) hindered interpretation. In the third area, around Whitrigg, a limited amount of work was carried out to supplement information gathered from two investigations carried out by Companies under the Minerals Exploration Investment Grants Act (MEIGA). In all three areas the opportunity was taken of testing the effectiveness of some geophysical and geochemical methods for particular purposes, such as fault detection, in this terrain.

Geology

The geology and mineralisation of the rocks at the northern margin of the Lake District are described in Part 1 (Cooper et al., 1991) and this information will only be summarised here.

The oldest rocks exposed are the Lower Palaeozoic rocks forming the Lake District Massif; these are unconformably overlain to the north by a Carboniferous succession laid down in the Solway Basin (Eastwood, 1930; Eastwood et al., 1968; Moseley, 1978). The stratigraphic succession is summarised in Table 1 and a simplified geological map shown in Figure 2.

The Lower Palaeozoic rocks, which reach the surface in the southern part of the Whitrigg and Ruthwaite areas, comprise a succession of turbiditic sandstones, siltstones and mudstones, forming part of the Skiddaw Group (Jackson, 1978), overlain by basaltic to rhyolitic lavas and tuffs of the Eycott Volcanic Group (Moseley and Millward, 1982). These rocks, all of Ordovician age, are folded, faulted and affected by low-grade (sub-greenschist facies) metamorphism which accompanied Caledonian tectonic events (Fortey, 1989). To the south of the regional survey area the Ordovician sedimentary and volcanic succession is cut by the late Caledonian (395 Ma) Skiddaw Granite and the older Carrock Fell gabbro-granophyre complex, which is associated with the Eycott volcanic event (Firman, 1978b; Firman and Lee, 1986).

During the Carboniferous, the much eroded Manx-Cumbria-Alston ridge lay to the south and the Solway Basin, a western extension of the Northumberland Trough, to the north. The hinge between these relatively buoyant and subsiding areas passed through the survey areas and is marked by a major east-west fault belt, the Gilcrux - Stublick - Ninety - Fathom fault system. Evidence for

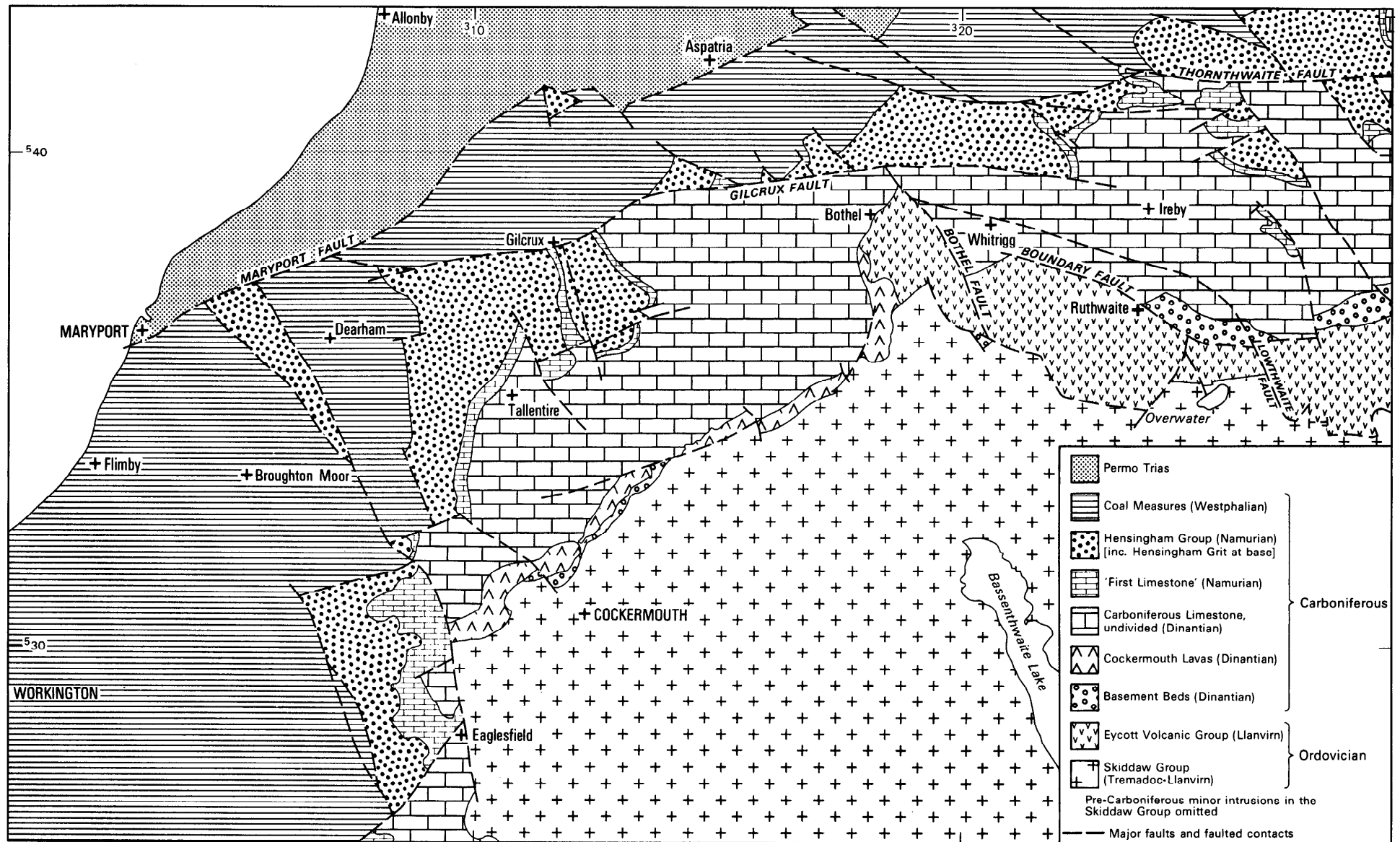


Figure 2 Simplified geological map of the Cockermouth area

contemporaneous Carboniferous movement along this fault belt is provided by the rapid increase in thickness of Carboniferous formations northward across the fault system.

Table 1 Stratigraphic succession in the Cockermouth area

PERMO-TRIASSIC	St Bees Sandstone St Bees Shales
-----unconformity-----	
CARBONIFEROUS	
Westphalian	Coal Measures
Namurian	Hensingham Group (Hensingham Grit at base) First Limestone
Dinantian	Second Limestone Orebank Sandstone Third Limestone Fourth Limestone Fifth Limestone Sixth Limestone Seventh Limestone Cockermouth Lavas Basement Beds
-----unconformity-----	
ORDOVICIAN	Eycott Volcanic Group Skiddaw Group

The Carboniferous succession (Eastwood et al., 1968; Mitchell, Taylor and Ramsbottom, 1978; Young and Armstrong, 1989) begins with a locally derived series of conglomerates, coarse sandstones and mudstones which reach a thickness of 30 m near Ruthwaite but which may be absent near Bothel. Between Cockermouth and Bothel these basal beds are overlain by the Cockermouth lavas, a series of tholeiitic basalts and andesites up to 100 m thick (McDonald and Walker, 1985). Overlying the lavas and basement beds the Dinantian succession comprises a series of limestones separated by sandstones and mudstones. Individual limestones are distinctive and have long been recognised: they are named the Second down to the Seventh. The highest, the First, is of Namurian age (Table 1). The sandstones and mudstones between the limestones thicken eastwards and mark the transition to the typical rhythmic Yoredale facies of the northern Pennines. These units are generally not named but an exception is a series of variable terrigenous sediments between the Second and Third Limestone termed the Orebank Sandstone. The Namurian succession follows conformably and comprises the First Limestone at the base overlain, except in

the extreme east, by the Hensingham Grit. This is a medium to coarse-grained, thickly bedded, massive sandstone overlain by a poorly known succession of predominantly non-marine sandstones and mudstones and thin marine limestones. The overlying Westphalian succession, the Coal Measures, comprises a cyclical, essentially non-marine, succession of mudstones, sandstones, seatearths and coals with rare dark grey mudstone marine bands whose fossils allow correlation across the area and with other coalfields. These rocks are overlain on the coast at Maryport and to the north and east of the regional survey area by a red-bed succession of Permo-Triassic age.

The Carboniferous rocks dip northwards away from the Lower Palaeozoic basement of the Lake District and are cut by many normal faults in which two principal trends, north-west - south-east and approximately east-west, are evident. The north-west-trending faults throw down to both the south-west and north-east, whereas the east-west faults mostly downthrow to the north. Throws of over 200 m are common and the Gilcrux Fault locally has a displacement of approximately 400 m. A belt of country about 5 km wide, on which the reconnaissance survey was centred, stretching from Maryport to north of Caldbeck is characterised by *en echelon* east-west-trending faults corresponding to the margin of the Solway Basin. There is evidence to suggest that major faults with this alignment which were active in Carboniferous times may have followed pre-existing faults or lines of weakness in the Lower Palaeozoic basement. These may have been re-activated in late or post-Carboniferous times (Cooper et al., 1991).

Glaciation during Pleistocene times produced extensive but discontinuous spreads of boulder clay. Erratic boulders within the boulder clay indicate derivation from both south-west Scotland and the Lake District (Eastwood et al., 1968). During the main glaciation ice moved northwards off the highlands of the Lake District and then westwards across the Solway Basin, where the course of the ice across low ground is marked by numerous elongate drumlins. Comparatively small areas of glacial sand and gravel, mainly deposited during the glacial retreat, are present locally. Post-glacial deposits include alluvium, river terrace sediments and peat.

Mineralisation

Mineralisation is present in both the Lower Palaeozoic and Carboniferous rocks. Polymetallic epigenetic vein mineralisation in the Lower Palaeozoic rocks was formerly worked extensively at mines in the Caldbeck and Carrock Fells, which lie immediately to the south-east of the area covered by the reconnaissance survey (Postlewaite, 1913; Dewey and Eastwood, 1925; Eastwood, 1921; Rastall, 1942; Firman, 1978a; Cooper and Stanley, 1990). The veins, which principally carry copper, zinc, antimony, tungsten, barium and lead minerals, are believed to be the product of a number of mineralising events, the most important of which are believed to be Lower Devonian, Lower Carboniferous and Upper Carboniferous to Lower Permian in age (Stanley and Vaughan, 1982). The ores are believed to have been deposited from convectively circulating hydrothermal fluids containing metals derived from the volcano-sedimentary pile and granitic intrusions (Shepherd et al., 1976; Firman, 1978a; Moore, 1982; Cooper et al., 1988).

Mineralisation in the Carboniferous rocks is less well documented, partly because only a few occurrences have been tried or mined, but during the reconnaissance surveys reported in Part 1 many new mineral occurrences were recorded (Cooper et al., 1991). Three styles of mineralisation were described.

Epigenetic vein mineralisation

This consists principally of fracture and fault fillings of baryte, often accompanied by brown carbonate and minor malachite or chalcopyrite, in limestones and sandstones. Quartz may be present but lead and zinc minerals are rare. Chemical analyses indicate that local mercury and arsenic enrichments are present and cinnabar was found in several panned stream sediment concentrates. The mineralisation is very similar to deposits assigned an Upper Carboniferous to Lower Permian age in the Caldbeck Fells by Stanley and Vaughan (1982) and, consequently, it was concluded that it forms part of the same mineralising event. The Solway Basin was considered to be the most probable source of ore fluids and metals (Cooper et al., 1991).

Disseminated/veinlet mineralisation in sandstones

In the Tallentire area patchy impregnations of pink and white baryte were found in two different sandstone units. These are described in more detail in this report.

Syngenetic/diagenetic mineralisation

This is most common in the Coal Measures, though small amounts of pyrite are disseminated through many of the Carboniferous shales. Pyrite is abundant in some coal seams and diagenetic siderite is widespread in mudstones, particularly seatearth mudstones, in both the Hensingham Group and Coal Measures. Millerite, sphalerite and chalcopyrite have been recorded in one bed of clay ironstone at an opencast coal site (Young and Nancarrow, 1988) and coarsely crystalline baryte within a septarian clay ironstone nodule found in the Coal Measures near Gilcrux is probably also of diagenetic origin.

RUTHWAITE

The Ruthwaite area lies about 14 km north-east of Cockermouth (Figure 1) at the boundary of the Lower Palaeozoic and Carboniferous rocks (Figure 2). The land is undulating and largely grass covered with small areas of scrub and woodland. Some of the low-lying grassland is poorly drained and marshy, whereas on the highest land in the south-west, towards Binsey, rough grass and heather grow on the acid, peaty soil. An old mine, worked for baryte, is situated in the hamlet of Ruthwaite.

The reconnaissance drainage survey results, described in Part 1, contained several large barium anomalies in panned concentrates collected from the streams of this area. Some anomalies were related to the mineralisation mined at Ruthwaite and tried in Mell Beck (eg. 30% Ba at [NY 2364 3704] and 4.6% Ba at [NY 2417 3686]) but others, for example samples collected near Stanthwaite (3.1% Ba at [NY 2509 3654]) and in Humble Jumble Gill (21% Ba at [NY 2214 3793] and 14% Ba at [NY 2219 3725]), had no obvious known source. Therefore, further work was carried out to look for undiscovered mineralisation in the area.

Geology and mineralisation

The geology of the Ruthwaite area is shown in Figure 3. In common with the nearby Whitrigg area much of the ground is mantled by boulder clay. Eycott Volcanic Group rocks occupy the southern part of the area though exposures are limited to small and incomplete sections in streams and a few broken outcrops in fields. Basalts and andesites are the main volcanic lithologies. These are mostly

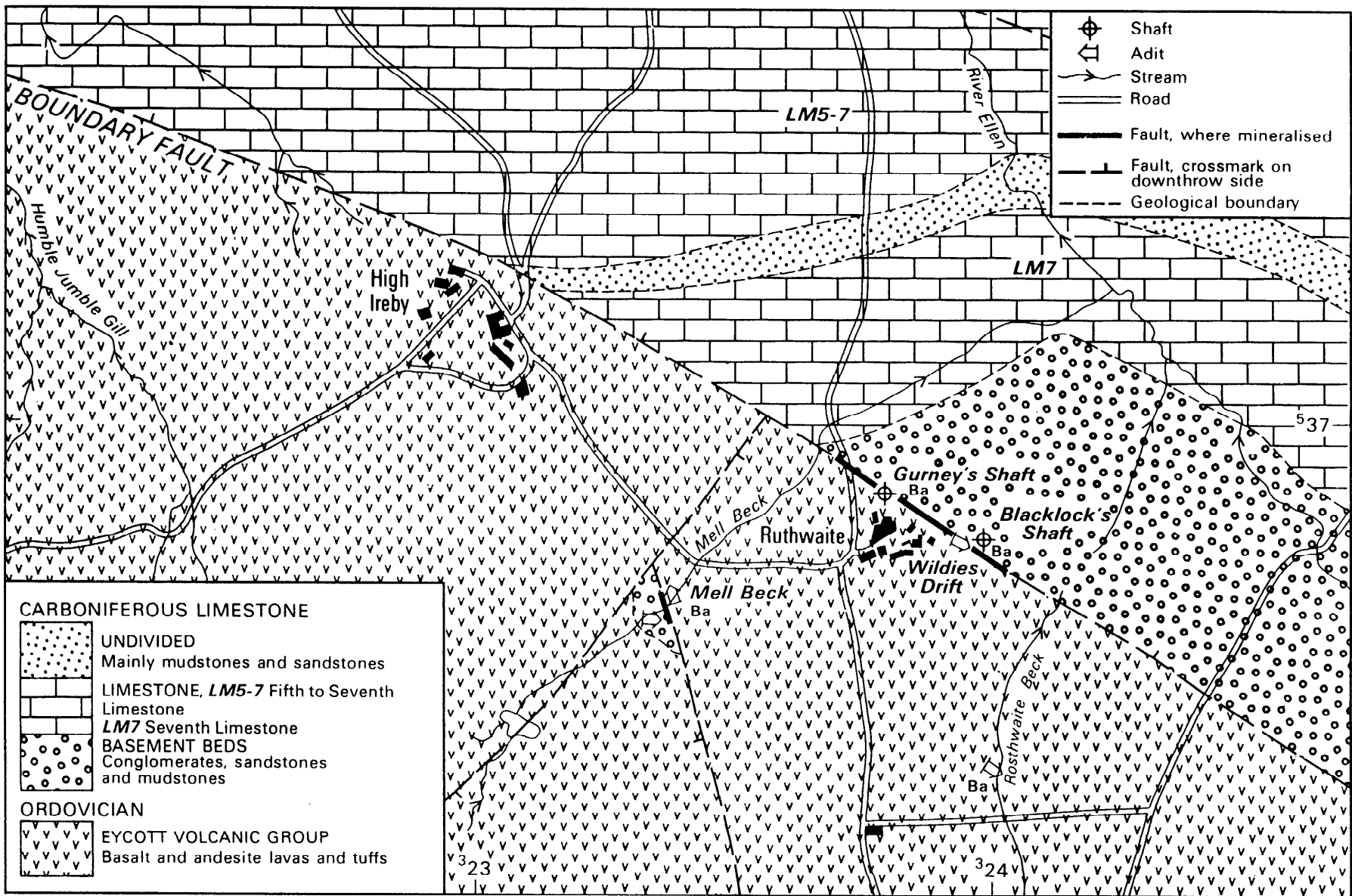


Figure 3 Geological map of the Ruthwaite area

fine-grained aphyric rocks, though a highly distinctive, markedly porphyritic, basic andesite crops out, mainly beneath boulder clay, in an east-west belt south of Ruthwaite and High Ireby.

Crossing the area in a generally north-west - south-east direction is a major fault, referred to as the "Boundary Fault" on 1:50,000 Geological Sheet 23 (Cockermouth) and by Eastwood et al. (1968, pp 11). This downthrows to the north and though the amount of throw in the Ruthwaite area is unknown, it must be in excess of 100 m. The Boundary Fault brings Carboniferous basal conglomerates and limestones, inferred to range from the Seventh up to the Fifth, in contact with the Eycott Volcanic Group. The basement beds are not well exposed in the Ruthwaite area but may be seen in a faulted inlier in Mell Beck [NY 2334 3663], south-west of Ruthwaite (Figure 3). Small exposures have also been seen south of Uldale, a short distance east of the area shown in Figure 3 (at [NY 2498 3621] and [NY 2545 3641]). Exposures of limestone may be seen in several old quarries between Ruthwaite and High Ireby.

Baryte mineralisation is present in fault-controlled veins in the Ruthwaite area. The best known occurrence is that in the Boundary Fault immediately east of Ruthwaite village, where a strike length of at least 300 m is known to have carried baryte. Apart from Rose Gill near Gilcruix, Ruthwaite is the only locality in the Carboniferous rocks of northern Cumbria from which baryte has been extracted commercially. Details of the Ruthwaite workings given by Dunham and Dines (1945, pp 101) are summarised here.

According to Dunham and Dines (1945) the vein has to the south-west at 10° from the vertical. If so reverse faulting is implied. The vein is said to have averaged about 2.4 m in width but up to 4.9 m was recorded locally. Workings on the outcrop were between 3 and 3.7 m wide, all in baryte. The occurrence of clay, no doubt altered wall-rock, on the hangingwall of the vein was mentioned. At depth the vein narrowed and quartz and broken country rock became contaminants of the baryte. Underground working was carried out from two main shafts. Gurney's Shaft [NY 2379 3687] was 27.4 m deep with levels driven at depths of 15.2 m, 21.3 m and 27.4 m. The 21.3 m level is known to have been driven 131.1 m south-east and 61.0 m north-west of the shaft. Blacklock's Shaft [NY 2397 3677] was sunk to a depth of 12.2 m and was connected with the 15.2 m level from Gurney's Shaft. Dunham and Dines (1945) also mentioned an old shaft at Dolly Byre between the two other shafts though the exact position of this cannot now be fixed. A section of the mine has been published by Adams (1988, pp 134). The six-inch geological sheet (Cumberland 47 NW) shows an adit, Wildies Drift [NY 2396 3678], driven south-eastwards on the vein from near Blacklock's Shaft but nothing has been discovered about workings from it.

Adams (1988, pp 102) comments that the mine seems to have been first worked in the 1870's though no records exist until 1910 when it was acquired by Messrs Keeble and Jellett. The mine was taken over in 1912 by Barium Compounds Ltd of Carlisle who worked it until 1920 when it was abandoned as exhausted. There are no exposures of the Ruthwaite deposit today. Blocks of coarsely crystalline white to very pale pink baryte up to 10 cm across are abundant around the site of Gurney's Shaft. A little calcite and ankerite accompany the baryte and very rare minute stains of malachite have been observed on baryte. In the fields south-east of Gurney's Shaft overgrown and partially disturbed dumps, no doubt derived from both the other shafts and surface workings, contain blocks from the Eycott Volcanic Group and Carboniferous conglomerate. Baryte and quartz are also present and traces of malachite were seen on veinstone locally. Textures in the blocks suggest that an early phase of quartz with a trace of sulphide (pyrite) mineralisation

preceded the formation of baryte. Variable alteration of the Eycott Volcanic Group host-rocks is evident and this may be associated with the early event.

In Mell Beck, approximately 400 m west-south-west of Ruthwaite, trials have been made on baryte mineralisation. The exposures in the heavily vegetated steep sides of Mell Beck are difficult to interpret, but recent BGS mapping (D Millward, personal communication) has revealed that Carboniferous basal conglomerate is here brought against Eycott Volcanic Group lavas adjacent to a north-north-west - south-south-east-trending fault (see Figure 3). This is in contrast to the interpretation shown on six-inch geological sheet Cumberland 47 NW and 1:50,000 Sheet 23 (Cockermouth). On the west bank of the stream [NY 2338 3667] there is a small pile of blocks of coarsely crystalline white to pale pink baryte up to 30 cm across, apparently derived from an adjacent trial pit, trench or blocked adit. Narrow strings of baryte are present within heavily altered and brecciated lava in the bed of the stream a few metres east of here. The lava is much altered to clay, a feature also noted in association with the Ruthwaite deposit. Depressions and a collapsed adit in the east bank of Mell Beck are consistent with trials along the line of the north-north-west - south-south-east-trending fault which is interpreted as the baryte-bearing structure. Apart from baryte and rare traces of chalcopyrite, the only introduced mineral seen at Mell Beck is calcite, which occurs both in a dark brown crystalline form and as later pale greyish-white crystalline encrustations on the earlier brown calcite. Chemical analyses (see below), however, suggest that zinc minerals may also be present. No information has been traced on the date of these apparently unsuccessful trials.

South of Ruthwaite, in Rosthwaite Beck, sheared and altered Eycott Volcanic Group lavas are exposed locally (eg. at [NY 2402 3624]). Small and much obscured shallow excavations by the stream north of here (around [NY 2402 3635]) could be trial trenches on a baryte show, as blocks of lava within the stream contain narrow veinlets of the mineral. Baryte fragments are also present in the drift here. No fault is known at this point and the origin of the baryte-bearing rock is unknown. Single blocks of altered lava with thin veins of baryte were also found near the line of the Boundary Fault north-west of Ruthwaite [NY 2331 3705] and in Humble Jumble Gill [NY 2227 3716].

The previously undescribed mineral occurrences recorded here suggest that baryte mineralisation, in the form of fracture/fault infillings, is more widespread in the area than realised previously and that the deposit worked in Ruthwaite Mine cannot be considered an isolated occurrence.

Geochemical surveys

Rock sampling

Rock samples were collected from exposures and tips around the old mine workings at Ruthwaite and around the trial in Mell Beck. The samples were analysed by X-ray fluorescence spectrometry (XRFS) for a wide range of elements to determine whether other metal enrichments were associated with the barium mineralisation. Au and Hg were also determined on a few samples by atomic absorption spectrophotometry (AAS). The results are listed in Table 2.

The results confirm that little or no sulphide or other metalliferous mineralisation accompanies the baryte-carbonate-quartz mineralisation at Ruthwaite. The relatively high level of Cu found in one rock (sample 1283, Table 2) is presumed to be a reflection of the small amounts of malachite seen

in some specimens (Wilson et al., 1922). Infra-red spectroscopy indicated that samples of brown carbonate taken from the tips here consist of calcite or ankerite. At Mell Beck, traces of chalcopyrite were seen in the vein material, which consists largely of baryte and a dark brown carbonate identified as calcite by infra-red spectroscopy. The analytical results indicate the presence of Zn mineralisation in Mell Beck (sample 1265, Table 2), but no sphalerite or other zinc mineral was recognised in hand specimens of the analysed material; smithsonite might be present. The same sample also contains appreciable amounts of Hg. Above background levels of Ag were reported in samples from both sites. However, the highest Ag values show a close correlation with the most Ba-rich samples and are attributed to analytical interference from a broad Ba peak.

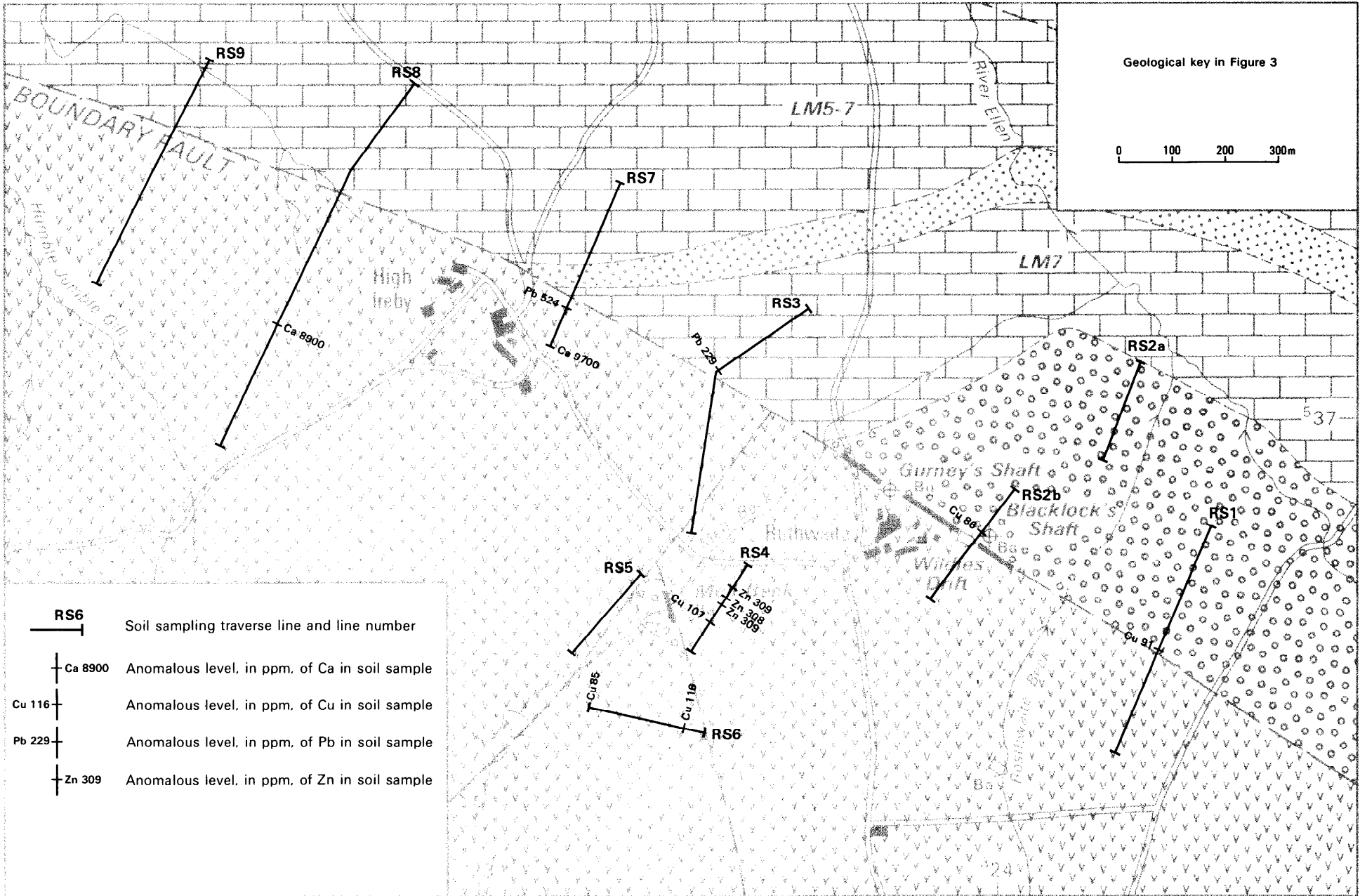
Table 2 Analyses of rock samples collected in the Ruthwaite area

Number	Grid Reference	Locality	Description											
1210	NY 2386 3683	Ruthwaite Mine	Baryte vein material from tips											
1263	NY 2381 3684	Ruthwaite Mine	Altered EVG* rocks from mine tips											
1283	NY 2399 3678	Ruthwaite Mine	Baryte vein material from tips											
1265	NY 2338 3666	Mell Beck Trial	Carbonate - baryte vein material											
1284	NY 2338 3666	Mell Beck Trial	Altered EVG* host rocks											
1285	NY 2338 3667	Mell Beck Trial	Baryte from tips											
Number	Ca	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	As	Rb		
1210	200	860	369	<2	20	400	1	5	93	3	<2	-		
1263	67800	2000	125	134	3480	20700	4	10	26	25	4	45		
1283	800	1220	-	-	510	3600	1	10	203	7	11	13		
1265	122100	4200	108	79	6100	27100	23	41	79	8191	35	57		
1284	5400	7580	-	-	1210	70700	18	16	33	98	7	98		
1285	100	770	-	-	50	300	<1	15	61	34	2	<1		
Number	Sr	Zr	Mo	Ag	Sn	Sb	Ba	W	Au	Hg	Pb	Bi	Th	U
1210	7308	-	8	24	5	<2	423800	<2	<10	20	78	<2	-	<2
1263	559	65	7	7	<2	-	68230	2	-	-	5	<2	6	2
1283	2450	78	18	22	5	<2	364000	<2	<10	-	24	<2	7	<2
1265	275	154	10	5	<2	3	38320	<2	-	1100	54	<2	4	4
1284	60	303	5	2	<2	2	640	5	<10	-	19	<2	12	3
1285	3011	63	18	27	11	<2	593900	<2	<10	-	47	<2	7	<2
All results in ppm except for Au and Hg (ppb)														
- not determined														
* Eycott Volcanic Group														

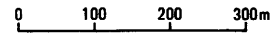
Soil sample survey

Soil samples (198) were collected at 20 m intervals along a series of traverses (Figure 4) in an attempt to clarify the source of drainage survey anomalies and test the response of the known mineralisation at Ruthwaite. Samples were collected from as deep as possible using a 1.2 m hand auger and, after drying and disaggregation, the -0.18 mm (-85 mesh) fraction was analysed for Ca, Cu, Zn, Zr, Ba and Pb by XRFS. The results are summarised in Table 3.

Threshold levels were set by cumulative frequency analysis (eg. Parslow, 1974; Sinclair, 1976). For all elements except Ba, the distribution of analytical results approximated to a single normal or log-



Geological key in Figure 3



	RS6	Soil sampling traverse line and line number
	Ca 8900	Anomalous level, in ppm, of Ca in soil sample
	Cu 116	Anomalous level, in ppm, of Cu in soil sample
	Pb 229	Anomalous level, in ppm, of Pb in soil sample
	Zn 309	Anomalous level, in ppm, of Zn in soil sample

Figure 4 Location of anomalous Ca, Cu, Zn and Pb concentrations in soil samples collected in the Rutwaite area

normal population with, in the cases of Ca, Zn and Pb, a few (2-3) outlying high values which suggested the presence of a poorly defined higher (anomalous) population. In detail the trace of the single main population for most of the elements is not smooth and it may be composed of several overlapping unimodal populations. The Ba distribution displays a sigmoidal form on a log-probability plot, indicating the presence of a lower log-normally distributed population with a median value of about 650 ppm and an overlapping higher (anomalous) population, believed to be caused by the presence of baryte in the samples. For Ca, Zn, Ba and Pb, thresholds were set to distinguish samples belonging to the higher population and outliers. For Zr and Cu, whose distributions did not suggest the presence of separate anomalous populations, the threshold was set arbitrarily at the 97.5% level of the distribution.

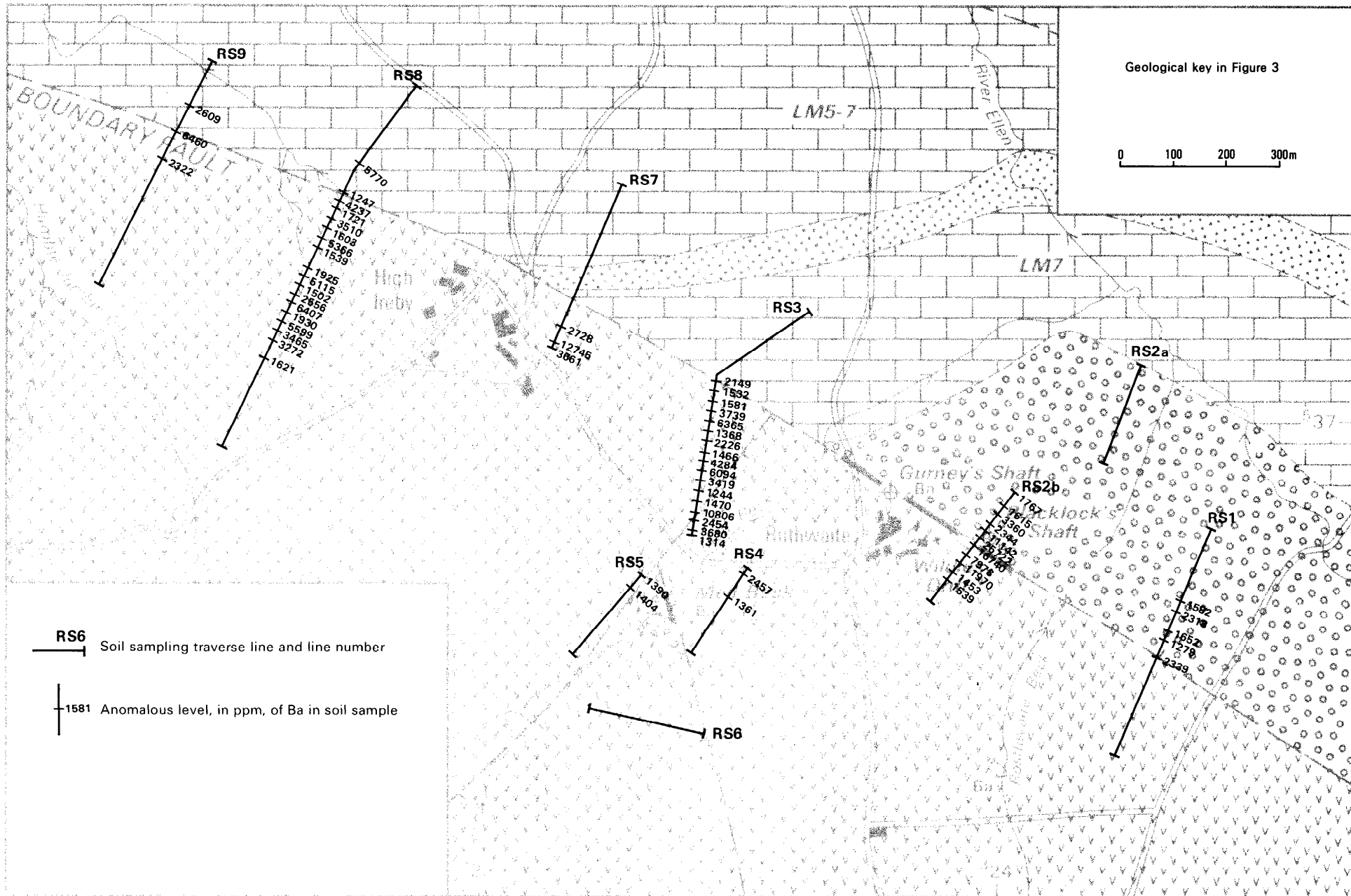
Table 3 Summary of analytical results in ppm for 198 soil samples collected from the Ruthwaite area

Element	Median	Mean	Standard Deviation	Maximum	Minimum	Threshold
Ca	3000	3227	1274	9700	1100	7500
Cu	40	43	17	116	13	81
Zn	96	101	41	309	24	210
Zr	244	244	42	365	133	340
Ba	713	1654	2854	25722	176	1200
Pb	41	48	43	524	9	150

Ca and Zr were determined principally to see if soil sampling could be used as an aid to geological mapping in this area. The results for these (and the other elements determined) suggest that their use for this purpose is very limited, changes in element concentrations failing to distinguish the boundaries between the major lithological units shown on Figure 3. This is probably because of (i) the spread northwards, across the Carboniferous, of glacial deposits comprising material derived from the Lower Palaeozoic succession, and (ii) most Ca from the Carboniferous limestone succession is believed not to reside in the soil as detrital carbonate grains, but to be removed in solution. The highest Ca results form isolated groups with a line of high values on traverse RS2b across the old mine workings at Ruthwaite, suggesting that at least some of the higher Ca concentrations may be caused by the presence of carbonate veins. The two outlying highest Ca results (Figure 4) are located on traverses RS7 [NY 2313 3713] and RS8 [NY 2261 3717] associated with Ba anomalies, suggesting that they may also be caused by carbonate veining. Low Zr values at the south end of traverses RS4 and RS5 and along the whole length of RS6 are coincident with the mapped outcrop of the highly distinctive porphyritic basaltic andesites within the Eycott Volcanic Group, suggesting that this lithology may be differentiated by Zr.

Both Cu and Zn variation are related principally to mineralisation and dominant rock type in till, although the spatial distribution of high values of the two elements is distinct and there is no significant positive correlation between the two sets of data. High Cu values (maximum 86 ppm) are recorded on traverse RS2b at Ruthwaite Mine, reflecting the weak Cu enrichment found in some vein material from here (Table 2). The highest Cu level on traverse RS1 (91 ppm) is over the mapped extension of the Boundary Fault to the south-east of the mine (Figure 4) and may therefore reflect further mineralisation along the fault at this location. The highest Cu results are in

Figure 5 Location of anomalous Ba concentrations in soil samples collected in the Ruthwaite area



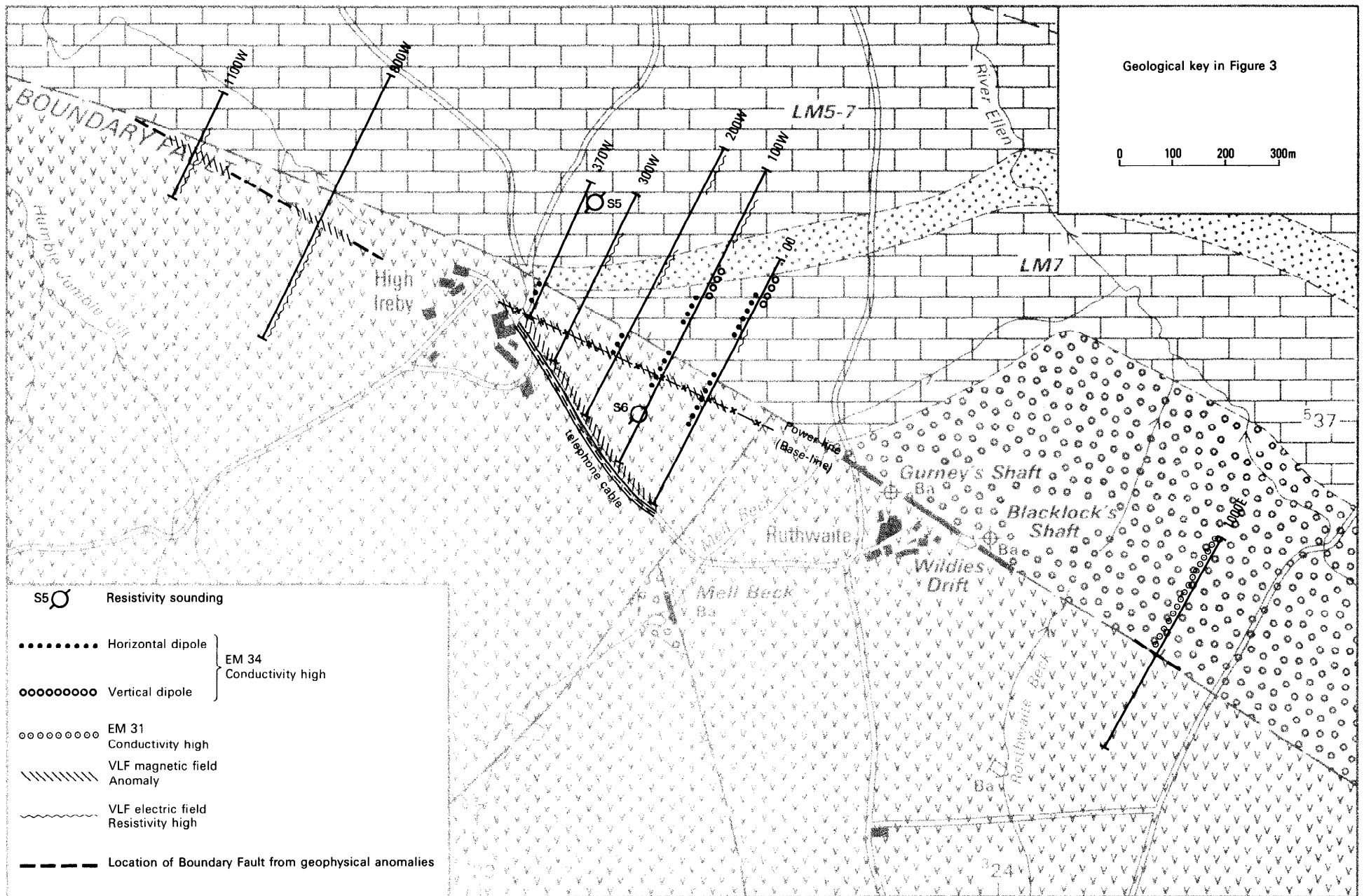
samples from traverses RS4 and RS6, south-east of Mell Beck. On traverse RS4 (at [NY 2343 3662]) the sample with the second highest Cu content (107 ppm) was collected from next to samples containing the three outlying highest Zn results (308-309 ppm), whilst the highest Cu result (116 ppm from [NY 2339 3641]) on traverse RS6 is not associated with other metal enrichments (Figures 4 and 5). In view of the traces of chalcopyrite and high Zn concentration in a rock from the Mell Beck tip (sample 1265, Table 2), these results are interpreted as probably reflecting the presence of mineralisation within the underlying Eycott Volcanic Group. Other relatively high Zn values (118-207 ppm) occur on traverse RS2b at Ruthwaite Mine and form small isolated groups on other traverses. The high values at Ruthwaite Mine were unexpected as the vein material and altered host-rocks analyses (Table 2) all contained very low levels of Zn. It is possible that the high levels in soil are caused by contamination or the local development of secondary Zn concentrations in the drift and made ground, the Zn being derived from lithologies other than those analysed.

Background levels of Pb tend to be lower over the Eycott Volcanic Group than the Carboniferous. Moderately high values (108-138 ppm) are located on traverse RS2b across the old mine workings, whilst anomalous concentrations were recorded close to the mapped line of the Boundary Fault on the two traverses (RS3 and RS7) to the north-west (Figure 4). The outlying highest value (524 ppm, nearest neighbour 229 ppm) is one of a group of high Pb results in samples from the southern end of traverse RS7, downslope of High Ireby. There is no appreciable Pb enrichment recorded in any of the rock samples collected from this area and it is possible that the high Pb values in soil are caused either by contamination, from agricultural or mining activities, or by secondary concentration processes. The latter appears to be the most likely cause of the anomaly over the Boundary Fault on traverse RS3 (229 ppm Pb at [NY 2344 3709]). This site is beside a stream draining the ground containing the largest Pb anomaly. However, the possibility of an ancient working (of which no obvious trace remains) below High Ireby cannot be excluded, particularly as the high Pb values here are accompanied in some samples by anomalous amounts of Ba and Ca which may reflect the presence of a mineralised structure (see below).

The dataset contains a large number of high Ba results with 30% of samples containing >1200 ppm Ba. Predictably, the highest Ba concentrations were recorded in samples from traverse RS2b where it crosses the old mine at Ruthwaite (Figure 5). However, substantial values are also reported from traverses to the north-west, notably on traverse RS3 (1.1% Ba at [NY 2340 3683]) over the line of north-east-trending fault and at the south end of traverse RS7 near High Ireby (1.27% Ba at [NY 2313 3715]). High values are restricted largely to the line of the Boundary Fault and ground underlain by the Eycott Volcanic Group on the south-west side of it, suggesting the presence of appreciable baryte mineralisation within the Eycott Volcanic Group of this area. Very high values on traverses RS 3 (6365 ppm at [NY 2343 3700]), RS 7 (1.27% at [NY 2313 3715]) and RS 8 (5366 ppm at [NY 2268 3734]) are nearly coincident with a projected fault line suggested by the geophysical data (Figure 6), and strongly suggest the presence of a mineralised structure c. 100 m to the south-west of the mapped line of the boundary fault.

Examination of the stream section in Humble Jumble Gill, to the south-west of traverses RS8 and RS9, revealed a highly altered and faulted succession of intermediate to acid volcanic rocks. These members of the Eycott Volcanic Group are locally brecciated and pyritic, but no baryte mineralisation was found in situ to account for the drainage and soil anomalies. A few clasts of altered Eycott Volcanic Group carrying vein carbonate and, in one case, baryte were found in the

Figure 6 Location of geophysical survey traverse lines and summary of geophysical anomalies recorded in the Ruthwaite area



stream but these may have been derived from the erosion of boulder clay which contributes greatly to the stream load. Both geochemical and geophysical data suggest the presence of a mineralised structure about 100 m south-west of the mapped line of the Boundary Fault at High Ireby.

Conclusions

1. Soil analyses suggest the presence of appreciable baryte mineralisation within the Eycott Volcanic Group on the south-west side of the Boundary Fault near High Ireby. Further work is merited to establish the extent of this mineralisation. Known mineralisation in the area suggests that it will occur as fracture infill. Both geochemical and geophysical data suggested the presence of a mineralised structure about 100 m south-west of the mapped line of the Boundary Fault at High Ireby.
2. Soil analyses also suggest the presence of base metal (Cu, Zn) mineralisation south-east of Mellbeck. This is probably weak and of no economic significance.
3. The few Pb anomalies in soil may be caused by mineralisation, contamination or secondary enrichment processes.
4. Rock sampling and soil analyses indicate that the baryte mineralisation along the Boundary Fault is not accompanied by significant sulphide mineralisation, but that at least some base metal (Cu, Zn, Hg) enrichment is present in Mell Beck. It is not clear whether these enrichments accompanied the baryte mineralisation or formed during a separate event.

Geophysical surveys

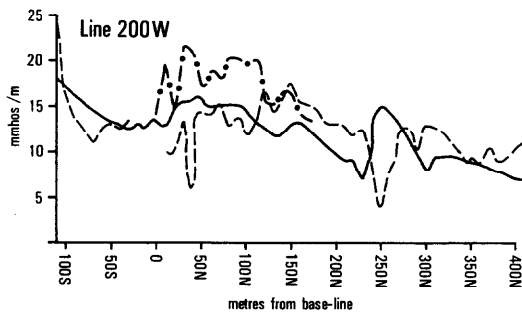
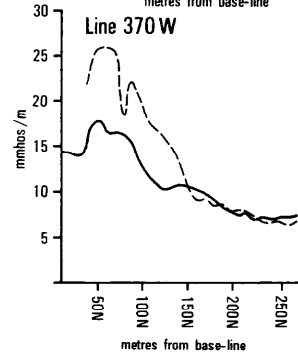
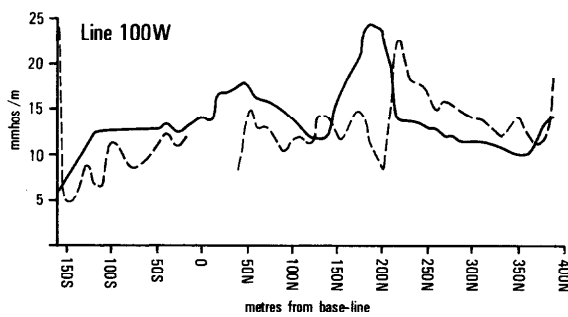
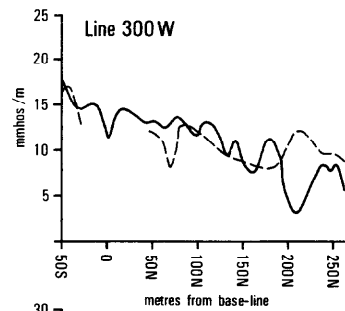
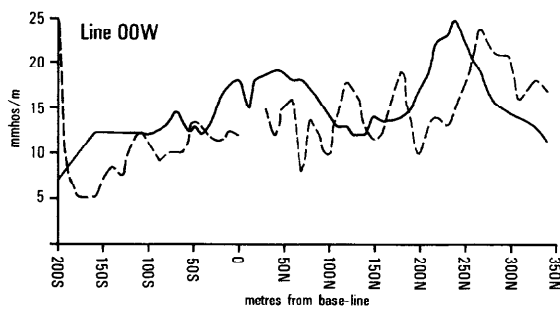
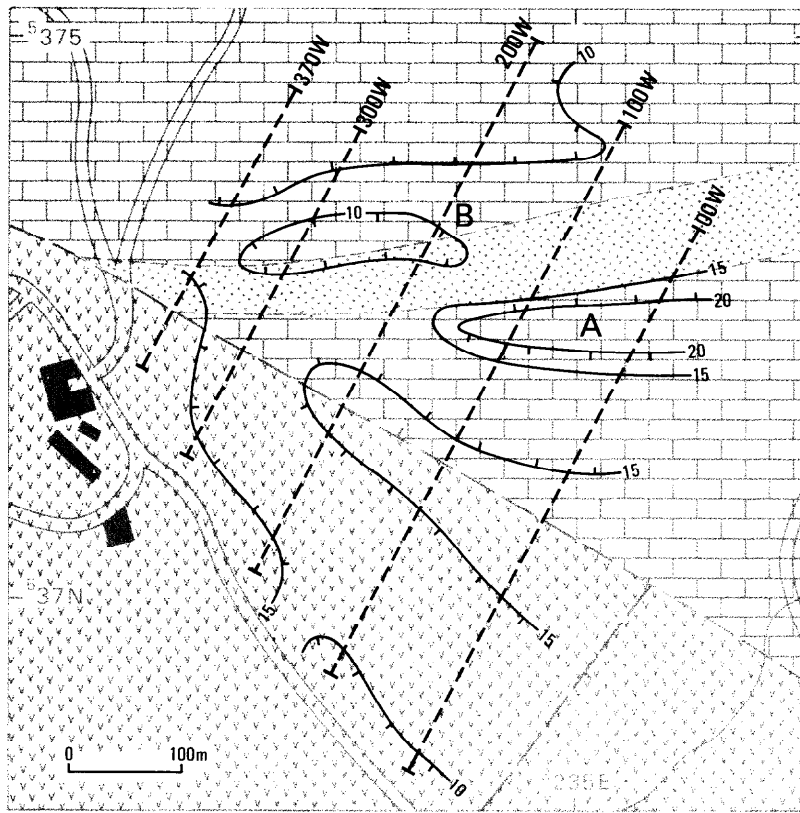
Reconnaissance ground conductivity surveys were undertaken in the Ruthwaite area to ascertain if electromagnetic (EM) methods could be useful for detecting the position of potentially mineralised faults beneath drift cover.

Methods

The EM34, EM31, Very Low Frequency (VLF(EM)) and magnetic survey methods were employed. Measurements were made at 10 m intervals along five survey lines between Ruthwaite and High Ireby (lines 00-370W; Figure 6). The EM31 method was only used on lines 200W and 1000E, which was sited alongside a geochemical traverse line (RS1) 500 m south-east of Ruthwaite Mine. To the west of High Ireby only VLF(EM) measurements were made on line 800W, sited close to geochemical traverse line RS8, and on line 1100W, near RS9 (Figures 4 and 6).

The conductivity survey was carried out using the Geonics EM34 system with a transmitter-receiver coil separation of 20 m, and adopting both the vertical loop (horizontal dipole) and horizontal loop (vertical dipole) configurations, which gave an "effective depth of exploration" of 15 m and 30 m respectively.

The VLF(EM) survey was carried out using a Scintrex IGS-2 digital VLF receiver which measures the in-phase and out-of-phase components of the resultant electromagnetic field (as a percentage), and the electrical component (as apparent resistivity in ohm metres) together with the phase angle. The depth of exploration with this method is thought not to exceed a few tens of metres. The GBR, Rugby, VLF transmitter was used.



- EM 31
- Horizontal dipole
- EM 34
- Horizontal dipole
- - - Vertical dipole

Figure 7 Conductivity map (EM34) in mmhos/m horizontal dipole and profiles measured in the Ruthwaite area

Magnetic measurements were also made with the Scintrex IGS-2 equipment. Two resistivity soundings were taken using a Schlumberger array (Figure 6).

Results

The EM34 conductivity measurements, especially the vertical dipole values, were affected at the southern end of the survey lines, between Ruthwaite and High Ireby, by a buried telephone cable which runs along the north side of the road, and by an overhead powerline which runs approximately along the baseline (Figure 6). This powerline is unfortunately parallel to, and about 100 m south of, the mapped position of the Boundary Fault, so that the apparent increase in conductivity here is probably caused by the powerline rather than by the fault itself. However, the conductivity high and adjacent low in the northern half of the survey area (A and B on Figure 7) which trend parallel to the local strike are probably genuine geological features. They are interpreted as a conductive mudstone and, perhaps, a locally resistive sandstone or limestone horizon within the Dinantian succession. Conductivity values recorded with the horizontal dipole are generally higher than those for the vertical dipole, indicating a decrease in conductivity with depth. In places this pattern is reversed: for example, at the northern end of line 00W conductivity increases with depth, suggesting that the conductive shale horizon dips to the north below more resistive rocks. It is probable that the shale horizon is represented by the 50 ohm m layer detected by resistivity sounding S5 (Appendix 1). However a similar layer appeared to be present at sounding S6, which was located over the Eycott Volcanic Group, but here must represent a thick drift sequence.

The EM31 profile for line 1000E (Figure 8A) shows a marked change in conductivity at about 160N, which is probably caused by the Boundary Fault separating apparently less conductive Eycott Volcanic Group rocks to the south from more conductive basal Carboniferous to the north.

The VLF(EM) measurements (Figures 9 and 10) have been affected by cultural noise, notably by the overhead powerline and buried cable which grossly distort the in-phase and electrical components of the resultant electromagnetic field. Wire fences also influence the VLF(EM) results here and on line 800W so that any geological conductors in this area are probably masked by these effects. However line 1100W, which was deliberately chosen to avoid any cultural noise, does give a good correlation between the mapped position of the Boundary Fault and an anomaly on the VLF in-phase component (Figure 10).

Total magnetic field measurements in the Ruthwaite (Figure 8B) area do not indicate any magnetic anomaly associated with the Eycott Volcanic Group and therefore this method does not help to locate the Boundary Fault. Although parts of the Eycott Volcanic Group are highly magnetic (Part 1), the increase in the magnetic field towards the south observed on all traverses is considered to be a regional effect.

Conclusions

The Boundary Fault has been successfully mapped south-east of Ruthwaite using the EM31, and west of High Ireby on line 1100W using the VLF(EM) method. However this fault cannot be located with any certainty east of High Ireby using geophysics, due to the excessive cultural noise and the absence of magnetic rocks within the adjacent Eycott Volcanic Group. Conductivity measurements with the EM34 away from the overhead powerline has identified a shale horizon which trends approximately east-west and dips to the north.

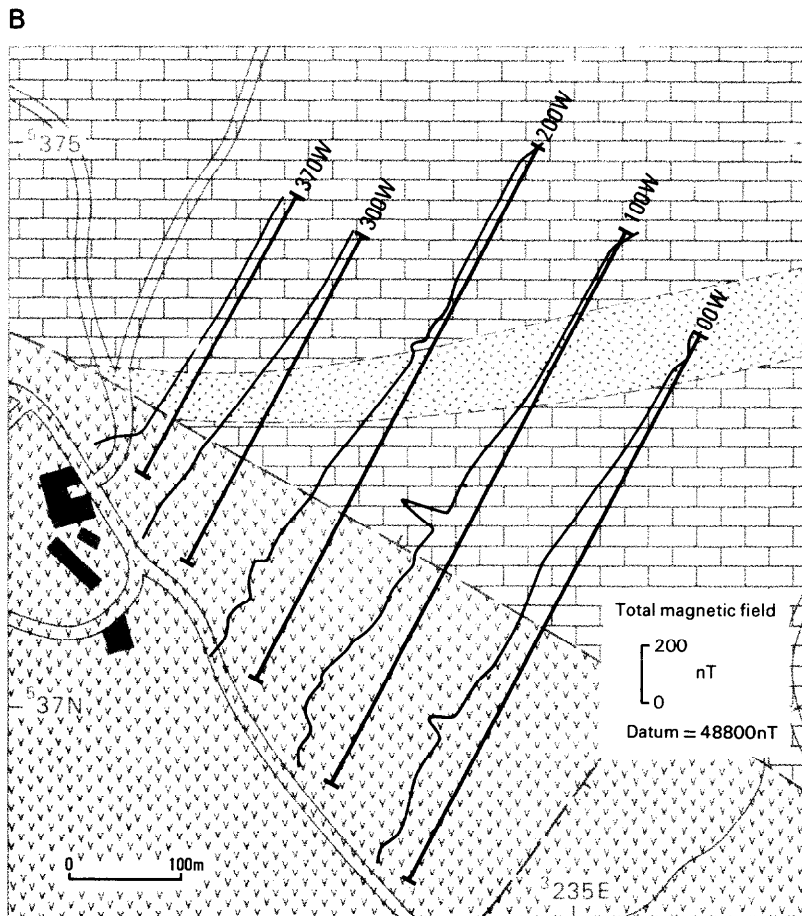
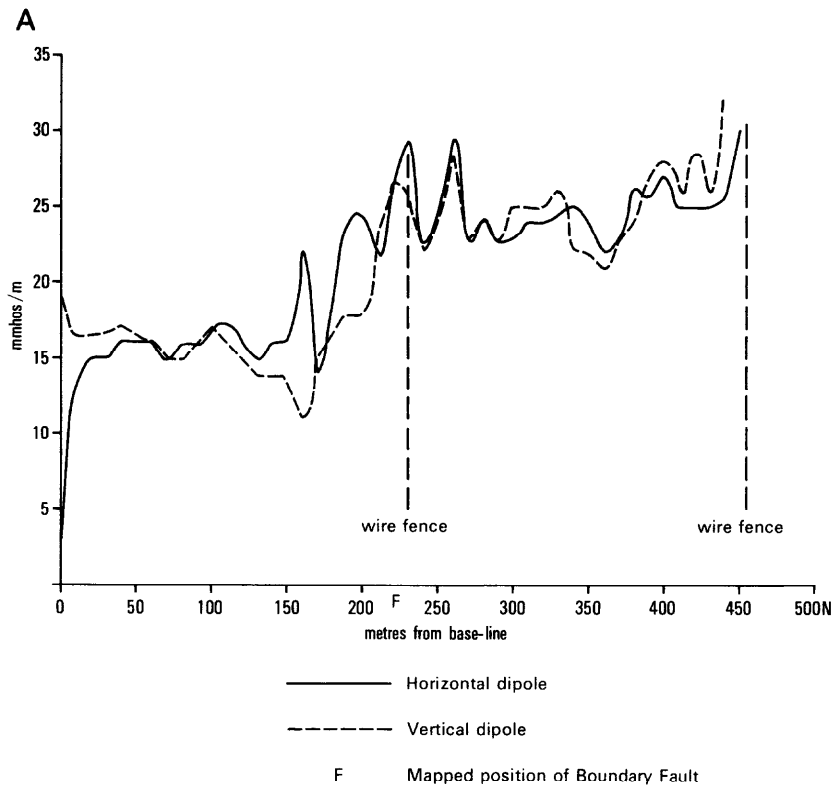


Figure 8 (A) Conductivity (EM31) profile for traverse line 1000E and (B) total magnetic field profiles measured at Ruthwaite

Figure 9 VLF electromagnetic (electric field) profiles in the Ruthwaite area

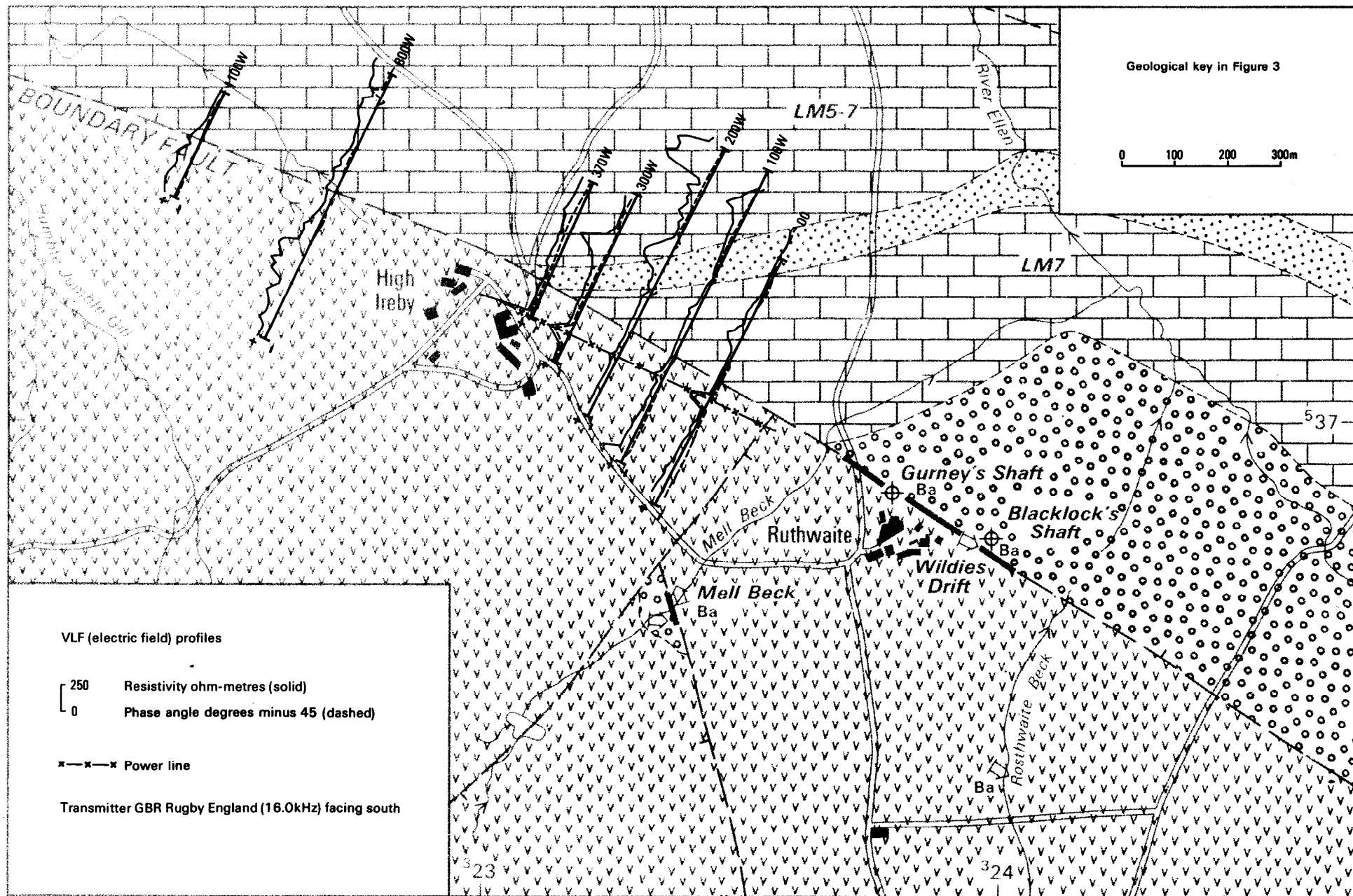
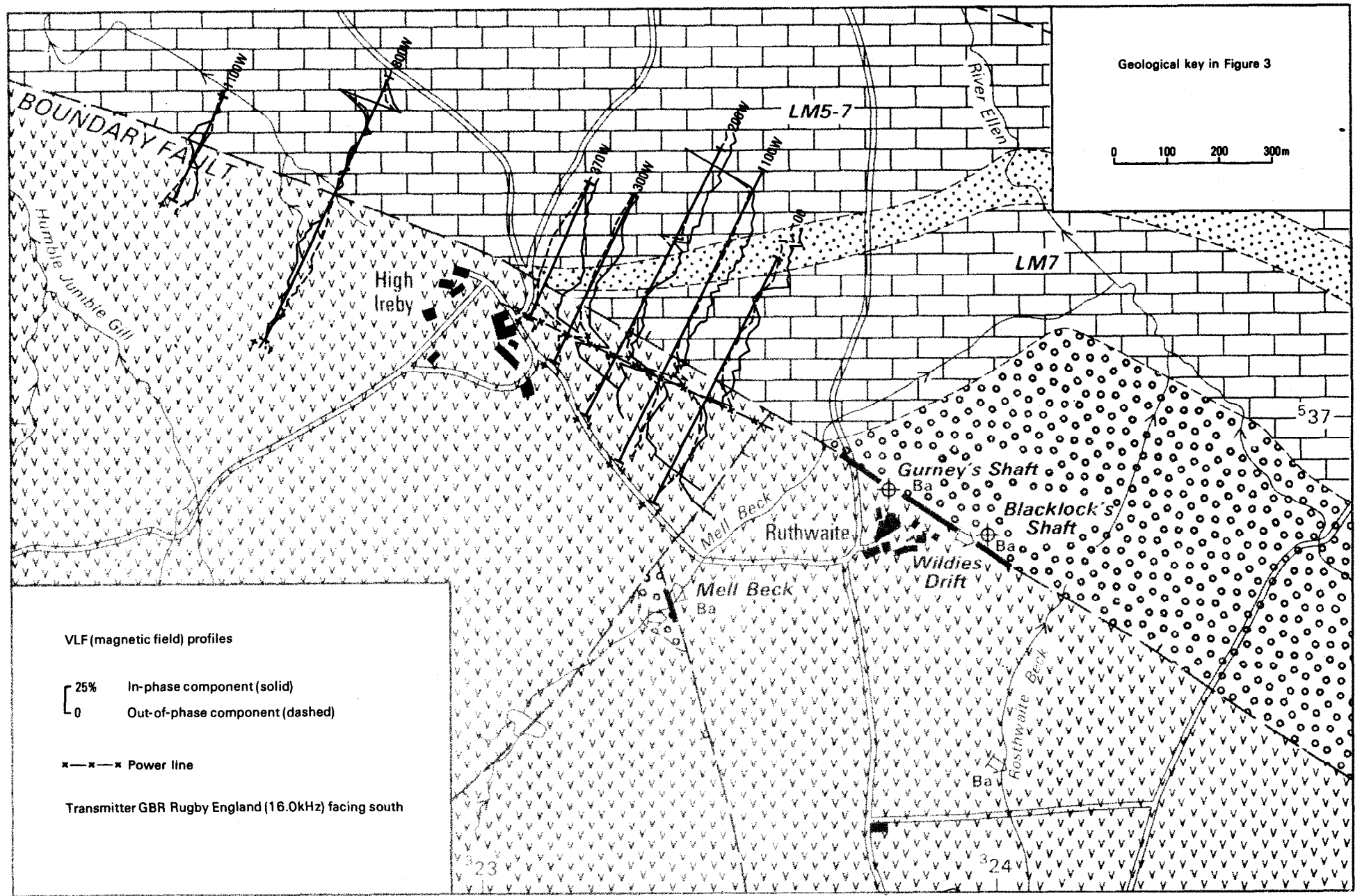


Figure 10 VLF electromagnetic (magnetic field) profiles in the Ruthwaite area



Discussion and assessment

The largest known body of baryte associated with the Carboniferous rocks of northern Cumbria occurs as a fracture filling along the Boundary Fault at Ruthwaite. Revision geological mapping of the surrounding area revealed two further localities, in Mell Beck and Rosthwaite Beck, where trials have been made into mineralisation of similar style. Blocks of Eycott Volcanic Group rocks carrying thin veins of baryte were also found in walls, drift deposits and streams, suggesting that fracture filling baryte mineralisation is common in this area. The soil survey data suggest that baryte mineralisation may be concentrated along the Boundary Fault and in the Eycott Volcanic Group rocks south and west of High Ireby. Both the surface shows and soil results suggest that mineralisation is preferentially developed in the Eycott Volcanic Group rocks or at its faulted boundary with the Carboniferous. There is little evidence of any mineralisation within the Carboniferous succession. The drainage data (Part 1) are less clear in this respect, with some drainage anomalies over the Carboniferous rocks. However, the anomalies over the Carboniferous are of lower magnitude than those in streams draining the volcanic rocks and it is possible that the baryte in them is derived from northward transported glacial deposits.

One of the attractions of the baryte occurrences from the economic viewpoint may be the virtual absence of sulphide minerals. The commonest minerals associated with the baryte are easily separated quartz and brown carbonate.

The data collected are insufficient to determine whether or not an economic concentration of baryte exists in the area. However, there appear to be no special geological conditions at the site of the Ruthwaite Mine that would preclude similar concentrations elsewhere in the area, at present screened by the extensive, but probably comparatively thin, cover of boulder clay. It is concluded, therefore, that the potential exists here for relatively small, but perhaps economically attractive, deposits of baryte beneath a cover of drift deposits. More detailed geochemical surveys, perhaps followed by base of till augering or drilling at an early stage, would be required to test these possibilities. Electric geophysical methods may be useful for tracing faults beneath drift cover in areas where there is no interference from artificial sources, and any large deposit may produce a gravity anomaly.

It is unlikely that the few indications of base-metal related mineralisation have any economic significance.

TALLENIRE

The Tallentire survey area, about 5 km north of Cockermouth (Figure 1), is dominated by a ridge of rounded hills running from Tallentire Hill in the south-west to Wardhall Common in the north-east. Most of the land is enclosed and grass covered, though some small areas of woodland are scattered across the area. Drift cover is very thin on the hill tops where there are several natural exposures. On the lower ground the rocks are obscured by drift deposits, dominantly of boulder clay. In these areas outcrop is only seen in a few stream sections and quarries.

Revision geological mapping of the Tallentire area indicated the presence of many baryte occurrences in the Carboniferous rocks, but the reconnaissance geochemical drainage survey data for the area was limited because of the absence of streams on the high ground. Panned

concentrates collected from streams peripheral to the high ground in the west and north contained highly anomalous amounts of barium due to the presence of baryte. Relatively weak copper and other base metal anomalies were also recorded in these samples. The work reported here was undertaken to obtain more geochemical data for the area deficient in surface drainage, and gain a better understanding of the extent and magnitude of the mineralisation seen at surface during geological mapping.

Geology and mineralisation

The geology of the Tallentire area is shown in Figure 11. The Carboniferous rocks occur in a series of generally westward tilted blocks separated by a rectilinear pattern of normal faults. The largest fault in the area is the Gilcrux Fault, along which the Coal Measures are faulted against Namurian and Dinantian beds to the south (Figure 11). This fault has a northerly throw of about 400 m at Gilcrux where strong springs mark its course.

Throughout the Tallentire area mineralisation is present in three distinct, though probably closely related, styles which are described below.

Mineralised faults

In the edge of the field [NY 1236 3588] approximately 200 m east-north-east of the summit of Tallentire Hill, angular blocks of brecciated sandstone, apparently clearance stones from the adjacent fields, contain numerous pockets of red earthy hematite and thin coatings of malachite. Locally there are crystalline aggregates of malachite, in some instances accompanied by massive chalcopyrite. Colourless calcite and small sprays of acicular aragonite crystals were noted in some blocks. Crusts of dark brown goethite and manganese oxides also occur. The mineralised material has not been found in situ, but its distribution and lithology are consistent with derivation from a small north-north-west - south-south-east-trending fault which cuts the Third Limestone and underlying sandstone a few metres west of the field edge.

Soil brash in the field [NY 1233 3569] approximately 150 m south of the above occurrence includes much reddened limestone and sandstone, some of it brecciated and in places with a little cream crystalline dolomite, white baryte and copper secondary minerals. A note on the six-inch Geological Survey sheet (1926) states that fine sandstone with traces of malachite were found here. Analysis of rock fragments (Table 6, samples 1262 and 1296) confirmed the presence of copper mineralisation and indicated the presence of accompanying mercury and arsenic enrichments. Although, like the previously described occurrence, nothing has been seen in situ, the location coincides with the mapped outcrop of a north-north-west - south-south-east fault which here cuts the sandstone beneath the Third Limestone.

On the north side of Tallentire Hill sandstone blocks with coatings of malachite, mammillated goethite, manganese oxides and colourless quartz are present in a drystone wall [NY 1207 3600]. These may well be float from a nearby mineralised fault.

In Moota Quarry the Fourth Limestone adjacent to a north-east - south-west-trending fault which downthrows to the north-west, has locally been brecciated and veined with calcite, dolomite and a little white baryte for up to 3 m. The limestone thus affected has been left as an unworked "wall" (centre at [NY 1425 3633]) separating sections of the quarry.

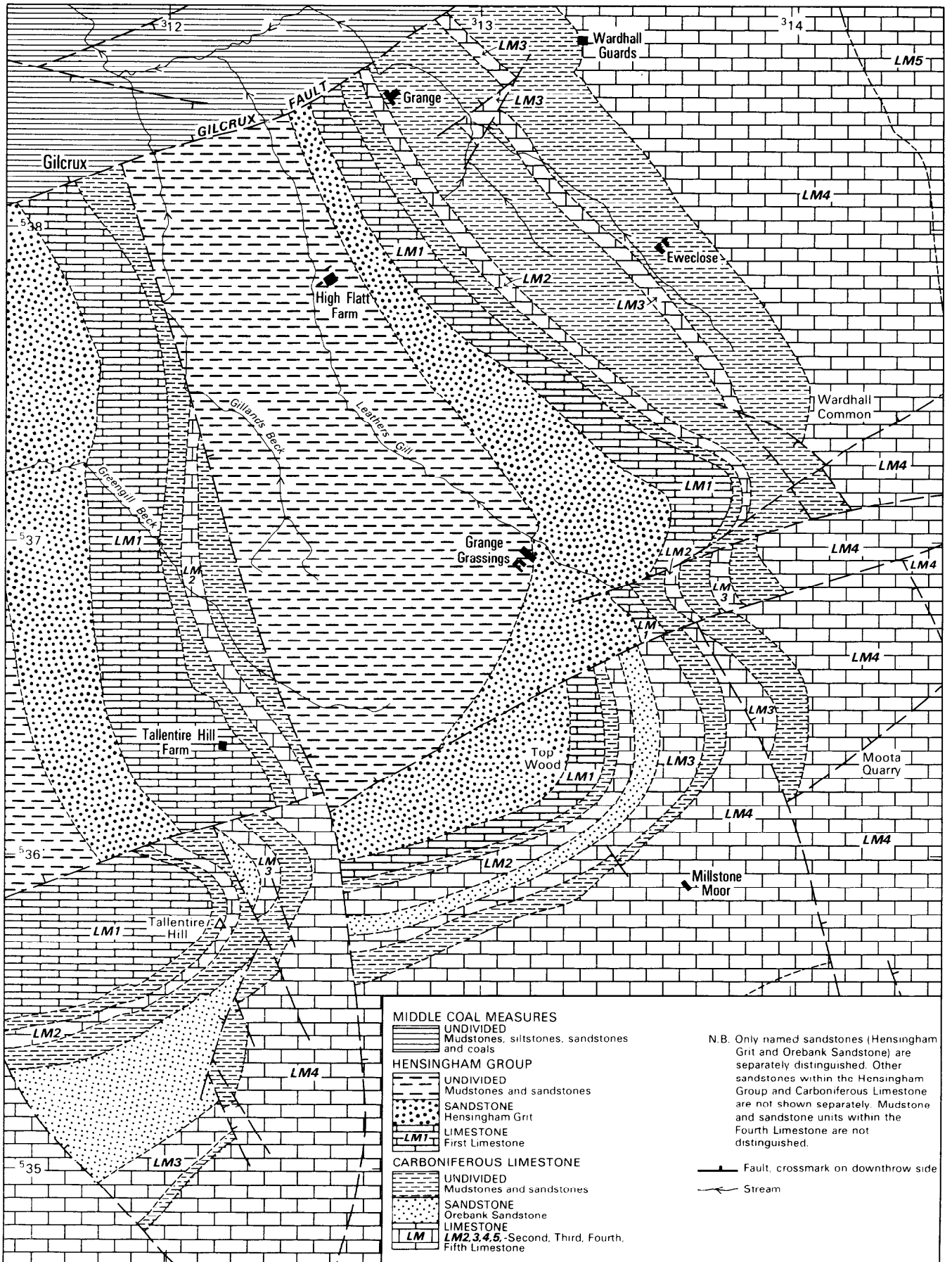


Figure 11 Geological map of the Tallentire area

The north-north-west - south-south-east-trending fault which runs immediately west of the old Moota Quarry is exposed at [NY 1467 3625]. Here it carries up to 2 m of coarsely crystalline pale fawn calcite in scalenohedral crystals up to 8 cm long. A little white baryte overgrows the calcite. Earthy red hematite locally coats both the calcite and baryte.

Mineralised joints

In these instances mineralisation occupies joints in limestone or, less commonly, sandstone. No displacement of the wall-rock can be demonstrated and, although in many places only one joint direction has been observed to be mineralised, exposures commonly exhibit mineralisation along conjugate joint sets.

White to pale pink baryte, up to 3 cm thick, coats joints in the First Limestone in the abandoned quarry on the south-west side of Tallentire Hill [NY 1185 3557] and calcite-lined joints, which strike 317° in the First Limestone exposed in the old quarry at [NY 1183 3574], contain rare malachite stains. Another old quarry in First Limestone, at [NY 1175 3777] south of Gilcrux village, shows joints trending approximately 307° filled with white baryte up to 3 cm thick. Similar crystalline white baryte coats joints in the Hensingham Grit in the old sandstone quarry [NY 1168 3763] 150 m south-west of here.

Baryte mineralisation is conspicuous in the Fourth Limestone in the western wall of the abandoned Wardhall Quarries [NY 1346 3832]. The prominent joint surfaces which strike parallel to the quarry face are coated with extensive areas of compact crystalline to rather nodular baryte up to 12 cm thick. The baryte coatings locally appear to be elongated parallel to the bedding of the limestone and are up to 0.3 m high and extend in places for 3 m along the strike. The baryte locally exhibits cavities lined with "cockscomb" aggregates of tabular crystals. Here, as elsewhere in the district, the baryte adjacent to the wallrock is typically salmon pink in colour: traced away from the walls it becomes white or colourless. No sulphides have been observed at Wardhall. Calcite and a little earthy "limonite", the latter perhaps derived from the weathering of siderite or ankerite, occur locally coating baryte crystals in cavities. It is perhaps surprising that no reference has been found to the presence of this mineralisation at Wardhall, as its relative abundance must have had a deleterious effect on the limestone worked here for lime burning and as steelworks flux. Similar salmon-pink to white baryte is present as small strings, up to 2 cm wide, in the Third Limestone in the stream [NY 1298 3832] immediately south of Wardhall Cottages.

Large tabular crystals of white baryte, up to 15 cm across, coat joint surfaces of First Limestone in the small limestone quarries [NY 1367 3717] north of the radio beacon on Wardhall Common. Apart from a little earthy brown "limonite" no other mineral has been seen here. Loose blocks of coarse-grained sandstone in the much degraded quarry [NY 1394 3729], about 250 m north-east of the radio beacon, contain veins of pink baryte up to 5 mm across.

The extensive workings in the Fourth Limestone at Moota Quarry [NY 144 363] have exposed mineralisation along joints and faults at several places. In the extreme north of the quarry [NY 1421 3652], several centimetres of white, coarsely crystalline baryte coat a joint which strikes 037° . Strong horizontal slickensides, indicating some post-mineralisation movement, were noted on the baryte. White baryte, accompanied by dolomite and a few small chalcopyrite crystals, is found filling joints which strike at 042° and 342° further west on this face [NY 1415 3647]. Veins of pale cream to pink dolomite, up to 3 cm wide, fill joints in the limestone at the extreme western end of

the quarry [NY 1409 3632]. These locally contain euhedral chalcopyrite, and rarely pale brown sphalerite in crystalline patches up to 5 mm across. In the central part of Moota Quarry [NY 1430 3629] several veins up to 6 cm wide, striking 337°, carry chalcopyrite in masses up to 4 cm across overgrown by coarsely crystalline pink to white tabular baryte. The baryte is in turn locally overgrown by pale fawn dolomite. Thin coatings of baryte also occur on joint surfaces in the old Moota Quarry [NY 148 362].

Impregnations in sandstone

Old shallow pits, presumably dug for building and walling stone, in and to the north of Top Wood (between [NY 1325 3635] and [NY 1329 3667]) in the Hensingham Grit show abundant baryte mineralisation. The mineral occurs both as thin veins (up to 1 cm wide) and as patchy impregnations of the coarse-grained porous sandstone. From the degraded and overgrown state of these pits it is impossible to assess the proportion of the sandstone so affected, but from the remaining debris and from the large amount of baryte-bearing sandstone incorporated into adjacent dry stone walls, it is clear that baryte is present here in some abundance. Analysis of a sandstone sample from the old pit at [NY 1328 3662] indicated baryte contents of up to 27%.

Similar impregnations of the sandstone beneath the Third Limestone are present in the old pits north-east of the radio beacon on Wardhall Common [NY 1395 3729].

Geochemical surveys

Additional drainage sampling

Panned concentrates were collected from two small streams between Bridekirk and Tallentire Hill not sampled by the reconnaissance survey (Cooper et al., 1991). In addition, reconnaissance survey

Table 4 Analytical and observational data for additional panned stream sediment samples collected south-east of Tallentire Hill

WCP	Ti%	Mn%	Fe%	V	Cr	Co	Ni	Cu	Zn
1186	0.366	0.138	3.89	40	110	11	16	68	63
1187	0.437	0.333	14.13	115	130	17	26	109	80
1188	0.300	0.336	5.08	152	37	8	23	75	36
1189	0.287	0.117	7.14	270	61	10	37	154	90
1195	0.358	0.150	7.58	189	80	13	41	129	80
1196	0.363	0.258	10.21	95	105	19	27	49	78
1197	0.198	0.122	6.74	196	25	3	17	89	64
WCP	Zr	Mo	Sn	Sb	Ba	Pb	Cinnabar	Gold	
1186	1435	<1	11	<2	663	30	1	0	
1187	533	7	15	4	2999	142	5	0	
1188	419	7	30	<2	88869	52	0	0	
1189	300	13	126	8	185607	289	3	2	
1195	541	10	158	<2	101901	496	1	1	
1196	349	5	21	2	4476	148	1	0	
1197	513	12	46	6	144650	205	0	0	

Values in ppm, cinnabar and gold in number of grains seen in the pan

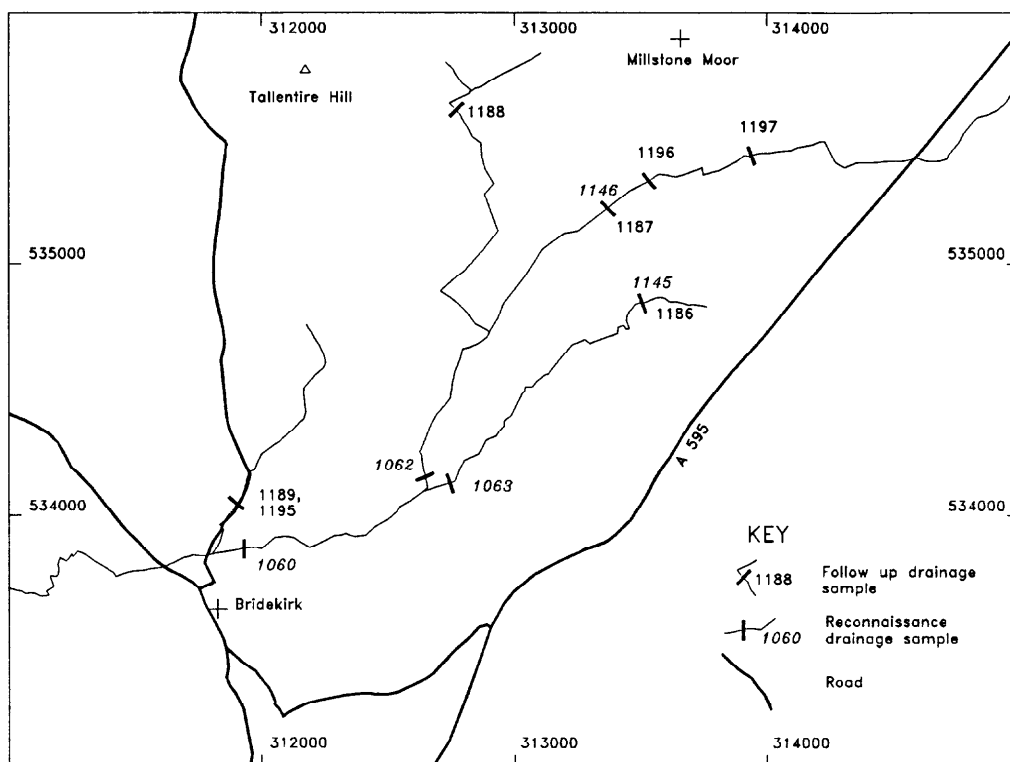


Figure 12 Additional drainage sampling south-east of Tallentire Hill

sites 1145 [NY 1351 3484] and 1146 [NY 1338 3522] were resampled and additional samples collected upstream of site 1146 (Figure 12). The analytical results and a summary of gold and cinnabar grains seen in the concentrates are listed in Table 4.

The results confirm the presence of cinnabar and, locally, gold in this area. There are also very large Ba anomalies, reflecting the presence of baryte, and weaker Pb and Cu enrichments (Table 4) which are also probably derived from mineralisation on the southern side of Tallentire Hill. Site 1188 (Figure 12), the closest to the reconnaissance soil sampling traverses on Tallentire Hill, only showed evidence of baryte mineralisation.

Soil sample survey

Soil samples were collected at 20 m intervals along 8 traverses to investigate the extent of fracture controlled mineralisation discovered during geological mapping and believed to be the source of drainage anomalies in streams peripheral to this area. Samples were collected from as deep as possible using a 1.2 m long hand auger and, following drying and disaggregation, the -0.18 mm fraction was analysed for Ca, Cu, Zn, Zr, Ba and Pb by XRF. Hg was also determined on the same size fraction of 95 samples by AAS. The analytical results are summarised in Table 5.

Threshold levels were determined by the analysis of cumulative frequency plots. The distributions of all elements indicated the presence of one or two major populations comprising 80-95% of the samples, plus a small population of high values and, except in the cases of Ca and Pb, one or more outlying very high values. Thresholds were set to discriminate as anomalous the small upper populations and the outlying very high values.

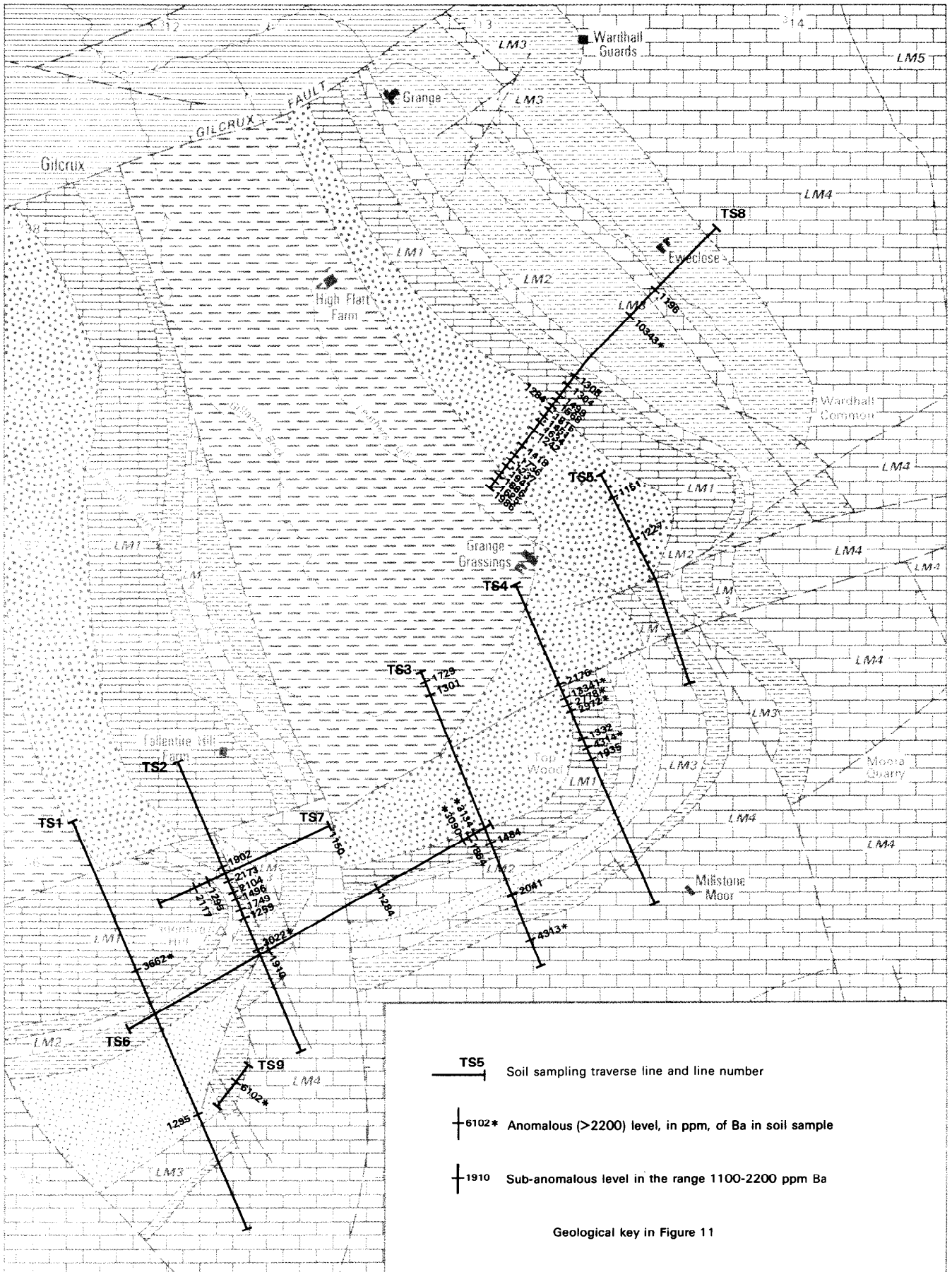


Figure 13 Location of anomalous Ba concentrations in soil samples collected in the Tallentire area

Table 5 Summary of analytical results for 429 soil samples from the Tallentire area

Element	Median	Mean	Standard Deviation	Maximum	Minimum	Threshold
Ca	2700	5931	10114	99700	200	31000
Cu	40	50.5	65.1	867	4	95
Zn	37	45.9	33.0	340	7	100
Zr	250	251	66.6	911	62	330
Ba	446	695	989	13341	78	2200
Hg*	250	318	261	1700	60	470
Pb	27	32.3	19.5	123	7	100

Results for Hg in ppb, other elements in ppm
* 95 samples

On the cumulative frequency plot a small population of anomalous samples containing more than 2200 ppm Ba plus three outlying values with greater than 5000 ppm Ba is evident. These results almost certainly reflect the presence of baryte. In addition a high background population with a median of c. 1100 ppm is present. This population is of uncertain origin but may also be related to baryte mineralisation, so results in the range of 1100-2200 ppm are also plotted on Figure 13. Predictably the largest Ba anomaly is located on TS4 over the Hensingham Grit at Top Wood [NY 1328 3645], close to outcrops and excavations into the baryte sandstone (Figure 13). Other very high Ba results form isolated anomalies, 10343 ppm at [NY 1347 3768] on traverse TS8 and 6102 ppm at [NY 1222 3528] on traverse TS9. The latter is accompanied by a Cu anomaly (187 ppm) and is close to mapped faults. In addition, the following prominent anomalies form an outlying group on the cumulative frequency plot and are probably related to fracture controlled mineralisation: 3090 ppm and 3134 ppm on traverse TS6 at [NY 1297 3604]; 3662 ppm accompanied by high Cu (156 ppm) on traverse TS1 at [NY 1192 3562]; 4313 ppm on traverse TS3 at [NY 1315 3571]; 3022 ppm at [NY 1230 3569] on traverse TS2, with high levels of Cu and Hg near mineralised float, and 4314 ppm at [NY 1335 3629] south of Top Wood (Figure 13). This last anomaly, over the First Limestone, is associated with high levels of Cu, Zn and Pb and probably reflects underlying mineralisation although there is a possibility that the baryte comes from Top Wood and the base metals represent a secondary concentration.

Evidence for further disseminated/replacement baryte mineralisation similar to that seen at Top Wood and Wardhall Common is ambiguous. The abrupt decrease in barium concentrations in soil along TS4 to the north of the Top Wood - Tallentire fault suggests that the mineralisation is controlled or displaced by this fault and is absent at surface to the north of it. However, a spread of sub-anomalous high values (1200 ppm to 2000 ppm Ba) in samples taken from drift deposits over 500 m at the western end of traverse TS8 (Figure 13) suggests that further Ba enrichment may be present in this area, which is largely underlain by Hensingham Grit.

Mercury was only determined on 95 samples from traverse TS7 and parts of traverses TS2 and TS6 (Figure 14). Two outlying high results (1300 ppb at [NY 1230 3569] on TS2 and 1700 ppb at [NY 1235 3600] on TS7) are related to mineralisation. The lower value was obtained from a sample containing anomalous Ba (3022 ppm), next to a sample enriched in Cu (140 ppm). Both samples were collected from close to a fault intersection near an excavation which revealed mineralised float enriched in Hg (sample 1262, Table 6). The highest Hg value was recorded in a sample which

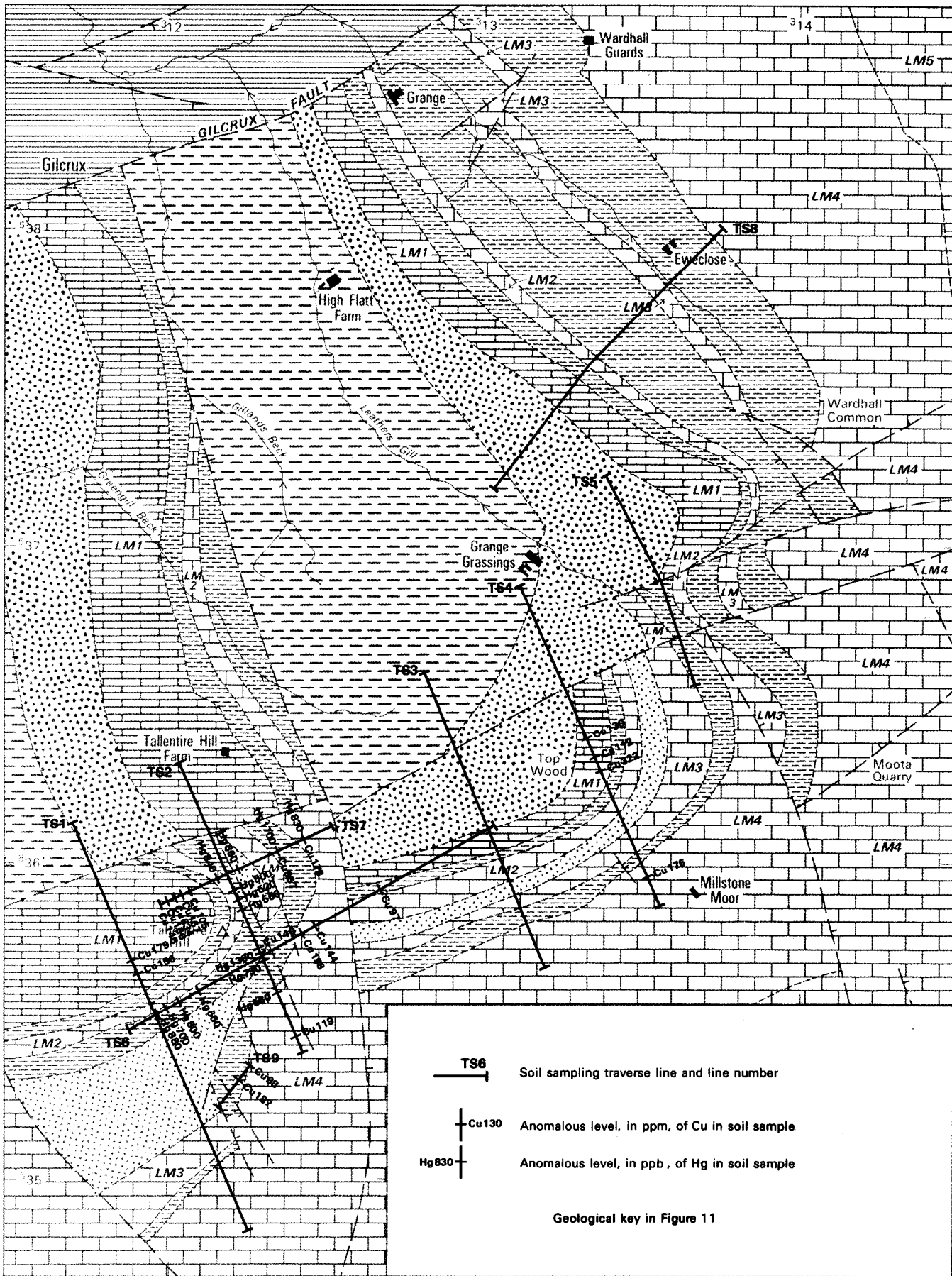


Figure 14 Location of anomalous Cu and Hg concentrations in soil samples collected in the Tallentire area

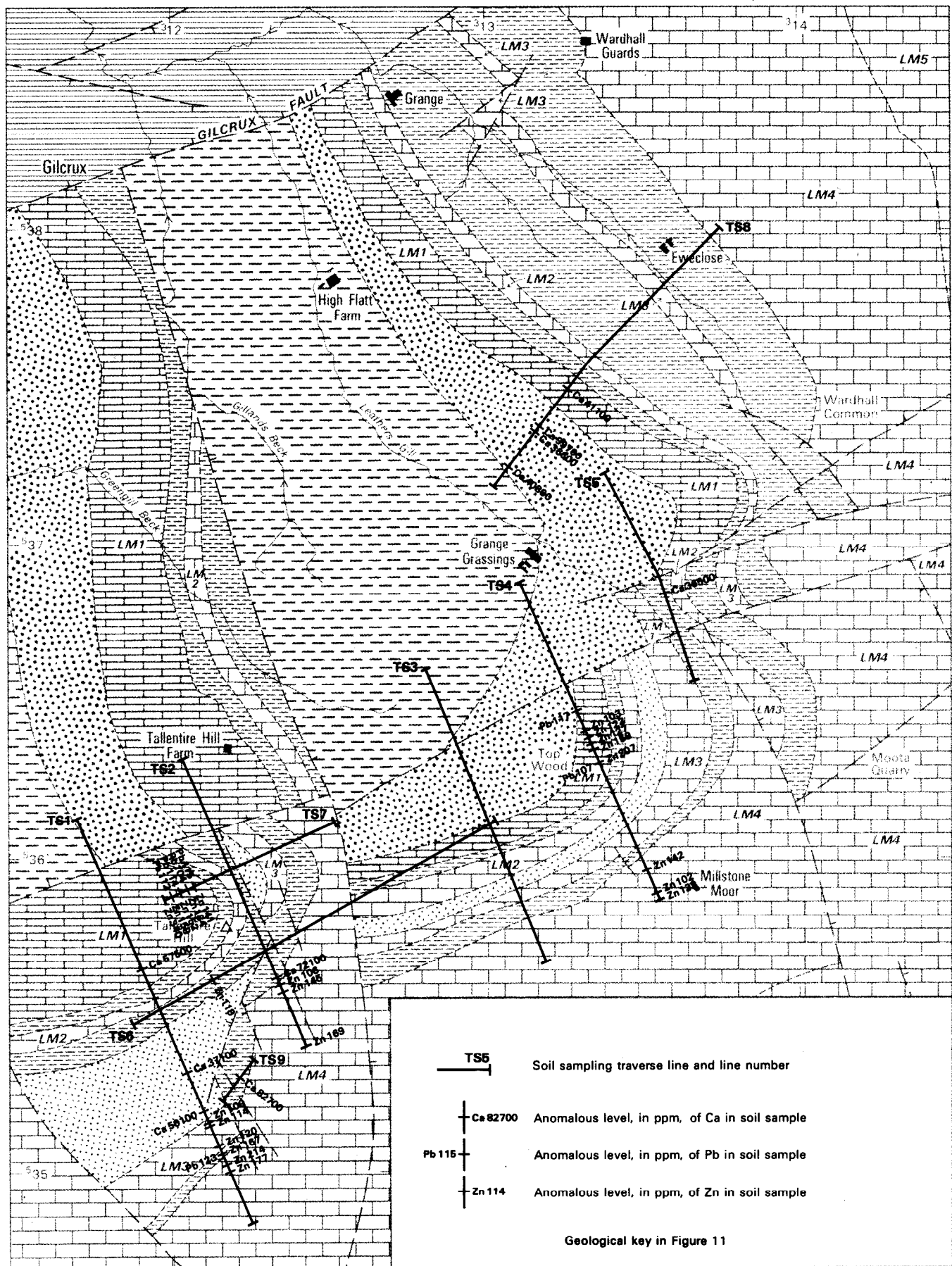


Figure 15 Location of anomalous Ca, Zn and Pb concentrations in soil samples collected in the Tallentire area

also contains the highest level of Cu reported from this area (867 ppm) and relatively high Pb (82 ppm). It is interpreted as reflecting the presence of underlying mineralisation similar to that seen in the mineralised debris. A further anomalous Hg (830 ppb) result, accompanied by high Cu (178 ppm), is recorded to the east on the same traverse [NY 1242 3603] close to the junction of the Orebank Sandstone with the Fourth Limestone; it most probably has a similar mineralised source. Weakly anomalous Hg (c. 500 ppb) levels may also represent dispersion from mineralised faults, for example on traverse TS2 south of its intersection with traverse TS7 [NY 1220 3594], where high Hg and Ba occur together close to the line of a north-west-trending fault.

High background levels of Cu (median 40 ppm) are a feature of the area, particularly around Tallentire Hill. The cause of this high background is uncertain, the most likely sources being metalliferous sedimentary rocks within the Carboniferous succession though contamination of the soil from Cu fertilisers, sprays or food additives cannot be excluded. The most prominent group of Cu anomalies occurs over First Limestone at the western end of traverse TS7, accompanied by high levels of Pb and Zn. Four samples from the thin soil contain between 105 and 167 ppm and another, the second highest Cu level reported from this area (634 ppm), is probably derived from fracture-controlled mineralisation. Other Cu anomalies on the First Limestone are located on traverses TS1 and TS4 (Figure 14). On the latter traverse the Cu anomalies are associated with high levels of Ba, Pb and Zn south of Top Wood [NY 1335 3630]. Further prominent Cu anomalies include those on traverses TS6 over the Fourth Limestone close to a north-west-trending fault (198 ppm at [NY 1242 3573], and on traverse TS9 (187 ppm at [NY 1222 3527]), again close to a fault.

Pb and Zn results show a close positive correlation (Spearman-rank correlation coefficient 0.79) and coincidence of high values (Figure 15). Except for one high Zn outlier, neither element shows a distinct anomalous group of high values which can be related to mineralisation, and rock analyses (Table 6) do not suggest the presence of Pb or Zn mineralisation. High values form two clusters over the First Limestone, one at the western end of traverse TS7 on Tallentire Hill associated with high levels of Cu (around [NY 1200 3585]), the other near Top Wood on traverse TS4 where Cu and Ba anomalies are also recorded (around [NY 1335 3630]).

Changes in Ca and Zr levels are not closely related to the mapped lithological units and proved to be of little use for geological mapping purposes. Two outlying high Zr values (911 ppm at [NY 1299 3614] on TS3 and 632 ppm at [NY 1194 3560] on TS1) may be caused by heavy mineral concentrations in soils derived from sandstones. Two Ca populations were discerned on the cumulative frequency plots. As was found in the other two follow-up areas, the higher population does not appear to be caused by the presence of limestones; it probably has a calcareous mudstone or sandstone source. There is some coincidence of high Ca with anomalous Ba results, notably at the western end of traverse TS8 and at [NY 1192 3561] on traverse TS1. This may be due to carbonate accompanying baryte mineralisation in fracture fillings, as the analysed sandstones containing disseminated baryte contain very low levels of Ca (Table 6).

Rock sampling

Samples of the Hensingham Grit containing baryte were collected for chemical analysis to determine whether other metal enrichments are present. For comparative purposes a sample (1256) of unmineralised grit was also analysed. Similarly, two samples of mineralised float from

Tallentire Hill were analysed to determine the range of elements enriched. Au and Hg were determined by AAS, other elements by XRFs.

Table 6 Analyses of rock samples

Number	Grid Reference	Locality	Description
1253	NY 1395 3729	Wardhall Common	Hensingham Grit with baryte
1254	NY 1328 3662	Top Wood	Hensingham Grit with baryte
1256	NY 0030 2460	Barfs Quarry	Hensingham Grit
1262	NY 1233 3569	Tallentire Hill	Mineralised float (sandstone)
1296	NY 1232 3570	Tallentire Hill	Mineralised float (sandstone)

Number	Ca	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Rb	Sr
1253	<100	670	138	3	<100	1100	3	8	13	<1	13	1288
1254	<100	610	193	<2	<100	400	<2	<2	25	<1	13	2282
1256	<100	1200	12	21	150	7400	7	6	4	<1	8	52
1262	23500	230	22	280	1200	32500	20	15	3056	54	3	<1
1296	1100	7790	-	-	270	97000	15	20	17969	-	52	9

Number	As	Zr	Mo	Ag	Sn	Sb	Ba	W	Au	Hg	Pb	Bi	Th	U
1253	<2	85	3	-	<2	-	105180	<2	-	420	<2	-	6	<2
1254	<2	78	2	-	<2	<2	162600	<2	-	120	<2	-	5	<2
1256	8	118	1	-	<2	<2	24	<2	-	-	4	-	4	<2
1262	54	8	9	1	<2	11	414	3	-	1600	72	<2	3	6
1296	495	57	10	6	30	28	85	<2	<10	-	61	<2	2	<2

Hg and Au results in ppb, other elements in ppm
- indicates not determined

The results (Table 6) show that, except for Sr, the disseminated/replacement baryte mineralisation is not accompanied by other metal enrichments. The analyses of mineralised float indicate the presence of Cu mineralisation accompanied by enrichments of As, Mo, Sn, Sb and Hg. Hand specimens also contained Ba (baryte) and Fe (hematite) mineralisation, indicating that the analysed material was not fully representative of the mineralisation. Insufficient samples were analysed for Au to determine whether or not the fracture controlled mineralisation is the source of the gold grains recorded in panned concentrates. The presence of elements typical of relatively early high-temperature mineralisation in the Lake District (As) with others identified with later low-temperature events (Ba, Fe) suggests that the mineralisation may be polyphase or, less likely, that some form of contamination is present.

Conclusions

1. Several soil anomalies in the vicinity of Tallentire Hill are believed to be caused by underlying fracture controlled mineralisation. Mineralised float and blocks in walls can be seen at surface in the vicinity of these anomalies.
2. Fracture controlled Cu and Ba mineralisation is accompanied locally by enrichments of As, Fe, Mo, Sn, Sb and Hg. Mineralisation may be polyphase.

3. Enrichments in Hg suggest that the fracture controlled mineralisation is the source of cinnabar grains found in some of the panned concentrates collected from the south side of Tallentire Hill. The source of gold grains found in these samples is uncertain.

4. Soil anomalies related to disseminated/replacement baryte mineralisation in sandstones were recorded at Top Wood, close to outcrops of this style of mineralisation. Ba anomalies at the western end of TS8, north of Grange Grassings, may have a similar source.

5. The disseminated/replacement baryte mineralisation is not associated with other metal enrichments except for Sr.

Geophysical surveys

Brief reconnaissance surveys were carried out to test the use of electrical methods for the detection of faults, lithological boundaries and disseminated baryte mineralisation beneath the variable drift cover.

Methods

A ground conductivity survey was carried out across the Top Wood area along two geochemical traverse lines (TS3 and TS4), using the electromagnetic (EM) method, to measure variations in conductivity over sandstone and mudstone horizons within the limestone-dominated sequence. The conductivity survey was carried out using the Geonics EM34 system with a transmitter-receiver coil separation of 20 m, and adopting both the vertical loop (horizontal dipole) and horizontal loop (vertical dipole) configurations. Measurements were made at 10 m intervals on both traverse lines and along the base-line of the Tallentire Hill survey grid before equipment failure occurred at this location.

The VLF(EM) method was also employed on lines TS3 and TS4 and along a surveyed grid at Tallentire Hill (Figure 16) to map near-surface variations in conductivity, and to locate faults which may be expressed as narrow steeply dipping conductors. The VLF(EM) survey was carried out using a Scintrex IGS-2 digital VLF receiver, and the source of the VLF primary field was Cutler Main (24.0 kHz) for north-south survey lines and GBR, Rugby (16.0 kHz) for east-west lines.

In addition, four resistivity soundings were taken using the Schlumberger array to obtain resistivity values for the different lithologies (Figure 16).

Results

The results of the EM34 survey across the Top Wood area are shown as profiles (Figure 17) of observed conductivity values for the horizontal and vertical dipoles. On line TS4 (1200E), a marked change in conductivity from variable values of 5-12 mmhos/m at the southern end of the line to stable low conductivity values of less than 5 mmhos/m to the north, occurs at the base of the First Limestone (LM1). The boundary between this limestone and the overlying Hensingham Grit cannot be distinguished here as they appear to have similar resistivity values. The resistive zone ends with a sharp increase in conductivity (horizontal dipole) at 950N which, together with a local step in the topography, probably marks the top of the Hensingham Grit, although a powerline at 1070N greatly effects vertical dipole conductivity values.

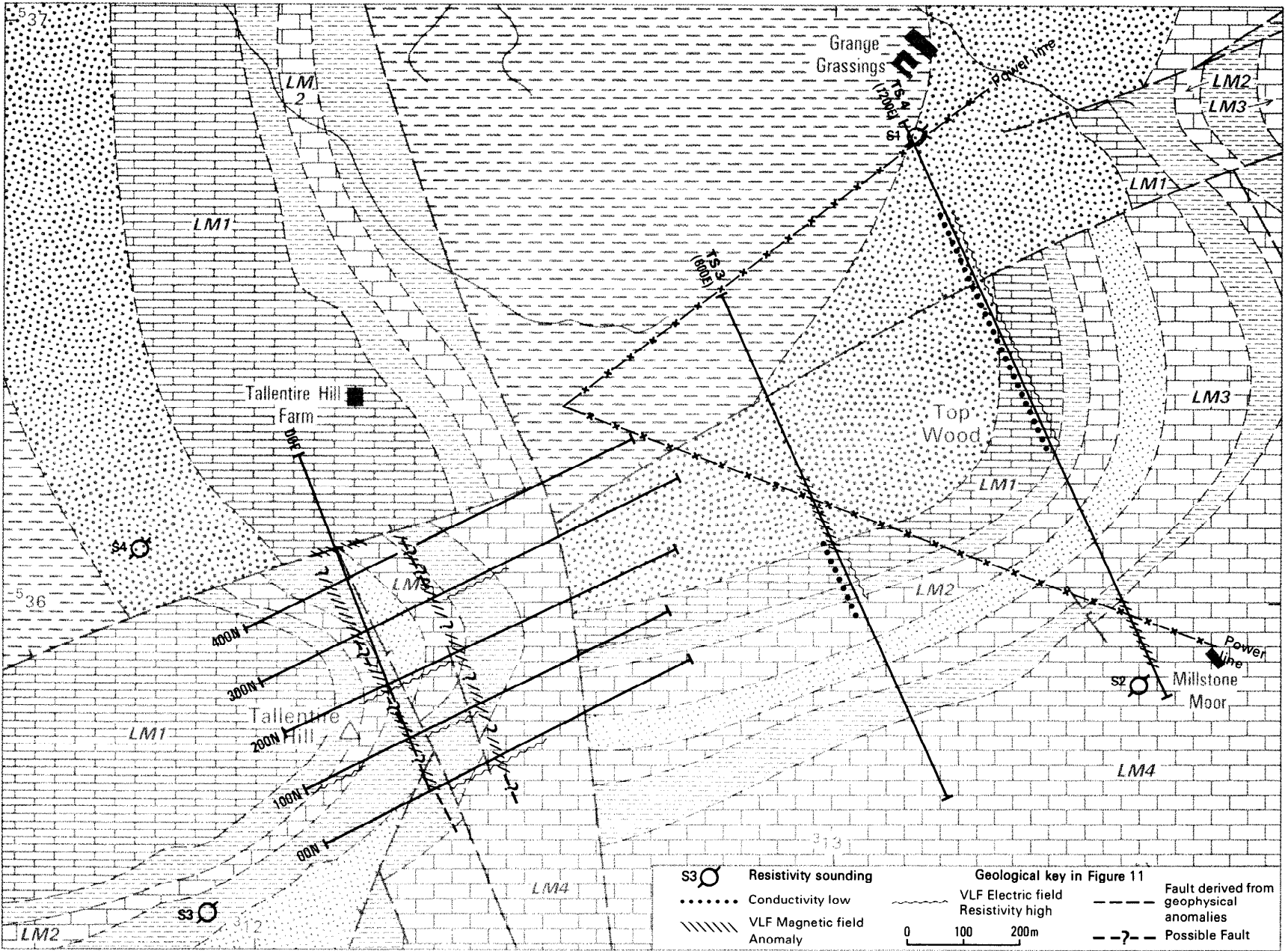


Figure 16 Location of geophysical survey traverse lines and summary of geophysical anomalies in the Tallentire area

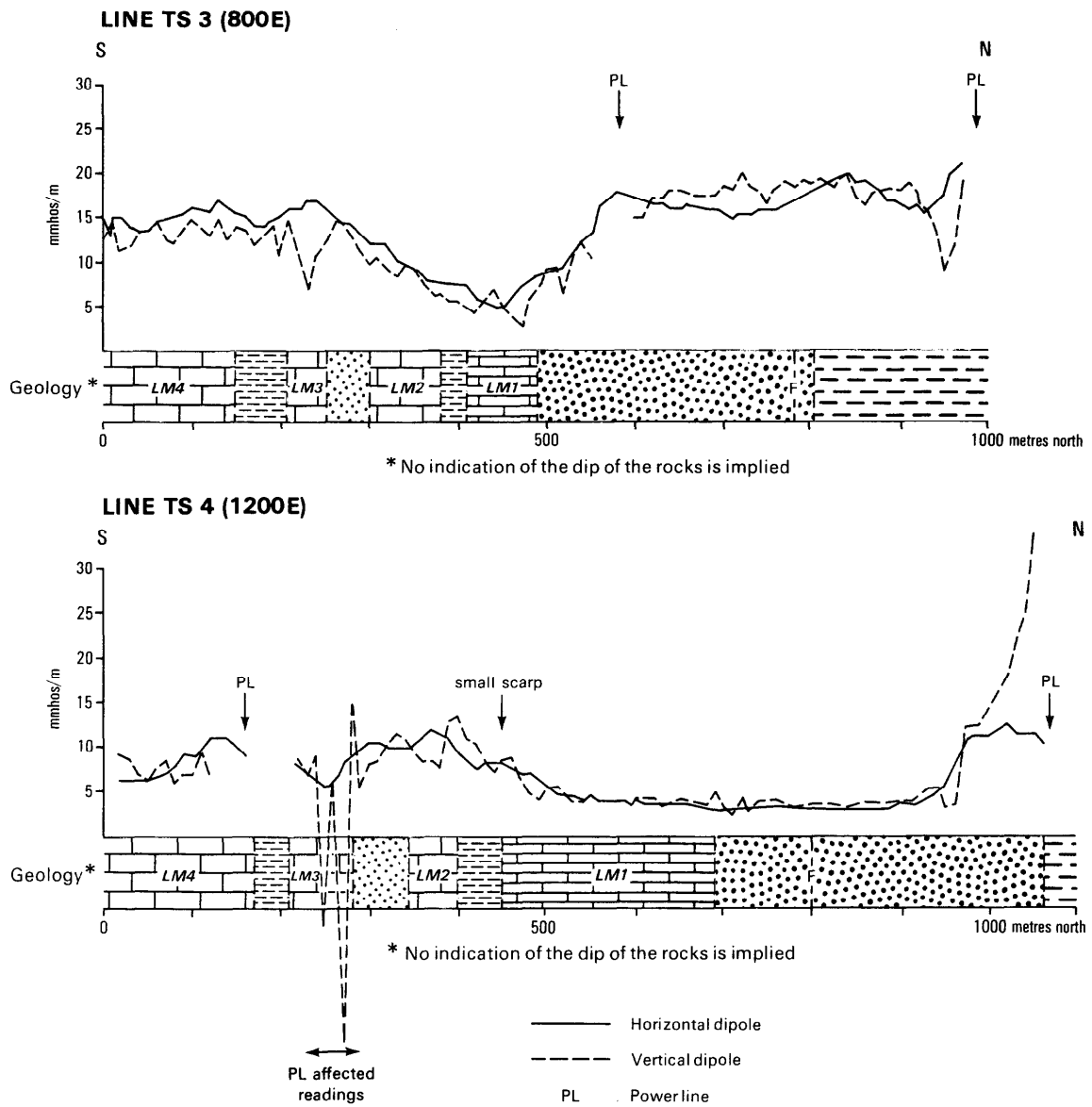


Figure 17 Conductivity (EM 34) profiles for traverses 800E and 1200E in the Tallentire area

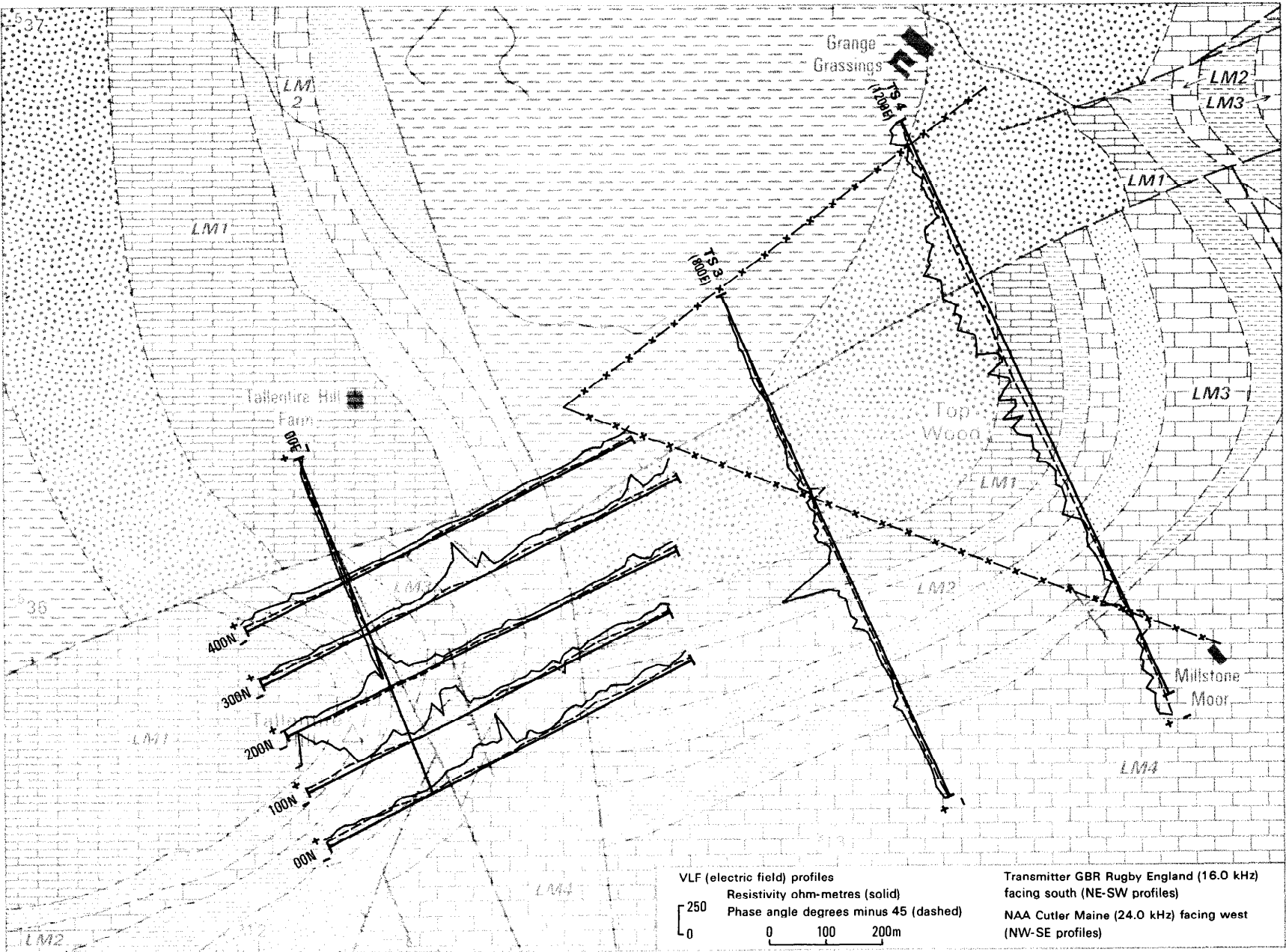


Figure 18 VLF electromagnetic (electric field) profiles in the Tallentire area

Line TS3 (800E) also shows variable, if somewhat higher, conductivity values over the Dinantian sequence at the southern end of the line and a fall in conductivity to produce a minimum value of less than 5 mmhos/m over the First Limestone. However, in contrast to line TS4 (1200E), conductivity values increase again over the Hensingham Grit and the overlying mudstone/sandstone sequence.

The VLF electric field (Figure 18) also shows a resistivity increase over the First Limestone and the Hensingham Grit on line TS4 (1200E), both of which display apparent resistivity values of between 200 and 300 ohm-m, and a sudden decrease at the top of the Hensingham Grit. On line TS3 (800N) high apparent resistivities occur over the First Limestone only.

The VLF(EM) survey (Figure 19) did not detect the Top Wood - Tallentire east-north-east-trending fault to the north of Top Wood. The only prominent anomalies are due to powerlines.

Resistivity soundings (S1 and S2; Appendix 1) at the ends of traverse TS4(1200E) suggest that the conductivity values measured with the EM34 (about 7 mmhos/m with a 20 m cable) at the two sites should be similar, although the model results at S1 are more complex. The resistivity values at S2 are low for limestones. Soundings S3 and S4 were located primarily to obtain resistivity values for different parts of the Carboniferous sequence and the results indicate a fairly complex layering with higher calculated conductivity values (9 and 11 mmhos/m respectively).

The VLF(EM) survey at Tallentire Hill identified two north-west - south-east-trending conductors (Figure 16 and 19) which correlate across all five survey lines and are near-coincident with two mapped faults. However they are also parallel to wire fences which cause small anomalies elsewhere along the grid. An anomaly at c. 450N on the baseline (Figure 19) is probably caused by an east-west fault, but the anomaly at the end of the line is due to a powerline.

Conclusions

The EM34 and VLF(EM) methods have not identified or traced at depth individual lithologies with any certainty. This is probably because the units are generally too thin, the dip is very shallow (8-10°) and the resistivity values for the limestones and sandstones are equally variable. The apparent variation in conductivity over the Hensingham Grit could be due to variations in the drift thickness or in the porosity of the sandstone. Low porosities (ie. low conductivities) may be caused by an increase in the amount of baryte. If so, these methods may be useful for indicating the extent of the baryte-rich sandstone. Further work is merited to ascertain the relationship between baryte impregnations and conductivity variation.

The VLF(EM) method at Tallentire Hill has identified conductors which relate to mapped faults, but they may well be caused by wire fences or other cultural noise.

Discussion and assessment

Throughout the Tallentire area, much of the observed mineralisation has been introduced along fractures (both faults and joints) within the Carboniferous rocks. Copper is a major constituent of the mineralisation in at least one fault vein on Tallentire Hill. Elsewhere in the area, baryte is by far the most abundant fracture filling and in many localities it is the only introduced mineral. Chalcopyrite locally accompanies baryte and at one locality in Moota Quarry a little sphalerite was seen. Iron is also found locally, mainly as earthy "limonite", presumably an oxidation product of

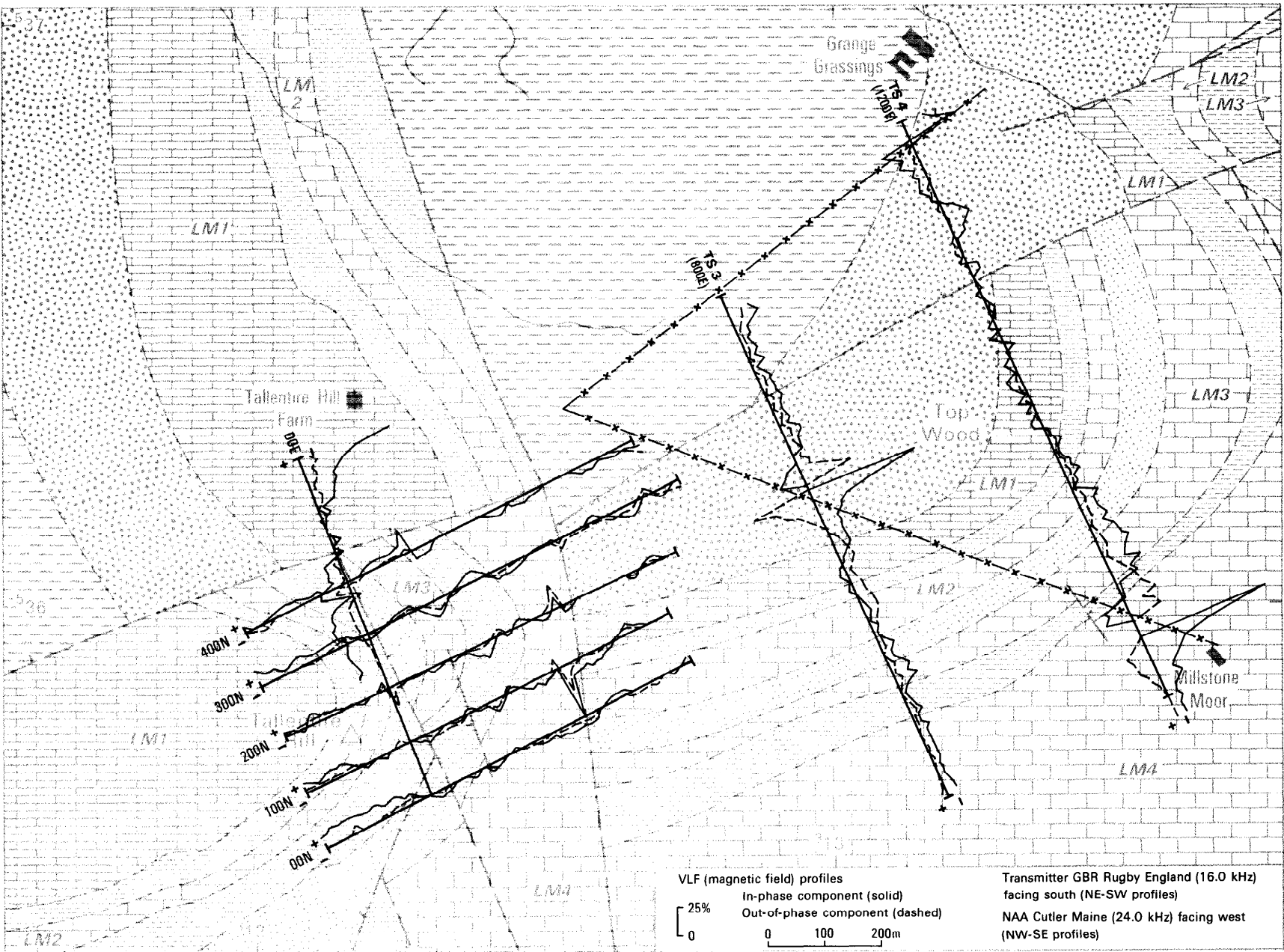


Figure 19 VLF electromagnetic (magnetic field) profiles in the Tallentire area

pyrite or a primary carbonate though the latter has not been identified. A little earthy hematite also occurs. The chemical analyses and panned concentrate observations indicate that mercury mineralisation may be present locally and there are also trace enrichments of arsenic, molybdenum, tin and antimony accompanying the copper mineralisation on Tallentire Hill.

It is reasonable to suppose that both the fault vein and joint fillings result from one mineralising episode of Upper Carboniferous to Lower Permian age (Cooper et al., 1991), although the range of metal enrichments in the copper-rich structure on Tallentire Hill suggests that this may be the product of more than one event. Few of the area's main faults are exposed and it is not known to what extent any of these are mineralised. However, if, as seems likely, some of the faults acted as channels along which mineralising fluids flowed and spread out into the joints of the country rocks, at least some of these may be expected to carry mineralisation. Many of the area's faults have substantial throws, commonly well in excess of 30 m. In areas of broadly similar geology with similar epigenetic mineral deposits, eg. the North Pennines, faults of such throws are commonly choked with fault breccia and do not carry abundant mineralisation. In these areas it is usually, though not invariably, the faults of small throw which bear the most abundant mineralisation. The results of the soil sampling exercise suggest that this is an effective technique for detecting such veins where the overburden is thin, though contamination may cause problems locally.

The Tallentire area includes one style of baryte mineralisation which so far appears to be unique in this part of Cumbria. Only in the Top Wood and Wardhall areas is baryte found within sandstones. The limited evidence available suggests that this is an epigenetic impregnation of a coarse-grained and initially very porous sandstone. There is no reason to regard the impregnating baryte as a syngenetic or diagenetic cement. The mineralisation occurs within 150 m of the mapped outcrop of a prominent east-north-east - west-south-west-trending fault which at Top Wood downthrows north about 70 m. There is some evidence from the soil results that this fault exerts a control on the distribution of baryte and it is possible that mineralising fluids, passing along this fracture, spread out into the porous sandstone, perhaps beneath an impervious cover of Namurian shales. The presence of substantial fissure fillings of baryte in the First Limestone and lower beds beneath Top Wood is thus possible. Geophysical techniques may be able to provide an estimate on the extent of the baryte-rich sandstone and base of overburden. Base of overburden sampling and analysis would provide information on its rockhead extent, but drilling would be required to test for the presence of baryte mineralisation in the underlying beds and along the fault line.

WHITRIGG

This area is located at the junction of the Carboniferous succession with the underlying Lower Palaeozoic rocks (Figures 1 and 2). The terrain is undulating with rock outcrop restricted to a few exposures on the steepest slopes and hilltops where drift cover is thin. The land is mostly grass covered and used for grazing.

A considerable amount of mineral exploration work was carried out in this area in two periods under the provisions of the Mineral Exploration Investment Grants Act (MEIGA). Firstly, following reconnaissance sampling in the Cockermouth-Sandale area, Consolidated Goldfields Ltd. carried out soil sampling, trenching and IP surveys in the area around Whitrigg, Stangerhill and Bird House. Geochemical and geophysical anomalies were identified and six diamond drill holes

sunk to investigate their cause, which it was hoped might be "Irish-style" mineralisation. No potentially economic sulphide concentrations were located. IP anomalies were attributed to pyrite in both the Carboniferous and underlying altered volcanic rocks, but the geochemical anomalies were not satisfactorily explained (Consolidated Goldfields, 1974). A few years later (1979-83) BP Minerals International re-appraised this data and concluded that the area merited further investigation. Detailed geological mapping, accompanied by further soil sampling and geophysical survey work, was completed under another MEIGA project. A substantial copper, lead and zinc in soil anomaly, with a coincident gravity anomaly, was located and investigated by two drill holes. These failed to provide an explanation for the gravity anomaly, which it was originally thought might have been caused by massive sulphide mineralisation in the volcanic rocks beneath the Carboniferous. No source of base metals was intersected and it was considered that the geochemical anomalies might be caused by leakage along fractures or mineralised faults. Following the drilling, deep overburden traversing and a VLF(EM) survey were carried out. The VLF(EM) data indicated the probable line of the boundary fault between the Lower Palaeozoic and Carboniferous rocks beneath the drift, while the presence of higher lead and zinc anomalies in overburden at 1 m than at the bottom of the holes suggested that the soil anomalies were transported (BP Minerals International, 1983).

The reconnaissance survey work reported in Part 1 (Cooper et al., 1991) suggested that fracture-controlled vein mineralisation or syngenetic base metal concentrations in mudstones were a more likely source of the geochemical anomalies than either "Irish-style" mineralisation in the Carboniferous or massive sulphide mineralisation in the underlying volcanics. It also seemed possible that baryte mineralisation might be present locally, although none was recorded in the boreholes. However, barium had not been determined in the geochemical samples collected during the MEIGA surveys, so there was an absence of information on the distribution of this element in the area. The reconnaissance drainage survey data reported in Part 1 did not provide clear evidence for this area because it is crossed by few streams. The most relevant panned concentrate sample, collected from the stream which runs from west to east across the area at [NY 2168 3816] contained weak copper (119 ppm), arsenic (94 ppm), antimony (29 ppm) and barium (4691 ppm) anomalies. A stream running north immediately to the east of this area (Humble Jumble Gill) contained large barium anomalies. Consequently limited additional work was carried out to provide information on barium mineralisation. The opportunity was also taken to test the use of some geochemical and geophysical methods for detecting faults beneath drift cover and estimating the thickness of drift deposits.

Geology and mineralisation

The geology of the Whitrigg area is shown in Figure 20. The map is based on the published Geological Survey map (six-inch County Series Cumberland 46 NE and 36 SE) modified in the light of information obtained during the MEIGA investigations. Boulder clay mantles much of the area and, apart from exposures on the Caer Mote ridge in the west and around the old quarries at Whitrigg, outcrops of solid rocks are few.

Mudstones of the Lower Ordovician Skiddaw Group crop out in the bed of Black Beck on either side of the A591 road south of Caer Mote [NY 1990 3635]. These are overlain by rocks of the Eycott Volcanic Group, which here consist mainly of basalts and andesites. They are exposed on the Caer Mote ridge west of Bird House. Mapping suggests that these rocks also crop out in the

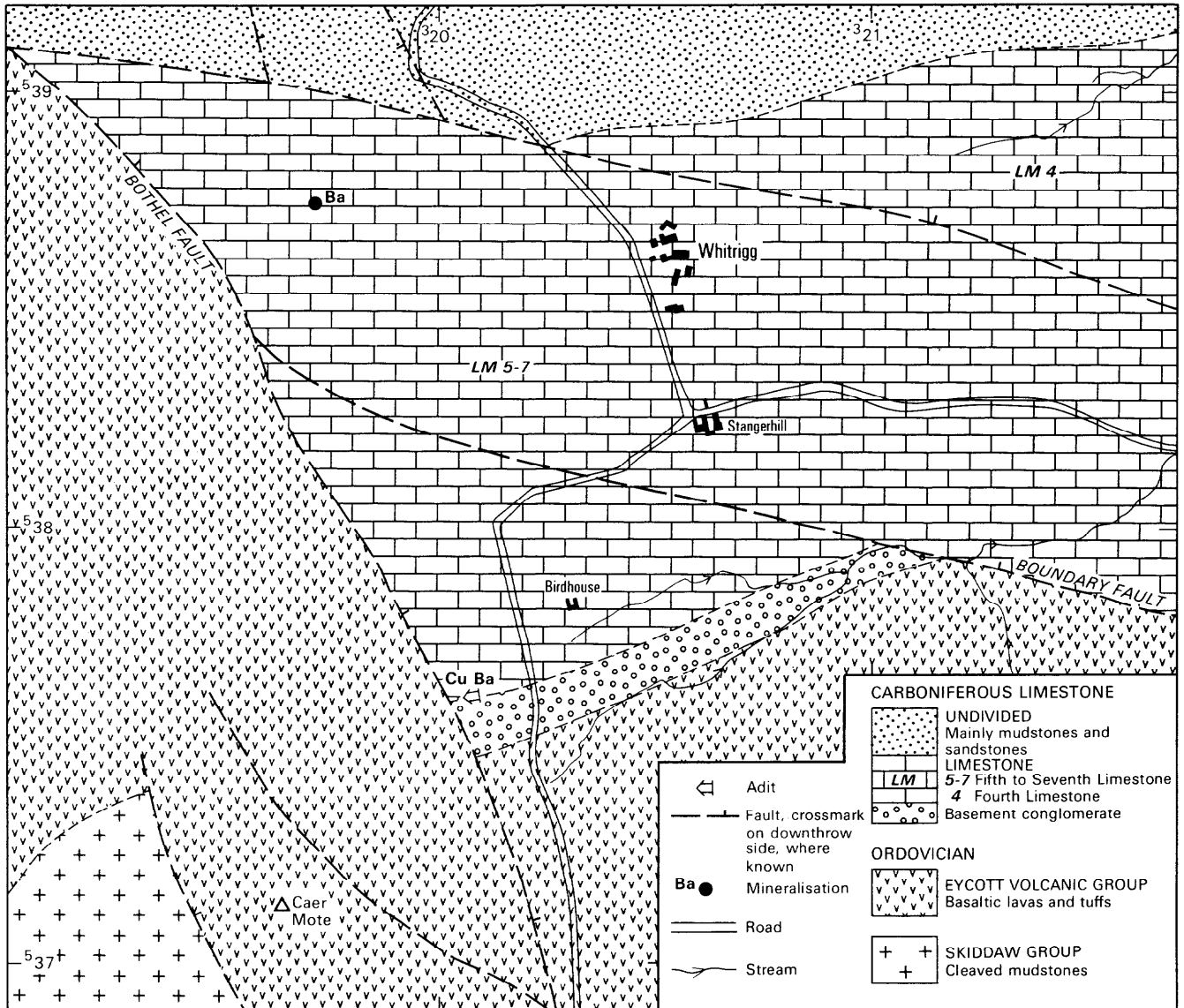


Figure 20 Geological map of the Whitrigg area

low ground south of Bird House, though here they are almost everywhere concealed beneath boulder clay and alluvium. Lower Carboniferous rocks, mainly limestones with some interbedded mudstones and sandstones, underlie the centre and north-east of the area and according to the published geological maps, these are everywhere faulted against the Eycott Volcanic Group. However, there is some evidence from boreholes drilled under the MEIGA scheme that at least locally south of Bird House the Carboniferous succession, with a conglomerate at the base, may rest unconformably on the Eycott Volcanic Group at outcrop, and that the Boundary Fault extends further to the west than shown on earlier maps, joining a north-westerly-trending fault north-west of Bird House (Figure 20). This north-west-trending fault, termed the Bothel Fault in Part 1, is believed to be a more significant feature than shown on existing geological maps and was perhaps active in Carboniferous times (Cooper et al., 1991). Grey nodular limestones and pseudobrecciated limestone, assigned to the Seventh Limestone, are well exposed in the abandoned quarries around Stangerhill [NY 205 382] and limestones referred to the Fifth to Seventh Limestone are exposed in the overgrown Borrowscale Quarries [NY 197 386].

Comparatively little mineralisation is visible at outcrop. The site of an old adit can be seen in the field west of Bird House [NY 2012 3764], though the entrance appears to have collapsed long ago. The adjacent small and largely overgrown dump contains fragments of Carboniferous sandstone and sandy limestone together with fragments of lavas and tuffs from the Eycott Volcanic Group. Quartz and a little white to pale pink baryte can be found and Eastwood et al. (1968, pp 168) noted traces of malachite. A few fragments of quartz pseudomorphing tabular baryte were also seen. Such pseudomorphs are common in lead-zinc veins ascribed to a Lower Carboniferous mineralising event in the central Lake District. No details of the date or of the extent of the workings have been discovered. The adit appears to be driven westwards along a roughly east-west striking fault mapped as throwing down Seventh Limestone to the north against Eycott Volcanic Group lavas. Mapping indicates that approximately 35 m west of the adit entrance this fault terminates against the north-north-west-trending Bothel Fault which bounds the Caer Mote ridge. North of the adit, this fault throws Seventh Limestone on the east against Eycott Volcanic Group lavas. Assuming that the mineralisation explored from the adit occupies a fault vein either of these faults, or perhaps both, could have been the target. There is no surface evidence for the presence of mineralisation in either fault and there seems little doubt that this adit was merely a trial.

Pink baryte forms veins up to 1 cm thick filling joints which strike between 122° and 242° in the limestone exposed in the old quarry at Borrowscale [NY 1970 3865]. No other introduced minerals have been seen here.

The major sulphide encountered in the boreholes drilled under the two MEIGA projects was diagenetic pyrite. This occurs most commonly as small nodules and fine disseminations in non-calcareous mudstones as well as small euhedral crystals on fracture surfaces. Rarely a little chalcopyrite was observed to accompany the pyrite.

Geochemical surveys

Soil sampling

Soil samples (233) were collected for chemical analysis at 20 m intervals along nine traverse lines (Figure 21) to look for evidence of barium mineralisation and its relationship to base metal anomalies discovered by the MEIGA funded projects. The samples were collected and analysed

using the methods described for the Ruthwaite area. The analytical results are summarised in Table 7.

Table 7 Summary of analytical results in ppm for 233 soil samples collected in the Whitrigg area

Element	Median	Mean	Standard Deviation	Maximum	Minimum	Threshold
Ca	3400	8803	18592	152900	900	62000
Cu	58	69	73	702	5	151
Zn	69	93	70	588	17	301
Zr	286	288	45	462	160	387
Ba	286	459	1136	14578	98	750
Pb	40	45	27	259	9	115

Threshold levels were set by cumulative frequency curve analysis. The cumulative plots of Cu, Zn, Ba and Pb consist of a poorly defined population of outlying high values above a continuum of overlapping background populations. In all four cases an upper background population is evident immediately below the outlying high values. Ca results describe a sigmoidal form on a log-scale probability plot, interpreted as two overlapping log-normal background populations with medians at c. 3400 ppm and 40000 ppm. The Zr data describe a single population approximately log-normal in form. For Ca and Zr, for which no distinct anomalous populations were present, the threshold was arbitrarily set at the 97.5% level of the distribution. For the remaining elements, the threshold was set to define as anomalous the ill-defined uppermost population of outliers; this comprised 3 (Zn) to 14 (Ba) samples. The high and low background populations for those elements and Ca were also plotted to examine their spatial distribution and relationship to the geology.

The two groups of Ca results occupy distinct areas, with most samples of the high background population coming from the high ground to the south and east of Stangerhill (Figure 21). However, there is no close relationship between changes in the Ca background and mapped lithological boundaries. For example, on traverses WS4 to WS7 there is no change in background levels across the Bothel Fault and there are consistent groups of low values over the Lower Carboniferous succession, where the lithology is mapped as similar to that at Stangerhill. One explanation of the pattern is that the low values occur in areas of thick drift cover and that this is largely derived from the Eycott Volcanic Group and has a relatively low Ca content. However, in both the Tallentire and Ruthwaite areas the limestone succession does not generate high Ca in soil values and it is considered more likely that the high values at Stangerhill are caused by a specific lithology which is not limestone, for example a calcareous mudstone or sandstone, within the Carboniferous succession. The highest Ca results are recorded within the zone of high background values on traverses WS1 and WS2 (Figure 21). The maximum value comes from the line of the Boundary Fault and may be supplemented by vein carbonate. Relatively high values compared with adjacent samples on traverses WS4, WS5 and WS9 are coincident with the line of the Bothel Fault and may be caused by the presence of carbonate mineralisation or alteration along this fault. The Zr data did not discriminate mapped lithologies or show significant positive or negative correlations with other elements determined. Locally, however, there is a coincidence between high Zr and the Bothel faultline, for example on traverse WS4 at [NY 1960 3832] and traverse WS5 at [NY 1980 3805]. The reason for this coincidence is uncertain.

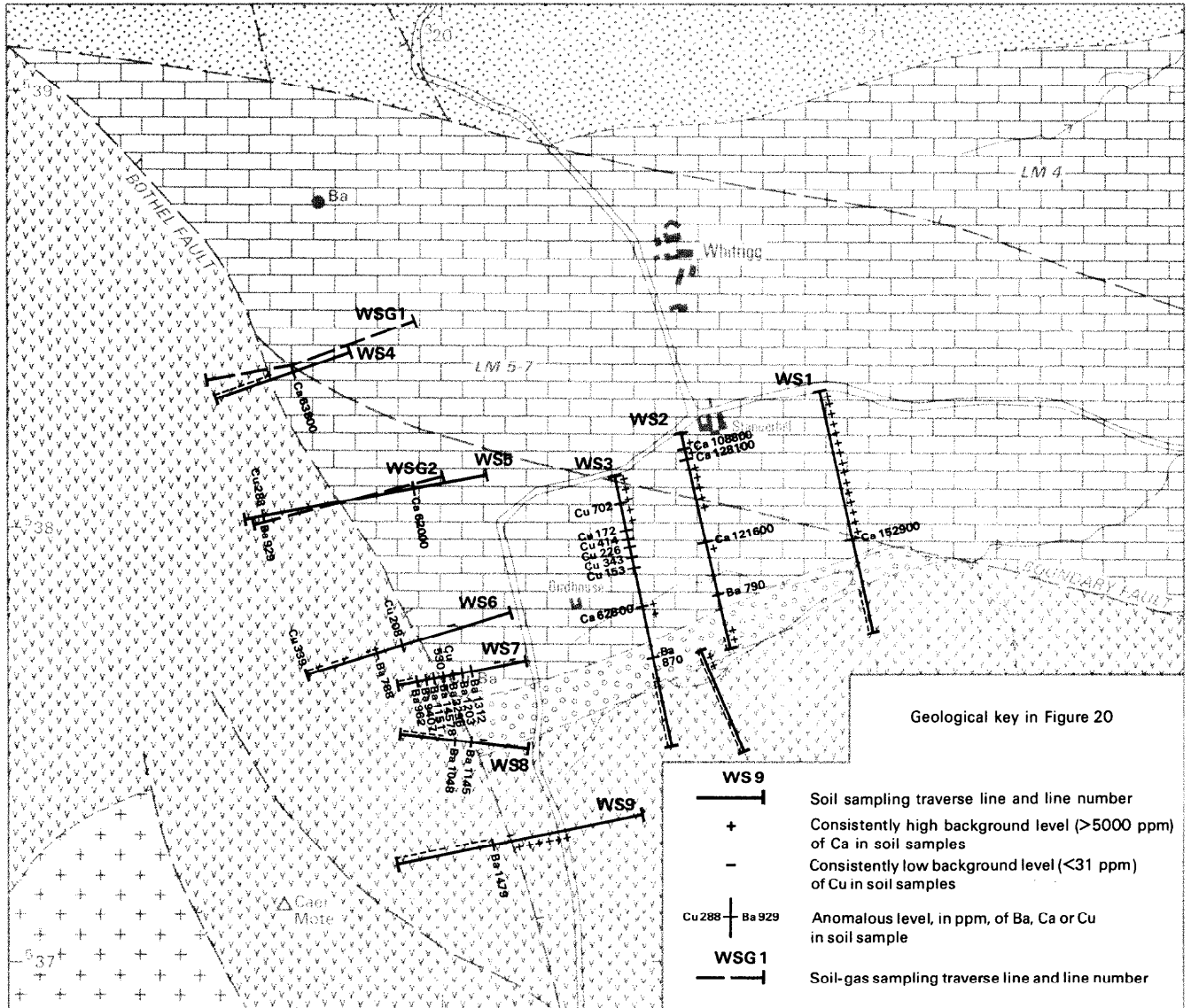


Figure 21 Location of anomalous Ca, Cu and Ba concentrations in soil samples collected in the Whitrigg area

The largest Ba anomalies, including all values above 1500 ppm, are on traverse WS7 (Figure 21) over the Bothel Fault close to the Bird House trial; they may reflect the underlying mineralisation or contamination from the workings. Weaker anomalies occur close to the Bothel Fault further to the south, on traverses WS8 (1048 ppm at [NY 2005 3751] and 1145 ppm at [NY 2009 3750]) and WS9 (1479 ppm at [NY 2014 3727]). These may indicate a southern extension of the mineralisation tried at Bird House. On the two traverses to the north (WS6 and WS5) isolated Ba anomalies occur over rocks of the Eycott Volcanic Group (788 ppm at [NY 1986 3771] and 929 ppm at [NY 1960 3802]). The northern of these anomalies is accompanied by Cu, Zn and Pb anomalies. Two weak Ba anomalies near the base of the Carboniferous succession on traverses WS2 and WS3 (870 ppm at [NY 2050 3770] and 790 ppm at [NY 2064 3785]) are not accompanied by other metal enrichments.

Cu levels are generally high due to the presence of a large high background population (median 58 ppm) whose source is uncertain. On some traverses, notably WS1-WS4, a change from high to low background values corresponds with the junction between the Carboniferous and Eycott Volcanic Group rocks, with the higher values over the Carboniferous, but elsewhere (for example traverse WS5) no such change occurs (Figure 21). The highest Cu concentration reported (702 ppm) is one of 13 consecutive high values (>75 ppm) at the northern end of traverse WS3 south-west of Stangerhill, coincident in part with high background levels of Ca, Zn and Pb. The highly anomalous concentration suggests the presence of Cu mineralisation, probably in rocks with a high background. The second highest Cu result (530 ppm at [NY 2000 3765] on WS7) is associated with large Ba anomalies close to the Bird House working and is believed to reflect the weak Cu mineralisation known to accompany the baryte extracted from here. Anomalous values on traverse WS6 (339 ppm at [NY 1969 3766] and 208 ppm at [NY 1992 3772]) and WS5 (288 ppm at [NY 1960 3802]), the latter coincident with Ba and Pb anomalies, may also reflect underlying mineralisation.

Pb and Zn results show a close positive Spearman-rank correlation (0.75). Both elements also show a weaker positive correlation with Cu (0.48) and negative relationship (-0.40 and -0.37) with Ba. High background levels of both elements occur over the ground to the east and south of Stangerhill on the northern sections of traverses WS1 to WS3 (Figure 22). Isolated high values, including the highest concentrations of both elements recorded in this area, occur on the east-west traverses which otherwise are dominated by low background values. The largest Pb anomaly (259 ppm at [NY 1960 3802] on WS5) is accompanied by the second highest Zn value (348 ppm) as well as Cu and Ba anomalies, strongly suggesting the presence of underlying mineralisation. The largest Zn anomaly (588 ppm at [NY 2016 3749] on WS8) is accompanied by levels of Cu (116 ppm) and Pb (70 ppm) which are twice the local background. The site is wet and the soil a grey gley, suggesting that the anomaly may be a secondary concentration. Other anomalous values of Pb and Zn are at the north end of traverses WS1 and WS2 (Figure 22). They are little higher than adjacent samples forming part of the high background population whose source is uncertain. This area of high Pb and Zn background is largely coincident with the areas occupied by high Cu and Ca results. It may be caused by the presence of a relatively metalliferous horizon, such as a pyritic calcareous mudstone, under the drift cover, or represent secondary concentrations in soil from this source or mineralised fractures.

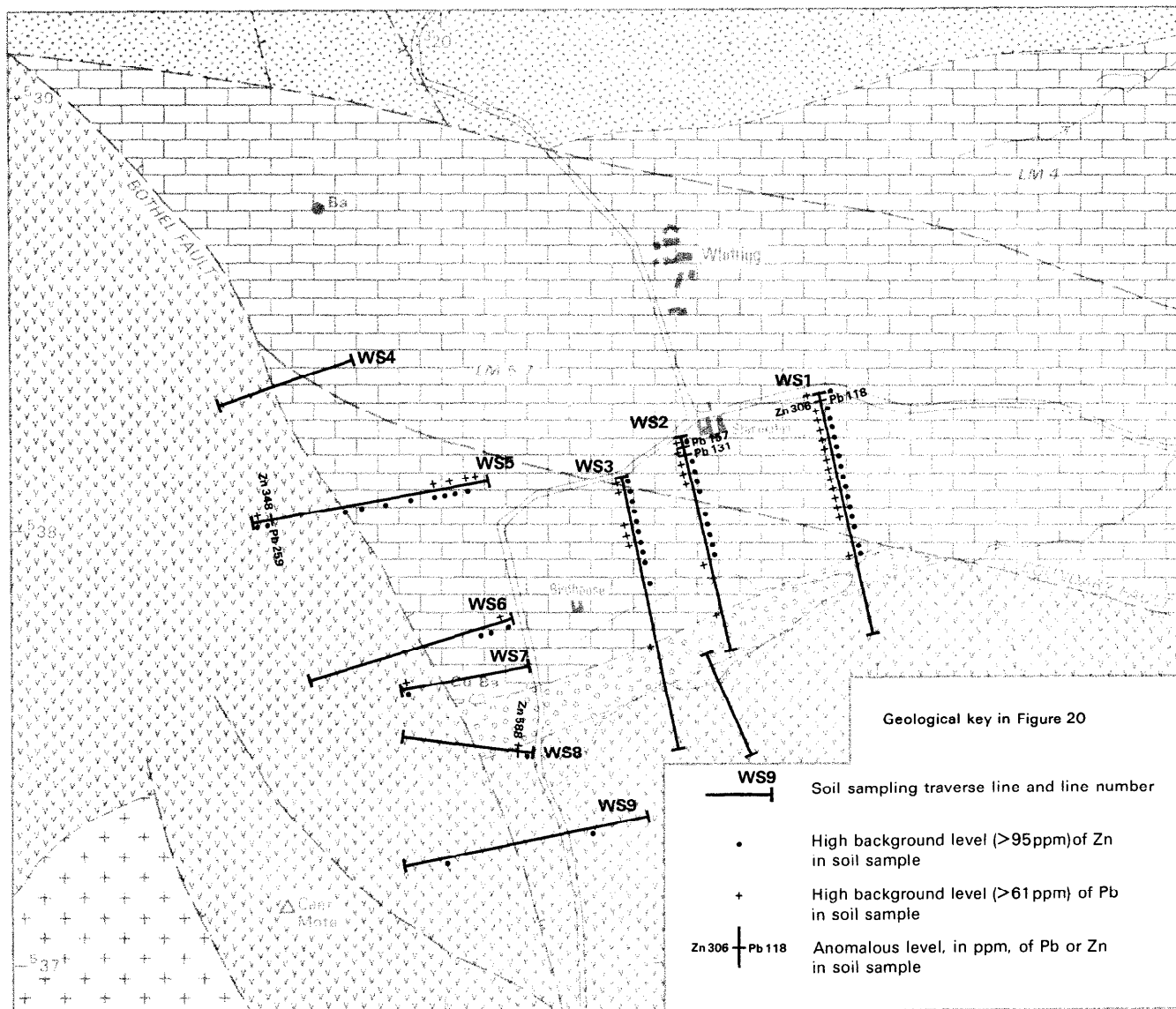


Figure 22 Location of anomalous Zn and Pb concentrations in soil samples collected in the Whitrigg area

Rock sampling

Rock samples of the quartz-baryte vein material and host rocks were collected from around the Bird House working to determine the range of metal enrichments associated with the mineralisation. A powdered sub-sample of each rock was analysed by XRFs for a wide range of elements and further sub-samples were analysed for Au and Hg by AAS (Table 8).

Table 8 Analyses of rock samples from the Bird House trial

Number	Grid Reference		Description									
1201	NY 2012 3764		Tip material; clasts of baryte, quartz and host rocks									
1203	NY 2001 3760		Andesitic volcanic rock									
1204	NY 2001 3760		Brecciated andesitic volcanic rock									
1205	NY 2001 3760		Brecciated volcanic rock									
1206	NY 2012 3764		Tip material; baryte, quartz, malachite and host rocks									
1207	NY 1996 3775		Brecciated volcanic rock with qtz.-carb.-sulphide infill									
Number	Ca	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	As	Sr
1201	11300	1880	229	<2	210	2700	2	2	68	2	3	1326
1203	4100	5970	20	<2	1260	67500	13	<2	4	95	3	115
1204	3200	6190	62	3	1210	47300	24	<2	34	65	19	69
1205	3400	6130	26	6	170	8400	32	9	29	8	41	120
1206	100	740	407	-	50	800	<2	4	255	<2	<2	3744
1207	2700	7340	89	8	50	12100	36	25	393	2	400	144
Number	Mo	Ag	Sn	Sb	Ba	W	Au	Hg	Pb	Bi	U	
1201	4	11	<2	<2	183200	<2	<10	7100	2	<2	7	
1203	<2	1	<2	<2	2014	5	-	-	4	<2	10	
1204	<2	<1	<2	4	1225	3	-	-	357	<2	11	
1205	<2	<1	<2	3	594	4	-	-	264	<2	10	
1206	9	25	7	<2	508900	<2	-	6500	<2	4	3	
1207	<2	1	<2	2	3827	3	<10	40000	25	<2	8	
All results in ppm except Hg and Au (ppb)												
- Not determined												

The results (Table 8) indicate that, besides Ba and Sr, there are significant Cu, As, Hg and Pb enrichments in either the veins or the wallrocks. The relatively high Ag result in sample 1206 is probably caused by analytical interference from the very high Ba content. The Cu enrichment is related to the presence of small amounts of malachite and chalcopyrite in the tip material but no Pb minerals were seen. Perhaps the most significant feature is the high Hg content of sample 1207 and presence of appreciable Hg in the other samples analysed. It suggests that Hg mineralisation occurs here and provides a source for the cinnabar grains found in panned concentrates. There are insufficient analyses to indicate whether Hg is associated with Ba or other metal enrichments.

Soil-gas measurements

Measurements were taken of the oxygen, carbon dioxide and radon content of soil gas at 20 m intervals along two traverses (WSG 1 and 2, Figure 21) crossing the Bothel Fault, to test the effectiveness of this technique for detecting faults and mineralised fractures beneath overburden.

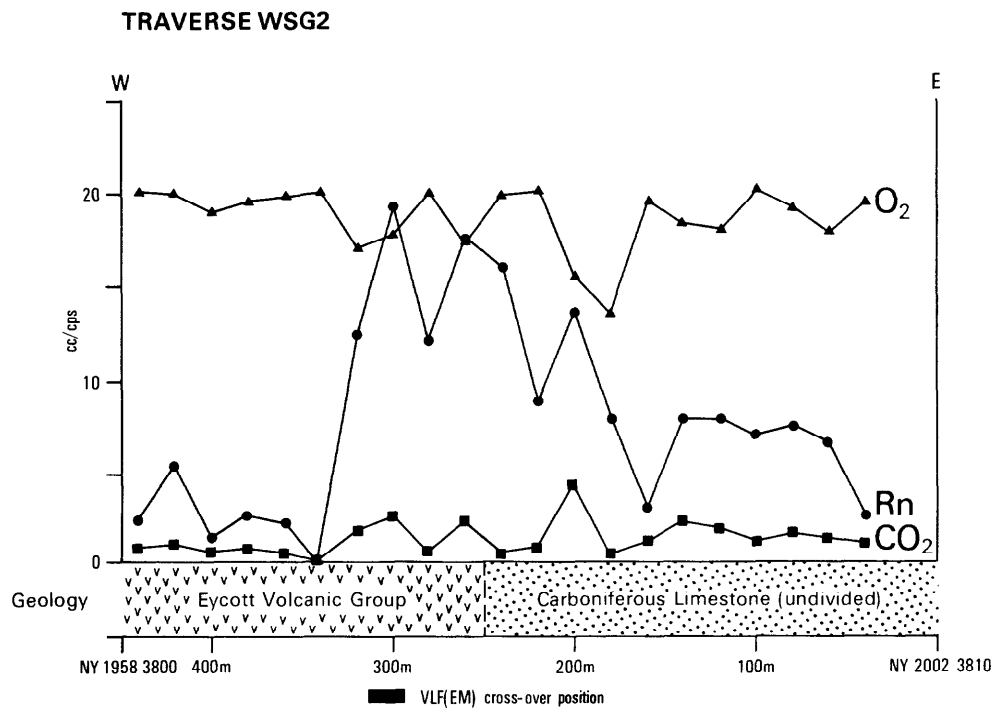
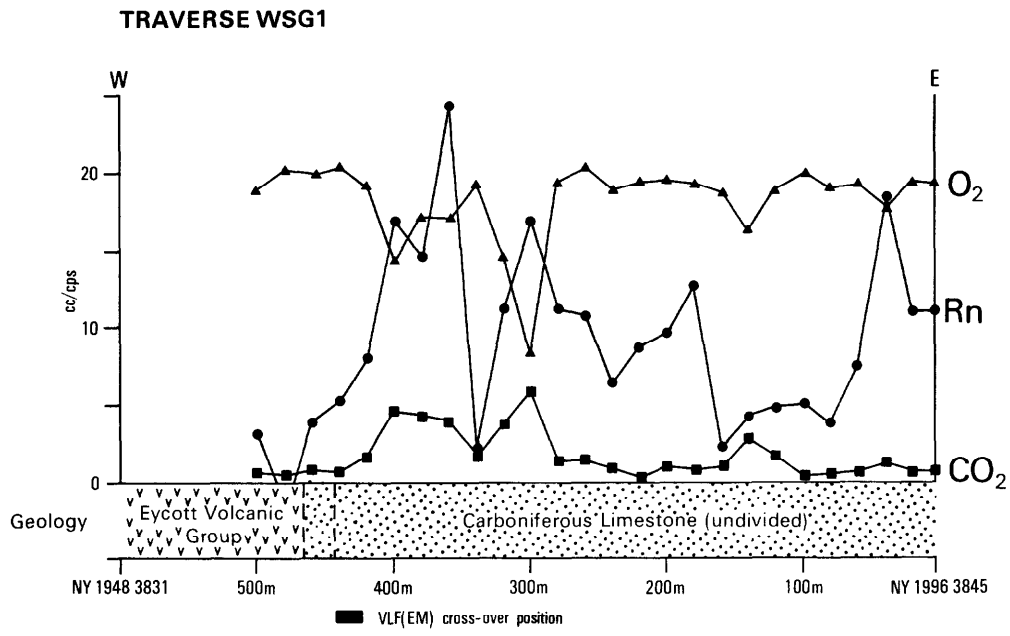


Figure 23 Oxygen, carbon dioxide and radon levels measured along two traverses across the Bothel Fault

The traverses were near-coincident with soil traverses WS4 and WS5 (Figure 21) and geophysical survey lines B1 and B3 (Figure 25). The gases were measured at site, radon by an emanometer and oxygen and carbon dioxide using the ORSAT apparatus (Ball, Nicholson and Peachey, 1985).

On the southern traverse (WSG 2) there is a broad radon high (Figure 23) about 200 m wide centred on the mapped line of the Bothel Fault. A weak oxygen low and carbon dioxide high lie on the eastern flank of the radon high (Figure 23). Geophysical VLF(EM) data (Figure 25) suggests that the position of the fault is about 50 m west of the mapped line at this point, under the western peak of the radon high (Figure 23). On the northern traverse (WSG 1), where the geophysical anomaly and mapped line of the fault are near coincident, the radon high is wider, more erratic and largely over Carboniferous rocks to the east of the fault. This may be due to the proximity of the Boundary Fault (Figure 21) or, as found elsewhere (Ball et al., 1991), a high background over the Carboniferous Limestone succession. On this traverse there is a well-defined carbon dioxide peak and coincident oxygen low to the east of the Bothel fault-line. The shape of the radon gas anomaly suggests that down-slope migration within overburden may have moved the centre of the anomaly eastwards from above the fault, whilst it is not clear whether the oxygen/carbon dioxide feature is derived from the fault or from one or more fractures, perhaps carrying mineralisation, in the Carboniferous rocks to the east.

Conclusions

1. Soil anomalies suggest that baryte mineralisation may be present along the Bothel Fault to the south of the Bird House trial.
2. Rock sampling indicates that Hg mineralisation is present at the Bird House trial and suggests that fracture-controlled mineralisation is the source of cinnabar grains found in panned concentrates.
3. Trials across the Bothel Fault suggested that the measurement of soil gas could be useful for detecting faults beneath overburden in this area.
4. Baryte and base metal mineralisation may be present locally within the Eycott Volcanic Group to the west of the Bothel Fault.
5. A high background and anomalous levels of Cu, Pb, Zn and Ca in soils from south and east of Stangerhill may be caused by a metalliferous horizon within the Carboniferous succession or represent a secondary concentration in overburden, perhaps derived from epigenetic fracture-controlled mineralisation.

Geophysical surveys

Conductivity mapping

Ground conductivity mapping was used on an experimental basis in this area to see if it would provide information on variations in drift thickness and on the location of any shale horizons within the predominantly limestone Dinantian sequence. Both these factors could have influenced previous survey results and would be relevant to any future exploration programme. For example, it was hoped to establish whether the small gravity anomalies detected during the MEIGA work could be caused by variations in drift thickness.

The conductivity mapping was carried out using EM31 equipment (McNeill, 1980) which has a 3-5 m depth of exploration. The measurements were made along traverses that in part had to be located to avoid standing crops. The contoured conductivity values shown in Figure 24 are observed values - corrections to true conductivity values (McNeill, 1980) became significant for values greater than about 30-40 mmhos/m.

The initial survey was carried out south of Stangerhill and the results indicated a marked decrease in conductivity values from the bottom of the valley northwards up the valley side. The low values corresponded to an area where limestone is close to or at surface, while the high values were initially considered to be due to a thicker cover of conductive boulder clay in the valley bottom.

The survey was subsequently extended to cover much of the Dinantian outcrop in the area (Figure 24). The results indicated that the conductivity high continues to the east along the valley bottom, but to the west it apparently bifurcates. The south-west branch continues along the valley floor, which corresponds to the base of the Carboniferous on the Geological Survey map, whilst the north-west branch crosses the topography diagonally and may correspond to an extension of the Boundary Fault indicated by the MEIGA work and shown on the geological base map (Figure 24). Two resistivity soundings were made to investigate the source of the conductivity variations. The results for EP1, sited within the conductivity high, indicated a near-surface high conductivity layer which was not present 150 m to the north at EP2 (Figure 24). The models are consistent with the conductivity data and suggest that the high conductivity layer could be thicker boulder clay, although alternative interpretations are shale at the bedrock surface or near-surface weathering in a fault zone.

In the central and northern parts of the area the generally low conductivity values (<15 mmhos/m) are consistent with limestone beneath a thin cover of drift. Increases in the thickness of the drift could be responsible for the zone with values greater than 15 mmhos/m in the north-east of the area, but it is possibly significant that these occur over a sequence of alternating shales and limestones, in contrast to the predominantly limestone sequence towards the base of the Dinantian to the south.

The Bouguer gravity anomaly data collected to the east of Stangerhill and Whitrigg, during the MEIGA surveys, indicate a few highs of 0.1-0.2 mGal amplitude and a step-like change of about 0.3 mGal (Figure 24). Anomalies of this size can arise from changes of less than 12 m in the drift thickness, assuming a density contrast between the bedrock and the drift of 0.6 Mgm/m³. Most of the gravity highs occur in areas of low conductivity (ie. near surface bedrock) and, although a detailed correlation is not observed, it is suspected that changes in the drift combined, possibly, with variations in the bedrock weathering are responsible for the gravity anomalies.

VLF(EM) survey across the Bothel Fault

Trial surveys with VLF(EM) equipment revealed distinctive anomalies on two profiles across the Bothel Fault immediately to the west of the area covered by the conductivity survey. The anomalies consisted of a dominant negative component (Figure 25), rather than the more typical VLF anomaly with positive and negative components of approximately equal amplitude. Topographic effects can give rise to abnormal anomalies and, as the Bothel Fault runs along the pronounced north-south feature formed by The Battery and Caer Mote hills, this alternative explanation had to be considered. However the well-defined anomaly occurs over a long unbroken slope and appears

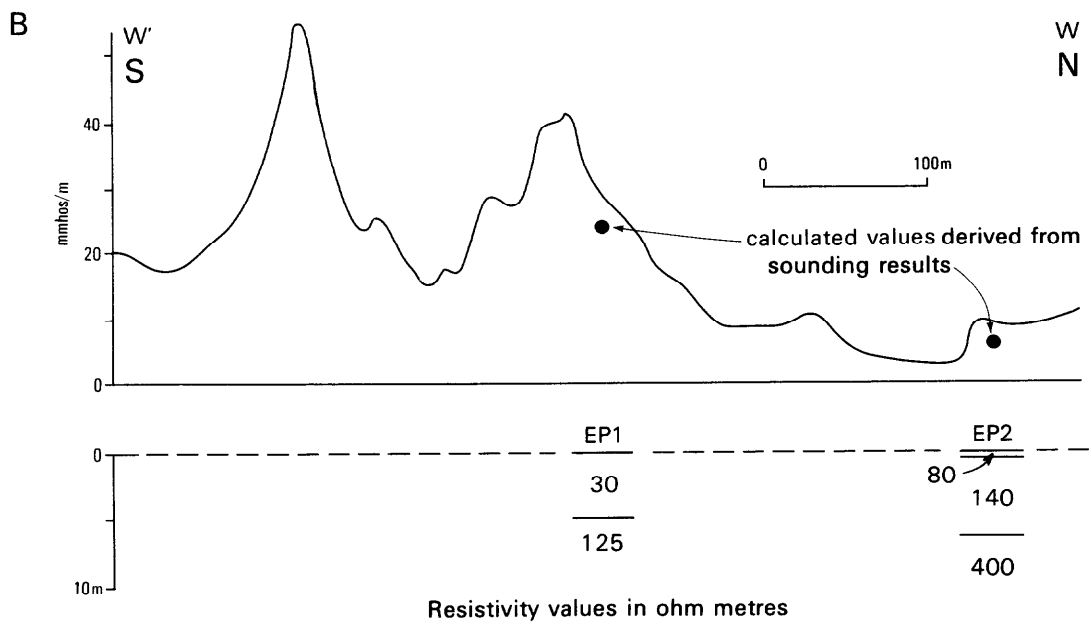
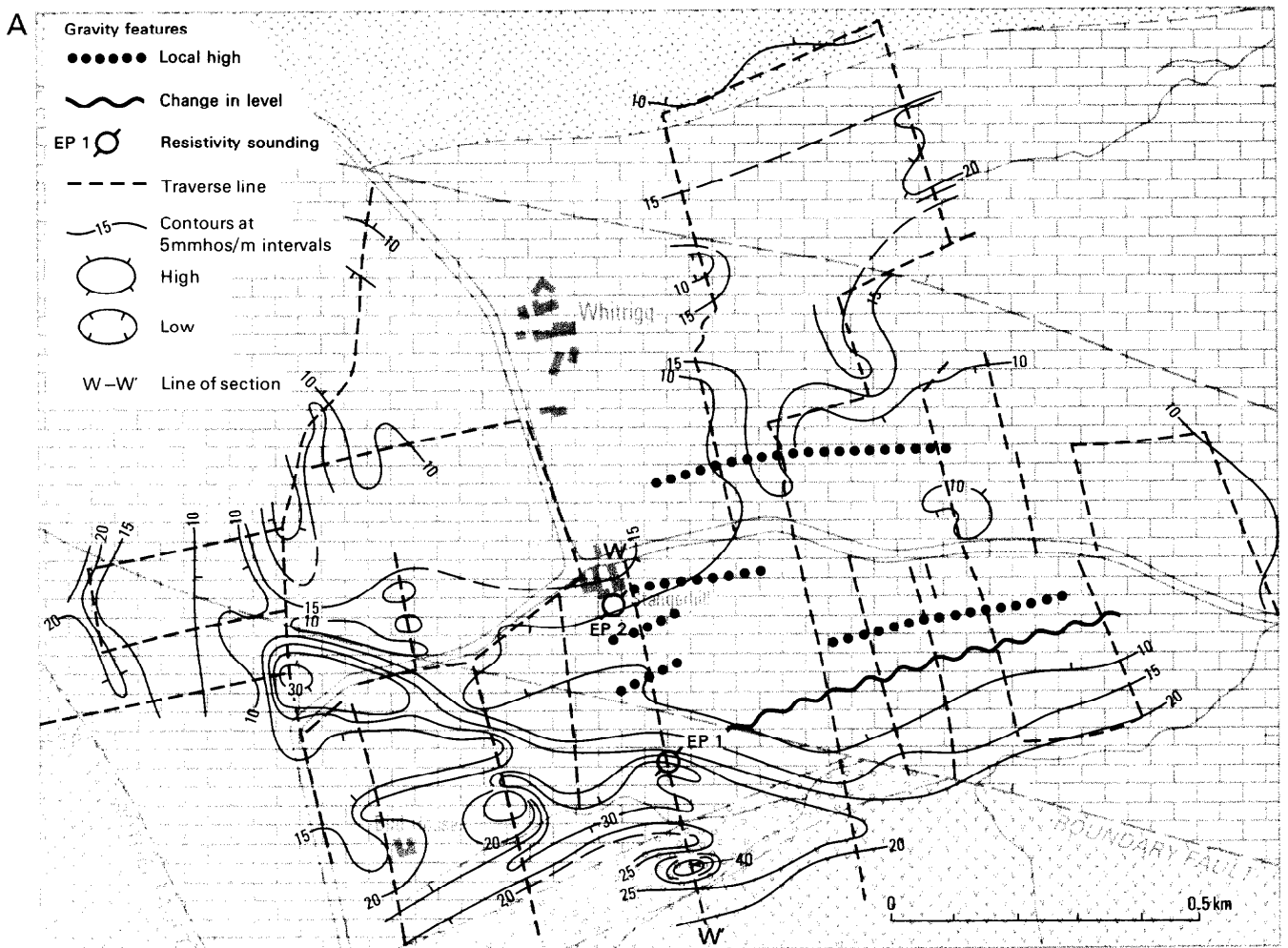


Figure 24 (A) Conductivity map of the Whittig area with gravity features from MEIGA survey results and (B) conductivity profile along the line W-W' and resistivity sounding models

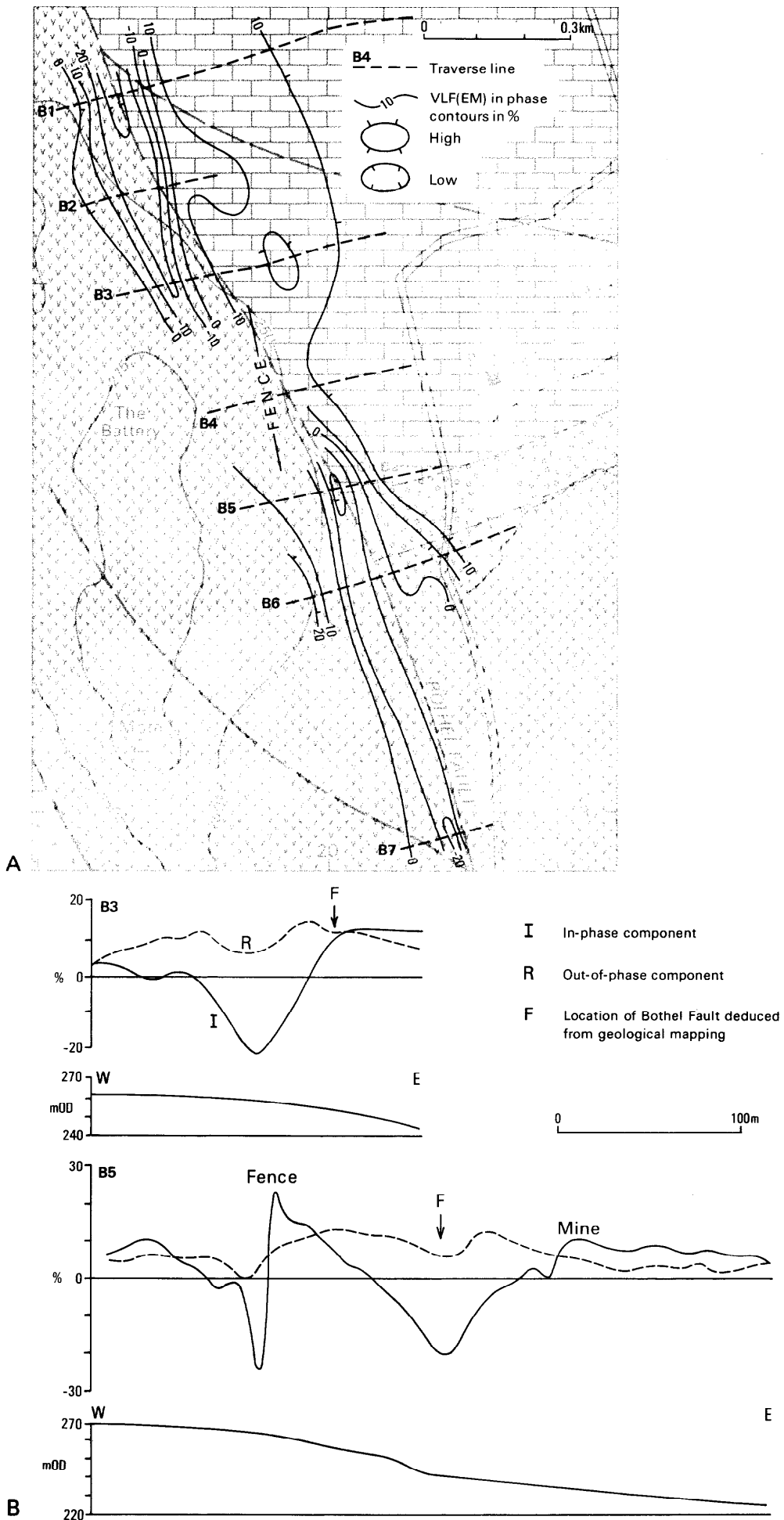


Figure 25 (A) VLF electromagnetic map across part of the Bothel Fault and (B) VLF electromagnetic and topographic profiles for part of traverses B3 and B5

to be too narrow for topography to be the explanation in the north of the area. It was therefore interpreted as being due to a zone of increased conductivity in the Bothel Fault between the Eycott Volcanic Group and Lower Carboniferous, both of which would normally have low conductivities. The increased conductivity is probably due to a fluid-filled fracture zone along the fault.

The VLF anomaly was subsequently traced over a distance of about 1.5 km, although data in the central section was badly disturbed by a wire fence (Figure 25). Topographic effects become significant in the south. On traverse B6, for example, adjacent to the Bird House trial, the anomaly minimum occurs at the foot of a steep slope, which can produce a theoretical anomaly of 20% according to the models of Baker and Myers (1980).

Although an isolated VLF(EM) profile, 1.2 km north of traverse B1, revealed no anomaly across the mapped line of the Bothel Fault, the regional geophysical evidence (Part 1) suggests that this fault may be a major feature which was active in Carboniferous times. The distribution of lithologies (shown on the published 1:50 000 geological map) within the poorly exposed Skiddaw Group rocks to the south suggest that the fault may persist southward through Bewaldeth [NY 2100 3470]. Pre-Carboniferous movements may have resulted in a fault-scarp against which the Carboniferous rocks were deposited.

Conclusions

1. Where not disturbed by artificial sources, the VLF(EM) method proved useful for tracing the precise position of the Bothel Fault.
2. The conductivity data supports the conclusions of the MEIGA work in suggesting that the Boundary Fault extends across the area in a north-westerly direction. The data also indicate that drift thins towards the hilltop and that drift variation, possibly combined with variations in bedrock weathering, may be responsible for the small gravity features recorded during MEIGA sponsored work. High conductivity values in the south and north-east of the area surveyed might be caused by thickening drift, mudstone bedrocks or, in the south, near-surface weathering in a fault-zone.

Discussion and assessment

The soil sample analyses suggest that baryte mineralisation similar to that investigated by the Bird House trial may be present in or adjacent to the Bothel Fault south of the trial. There is also evidence for fracture controlled mineralisation (Ba and/or base metals) locally within the Eycott Volcanic Group to the west and the Carboniferous succession to the east of this fault. A feature of the mineralisation associated with the Bothel Fault at the Bird House trial is the presence of appreciable amounts of mercury, which appears to be concentrated in the brecciated and altered Eycott Volcanic Group host rocks with traces of copper, arsenic and lead. However, the extent and magnitude of the soil anomalies and the surface evidence seen at the Bird House trial suggest that the mineralisation is probably patchy and weak.

There is no evidence that the fracture-controlled baryte mineralisation along and to the south of the Boundary Fault at Ruthwaite persists into this area.

The principal base metal (Cu, Zn, Pb) anomalies in soil, located east and south of Stangerhill, form part of the large soil anomaly discovered and investigated by the MEIGA projects. The results reported here show that a feature of the anomaly is the absence of any barium enrichment. This

feature distinguishes the anomaly from most others found in the Cocker mouth area during this study and suggests that it may have a different source or mechanism of formation. Profile overburden sampling carried out by one of the MEIGA projects indicated that the base metal anomalies were probably transported from source whilst the work reported here has shown that the peak values are associated with a broad area of high background levels of base metals and calcium. The source of the high background is uncertain. Geophysical conductivity data shows no special features coincident with the high geochemical background and the low values recorded are consistent with the presence of limestone under thin drift as shown on the geological map. The situation is therefore similar to the area of high base metal values reported at the western end of traverse TS7 near the top of Tallentire Hill (Figures 14 and 15). We therefore conclude that the most likely source of the anomalies is secondary enrichment in overburden from a metalliferous source, which may be a pyritiferous/calcareous shale or mudstone, but more probably comprises weak base metal mineralisation on joints and fractures. Baryte may also be present in the fractures but, if so, barium has not migrated into the soil. Peak values may reflect lithological boundaries in the drift, the location of specific mineralised fractures and/or groundwater channels.

CONCLUSIONS AND RECOMMENDATIONS

1. In the Ruthwaite area, surface shows of mineralisation and the results of a geochemical soil survey indicate that baryte mineralisation is more extensive than recognised previously. The distribution of soil anomalies suggests that fracture-controlled baryte mineralisation may be concentrated along the Boundary Fault and within the Eycott Volcanic Group to the south and west of High Ireby. Relatively small, but in some circumstances perhaps economically attractive, deposits of baryte may be present locally under the thin drift cover. Little evidence was found of mineralisation within the Carboniferous succession.
2. Epigenetic, fracture-controlled mineralisation is widespread in the Tallentire Hill area. The fault and fracture fillings are dominated by baryte, often with brown carbonate and locally with traces of copper and mercury. At one locality copper-barium-iron mineralisation is accompanied by trace enrichments of arsenic, molybdenum, tin, antimony and mercury. Where seen at surface the mineralisation is too weak and patchy to be of economic significance.
3. In the Top Wood part of the Tallentire area, baryte impregnations in sandstone may reflect the presence of more extensive fault-controlled baryte mineralisation in the underlying limestone succession. Further baryte-rich sandstones may be present beneath drift to the north of Top Wood. Drilling would be required to test these possibilities.
4. The source of base metal anomalies at Stangerhill in the Whitrigg area remains uncertain. Secondary concentration in overburden, following leakage along faults and fractures, is considered the most probable cause of the peak values. The source of metals may be a metal-rich calcareous shale or mudstone within the Carboniferous succession or, more probably, epigenetic fracture-controlled mineralisation. There is evidence that fracture-controlled baryte and/or base metal mineralisation is present locally along the Bothel Fault and in the adjacent Eycott Volcanic Group rocks. This mineralisation is probably patchy and of low grade. There is no evidence to suggest that the fracture-controlled baryte mineralisation associated with the Boundary Fault at Ruthwaite persists into this area.

5. Closely spaced soil sampling was found to be an effective means of detecting mineralisation in areas where the drift cover is thin. The soil analyses (for Ca, Cu, Zn, Zr, Ba, Pb) were found to be of very limited use for geological mapping purposes, but soil gas measurements may be useful for tracing fault lines beneath drift. The geophysical methods tested (conductivity and VLF(EM)) were found to be useful for tracing major faults and providing information on the thickness of overburden in areas free of artificial sources. Conductivity methods may also be useful for indicating the extent of baryte-bearing sandstones.

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APPENDIX 1 Interpretation of Resistivity Depth Soundings in the Tallentire Hill and Ruthwaite Areas.

S1-4 Tallentire Hill, S5-6 Ruthwaite

Site number and grid reference (NY)	Layer interpretations			Geological interpretation
	No.	Resistivity (ohm-m)	Depth to base (m)	
S1 1312 3681	1	140	1.5	Drift or shale
	2	650	7.0	Sandstone
	3	100		Limestone or Shale
S2 1353 3587	1	110	9.0	Limestone
	2	280		Limestone
S3 1193 3545	1	80	0.8	Drift
	2	50	2.0	Drift
	3	100	8.0	Limestone
	4	900	20.0	Limestone
	5	100		Limestone
S4 1180 3610	1	80	0.6	Drift
	2	60	2.0	Drift
	3	85	12.0	Drift or Sandstone
	4	140	30.0	Sandstone
	5	100		Limestone
S5 2321 3742	1	150	1.0	Drift
	2	50	5.0	Sandstone
	3	1000	17.0	Limestone
	4	100		Limestone
S6 2328 3702	1	130	2.0	Drift
	2	50	12.0	Drift?
	3	500		Eycott Volcanic Group

