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Mineral Reconnaissance Programme Report

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No. 57

Mineral exploration in the
Ravenstonedale area, Cumbria

Mineral Reconnaissance Programme

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Mineral Reconnaissance Programme Reports

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CONTENTS

SUMMARY

Soil and stream sediment samples collected from an area of Lower Carboniferous rocks close to the Silurian unconformity were analysed for copper, lead and zinc. Four areas of anomalous soils were recognised, at Stennerskeugh Clouds, Birkett Common, Crosby Garrett Fell and Windy Hill. VLF-EM and IP surveys at Stennerskeugh Clouds and Crosby Garrett Fell showed anomalies which were attributed to the presence of shale bands in the Carboniferous succession. Geophysical surveys at Birkett Common, described in an earlier report, suggested the presence of small mineralised structures, but the geochemical and geophysical results do not indicate the presence of mineralisation of economic significance in the area. No follow-up investigations can be recommended on the basis of the results of the survey.

INTRODUCTION

The area investigated (Figure 1) lies in the valley of the River Lune where this flows westwards approximately along the line of the unconformity between the rocks of the Lower Carboniferous and the folded Silurian sediments of the northern flank of the Cumbrian massif. The area extends south-east into the River Eden catchment, to include areas of known mineralisation in the Carboniferous close to the Dent Fault line. The investigation included both soil and stream sediment geochemistry, geophysical investigations and examination of the exposed Carboniferous succession.

The lowest sediments of the Carboniferous succession are in presumed unconformable contact with the older Lower Palaeozoic sediments (here of Silurian age) of the Cumbrian massif. The possibility that any mineralising fluids moving through the area may have been forced along the unconformity between these differing rock types required investigation — particularly since there are known orebodies in the carbonate rocks of the Irish Carboniferous in very similar structural situations. Much of the contact is obscured by thick drift, thus allowing the possibility of previously undetected faulting associated with the Carboniferous—Silurian boundary which would provide a local structural control similar again to some Irish examples of base metal mineralisation

(Morrissey and others, 1971).

In addition, the proximity of the major Dent fault zone and the already well-known (and to some extent exploited) mineralisation adjacent to this feature encouraged the investigation.

The published descriptions of the geology of the area indicate that the Carboniferous rocks were deposited in an embayment bounded by the Askrigg Block to the south-west and the Alston Block to the north-east (Dakyns and others, 1891; Garwood, 1913; Taylor, 1971).

The shallow marine environment in which some of these sediments were deposited may have resulted in the formation of lithological types suitable as host rocks for mineralisation (sandstone/conglomerates, bands of organic derived debris etc.), offering further grounds for comparison with some of the mineralisation of the Irish Carboniferous.

GEOLOGY

STRATIGRAPHY

The rocks of the area include both Tournaisian and Visean sediments and comprise the well defined Ravenstonedale, Orton and Alston Groups (Figure 1).

The Ravenstonedale Group (Taylor, 1971) commences with the Pinskey Gill Beds, a sequence of shales, sandstones and dolomitic limestones resting unconformably on the Silurian slates. Their very restricted fauna with *Spirifer pinskeyensis* conodonts and spores indicate an early Carboniferous age. The succeeding conglomeratic unit (the Feldspathic Conglomerate), and sandstones with detritus derived from the denudation of the Shap Granite and the limestones above, are presumed to be of Tournaisian age. The general lithologic characteristics of this part of the succession (thin dolomitic limestones) and the common occurrence of nodular algal beds lend support to the thesis that these beds were laid down in a constricted embayment in shallow marine conditions. The top of the Group, which is some 280 m thick, is identified by *Spongiostroma* and algal beds which also were deposited in very shallow water conditions.

The overlying Orton Group commences with dolomitic limestones, with *Thysanophyllum pseudovermiculare* common at several horizons, succeeded by the Brownber Pebble Beds, an oolitic limestone with quartz pebbles. The lime-

GEOLOGY OF RAVENSTONEDALE

Permo-Trias

Millstone Grit

Alston Group

Lower Carboniferous

Orton Group

Ravenstonedale Group

Silurian

- - - - - Geological boundary

—+—+— Faults

× × × × × Mineralised feature

Area soil sampled

Airborne geophysics

0   1   2   3 kms

ORTON

Crosby Garrett Fell

RAILSBECK

RIVER LUNE

HOWGILL FELLS

POTTS BECK

SCANDAL BECK

RIVER EDEN

KIRKBY STEPHEN

Ashfell Edge

RAVENSTONEDALE

Great Bell

Birkett Common

Stennerskeugh Clouds

Lordbury

WILD BOAR FELL

Area of investigation
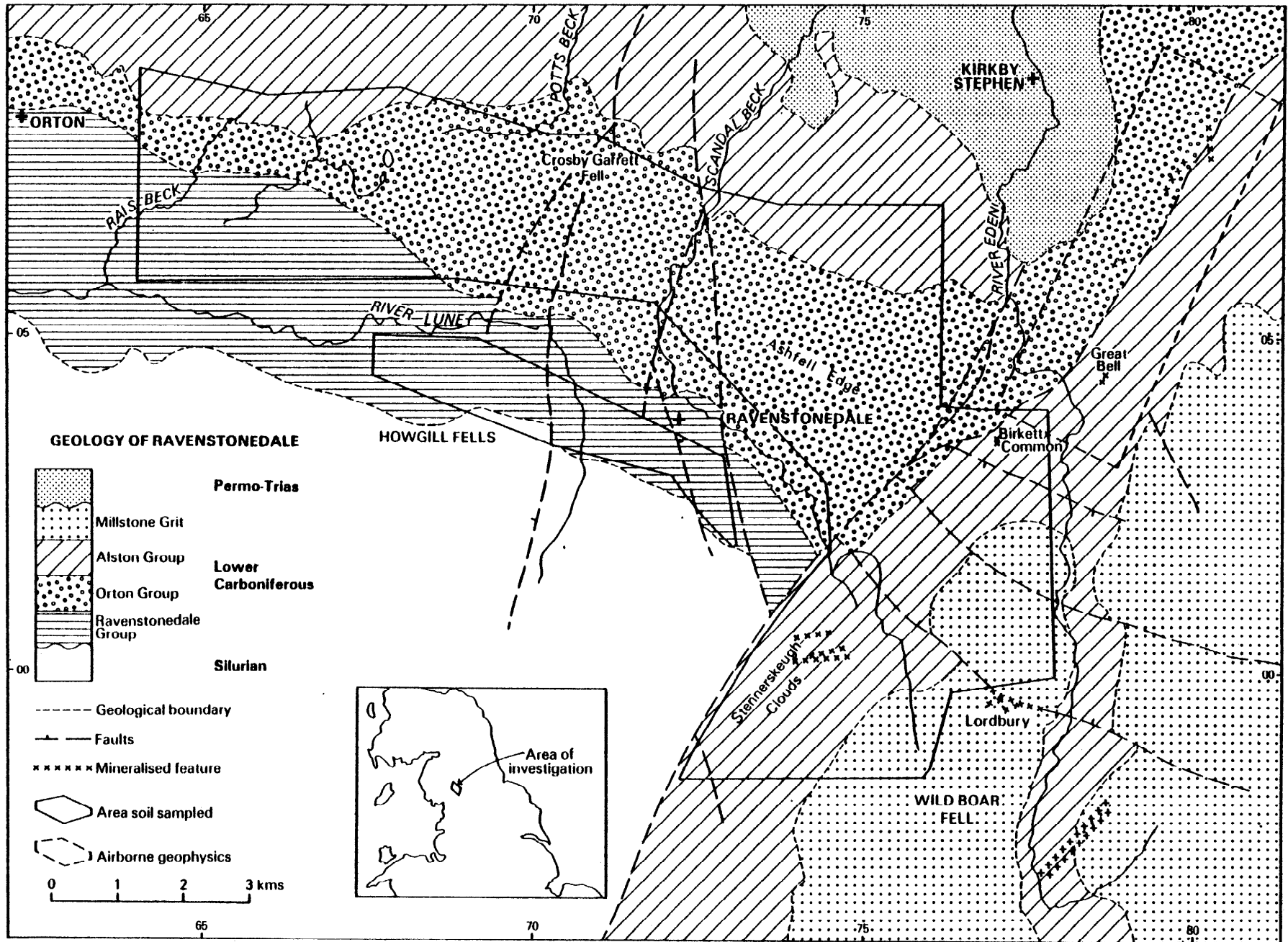
65   70   75   80

05

00

Fig.1 Geology of Ravenstonedale

2

stones which follow are characterised by the coral *Michelinia grandis* and are estimated to be 210 m thick. Shaly units form the upper part of the Group continuing to the base of the Ashfell Sandstones — a series of fine-grained quartzitic sandstones interbedded with thin limestones. The sandstone lithology tends to be diachronous and further to the north, out of the area of investigation, thick units of sandstone extend over a greater time-span than do the sandstones in the area of Ashfell Edge.

The stratigraphical sequence continues above the sandstones with grey-white weathering limestones which contain rich bryozoan and brachiopod faunas. The Bryozoan Band, which includes up to 10 m of variously shaly and porcellanous limestones, is taken as the topmost unit of the Orton Group.

The succeeding Alston Group has at the base a thickly bedded bioclastic limestone sequence which is the lateral equivalent of the Knipe Scar limestones of the area around Shap and roughly equates to the Melmerby Scar limestones of the Alston Block. In the area of Ravenstonedale these bioclastic limestones attain 58 m in thickness and are known as the Great Scar Limestone above which commences a rhythmic succession of limestones, mudstones and sandstones and which continues into the Namurian sequence.

STRUCTURE

Structurally the area is dominated by two features: the unconformity of the Carboniferous sediments resting on the Silurian and the major dislocation, the Dent Fault, which traverses, in a NNE direction, the south-eastern part of the area, downfaulting to the south the Great Scar Limestone. The lower part of the Carboniferous succession described earlier is not exposed to the east of the Dent Fault.

MINING AND MINERALISATION

Within the area investigated, mineralisation is known at Stennerskeugh Clouds, Fothergill Sike and Lordburg.

At Stennerskeugh Clouds, four mineralised structures are recorded (Dunham and Wilson, in prep.) three of which were worked near to the surface by trenches or bell-pits. Available data suggest that they nowhere exceeded a metre in width. The fourth structure, the Clouds Vein, can be traced for some 450 m along an east-west line, its course now identified by a series of old shafts. Spoil heaps from this series of workings and from the other less extensive open-cast ventures, indicate that the principal minerals are galena, barite, fluorite and copper oxides and sulphides, although not all of these species are in evidence at each of the four locations.

Although exploitation of these occurrences probably began prior to the seventeenth century, it is unlikely that total production could have been more than a few tons of ore (Dunham and Wilson, in prep.).

A mineralised fault trending NNE has been tested by shafts and an adit at Fothergill, southwest of Birkett Common, where the mineralised fault zone carries galena as it cuts through the Great Scar Limestone. Unlike the mineralisation at Stennerskeugh Clouds this location has dolomite as the only associated mineral.

The workings on the south slope of Great Bell, just outside the area of investigation, are situated also in the Great Scar Limestone and from them purple and amber fluorite, galena, dolomite and calcite have been recorded (Dunham and Wilson, in prep.). This mineralisation is regarded by Dunham (1952) as of no economic significance.

At Lordburg Rigg there is evidence of ancient prospecting along the line of an approximately east-west trending fault structure with barite and calcite veinlets cutting quartzitic sandstones stratigraphically beneath the Main Limestone at the base of the Millstone Grit Series. There is no evidence of ore extraction from this location. The fault investigated here continues in a north-westerly direction for a distance of 5 km, as far as the line of the Dent Fault, and therefore underlies the northernmost part of the anomalous area as defined by the geochemical soil data.

There is no evidence to suggest that any mineralisation is associated with the main line of the Dent Fault.

The attitude of the beds in the Lune Valley is one of gentle dips in a north to north-easterly direction, with some local disturbances of strike caused by the large number of dip faults (NE—SW). Dips to the south-east are a feature of the attitude of the strata south-east of the Dent line, with dip faulting in places resulting in greatly steepened bedding plane dips locally.

GEOCHEMICAL SURVEYS AND INTERPRETATION

The topography of the Lower Palaeozoic rocks to the south of the River Lune, where the rounded hills of the Howgill Fells rise to heights in excess of 515 m, and where a dendritic drainage pattern has developed, was suitable for the geochemical investigation to be conducted using stream sediments and pan concentrates as the media for geochemical analysis.

Drainage on the Carboniferous rocks to the north of the Lune, however, is too poorly developed to give satisfactory stream sediment cover, and consequently this area was investigated by means of soil samples collected on a regular 300 × 300 m grid. Samples were taken by hand auger from beneath the humus-rich 'A' horizon in the

Table 1 Geochemical values

| | Sediments (n = 87) | | | | | Soils (n = 797) | | | | |
Element	Range ppm	Background Log ppm	ppm	Threshold Log ppm	ppm	Range ppm	Background Log ppm	ppm	Threshold Log ppm	ppm
Cu	10–500	1.37	23.40	1.66	45.70	0–130	1.27	18.60	1.67	46.70
Pb	20–380	1.70	50.10	2.05	112.50	10–3000	1.69	48.90	2.13	134.90
Zn	60–500	2.25	177.80	2.57	371.50	10–700	1.80	63.00	2.58	380.00

soil profile. The actual depths from which the samples were obtained were somewhat variable (15–110 cm), reflecting soil depths overlying these predominantly carbonate sediments. A further series of soil samples was taken from the low ridges to the south of the River Lune across the line of the Lower Carboniferous/Silurian junction (Figure 2). Both stream sediments and soils were analysed by AAS for copper, lead and zinc and the data from each sample type assessed separately, although the same basic statistical technique was used on each.

The various statistical parameters from each sample set are in Table 1 and have been derived from the cumulative frequency/logarithm of metal content curves on Figures 3 and 4. Background values (B) are taken at the 50% population frequency level and threshold (t) at the 97.5% level. All values in excess of the threshold are considered to be anomalous and have been plotted on the map (Figure 2).

In addition an attempt has been made to examine the geochemical data by combining the values obtained for Cu, Pb and Zn. The method by which this was accomplished may be represented by:

$$\frac{Cu}{Cu_B} + \frac{Pb}{Pb_B} + \frac{Zn}{Zn_B}$$

in which each of the metal values is divided by its own 'background' (B) level. The value obtained from the summation of these three figures has been calculated for each soil sample and used as the basis for the contoured map (Figure 5) and is referred to as the 'Index of Mineralisation'.

STREAM SEDIMENTS

With the exception of data from the samples collected in Scandal Beck, high values for any of the three metals are few and isolated. The samples from Scandal Beck differ from the rest in that they have been taken from streams flowing over predominantly carbonate sediments. Of the three samples with anomalous Zn from this water course, two have in addition high values for Pb, and their geographic distribution clearly relates them to the mineralisation extending north-eastwards from Stennerskeugh Clouds.

Table 2 shows clearly the progressive decrease in Zn values over a distance of 3.6 km from the high value obtained in sample 53.

It is noted that the value of Zn in samples 86 and 87, although not in the anomalous range (in excess of the threshold value of 371 ppm), still show values in excess of the background of 178 ppm.

Lead values in the same samples also demonstrate some tailing-off downstream, but the anomalous values (>112 ppm) are maintained for a greater distance from the source (2.5 km) than the anomalous Zn values.

The values obtained from stream sediments derived from the Lower Palaeozoic rocks are, almost without exception, at or about background level, and those isolated samples which exceed the threshold value are interpreted as indicating the presence of minor local vein mineralisation.

SOILS

The distribution of anomalous soil values is presented on Figure 2 and shows four groupings which require comment.

The largest of these groups (A) extends over four km in a NNE direction, in the south-eastern quadrant of the area of investigation. It lies parallel and to the south-east of the Dent Fault zone and includes the area of known mineralisation at Stennerskeugh Clouds. The pattern of the geochemical soil anomaly here extends approximately 2 km NNE beyond the known mineralisation. The values obtained for Cu, Pb and Zn attain maxima of 6, 60 and 9 times background.

It is quite clear that the geochemical anomalies recorded from Stennerskeugh Clouds reflect the known mineralisation. It would seem reasonable to interpret the high values obtained further to the north-east as also being due to mineralisation. The style of this is unknown but two possibilities present themselves; either that the high values are related to very small local mineralised fractures, as at Stennerskeugh Clouds itself, or that there is local mineralisation along the rather more extensive north-west trending fault that cuts through the northern part of the area defined by anomalous soil values. The Lordburgh mineralisation described earlier lies along this last structural feature.

The possibility of glacial smearing, in a north-easterly direction, of the surficial deposits

Fig 2. Ravenstonedale Reconnaissance Survey: Soils and Streams
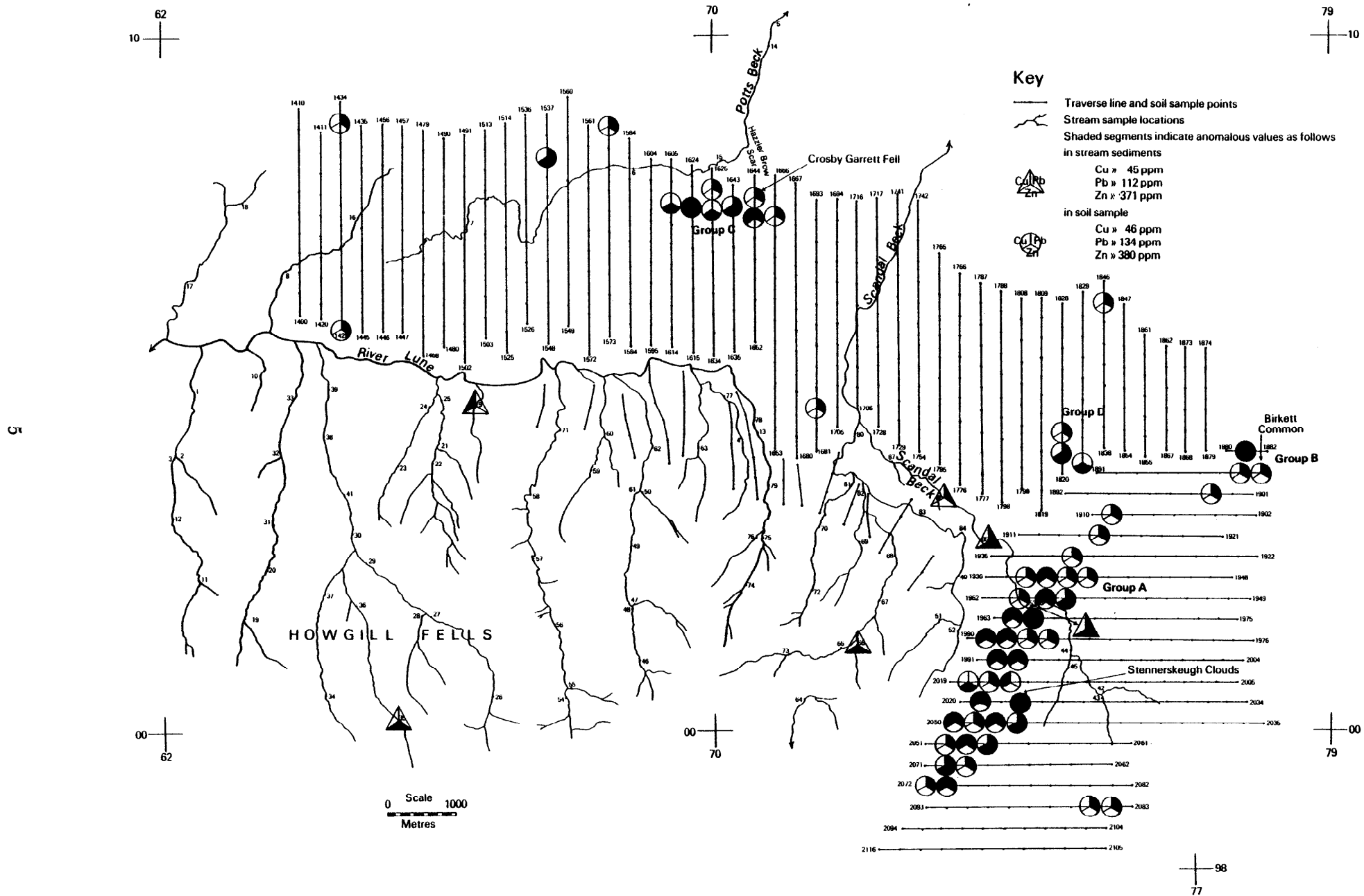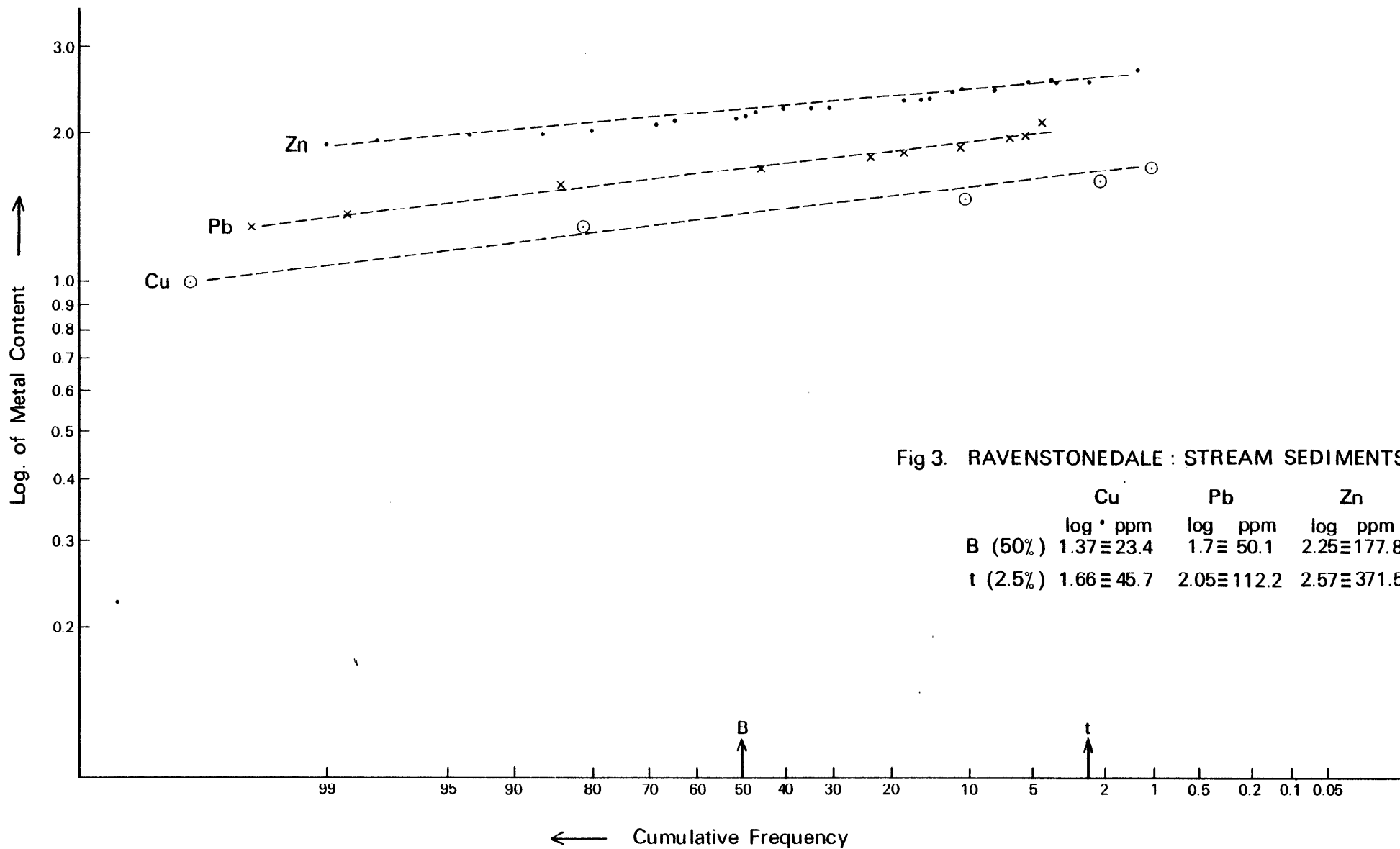
Fig 3. RAVENSTONEDALE : STREAM SEDIMENTS

	Cu		Pb		Zn	
	log · ppm		log ppm		log ppm	
B (50%)	1.37 ≡ 23.4		1.7 ≡ 50.1		2.25 ≡ 177.8	
t (2.5%)	1.66 ≡ 45.7		2.05 ≡ 112.2		2.57 ≡ 371.5	
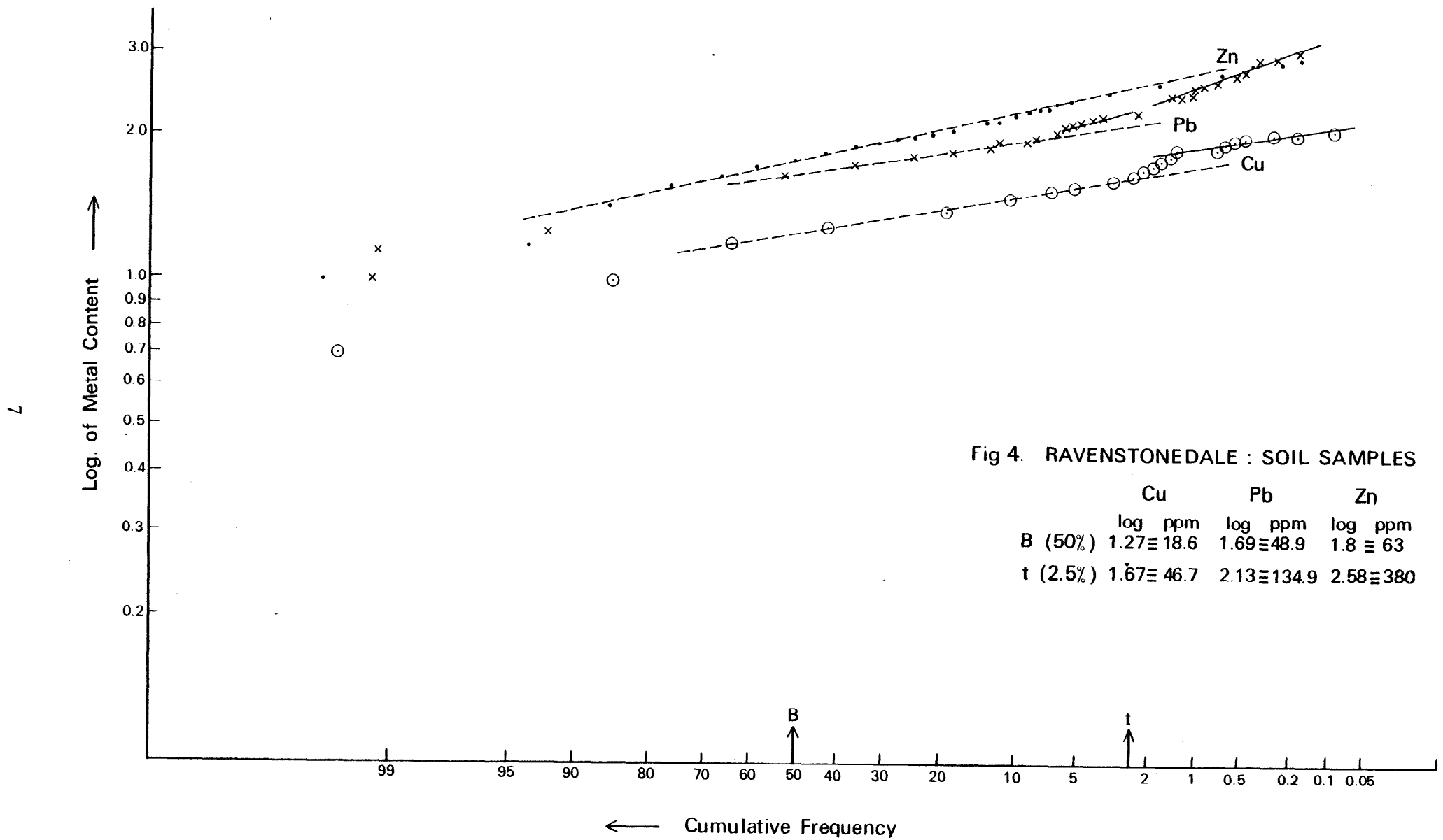
Fig 4. RAVENSTONEDALE : SOIL SAMPLES

	Cu		Pb		Zn	
	log	ppm	log	ppm	log	ppm
B (50%)	1.27≡	18.6	1.69≡	48.9	1.8 ≡	63
t (2.5%)	1.67≡	46.7	2.13≡	134.9	2.58≡	380

Log. of Metal Content

L

⟵ Cumulative Frequency

PERMO-TRIAS

Base of Alston Group

Top of Ashfell Sandstones

Base of Alston Group

Base of Ashfell Sandstones

Top of Ashfell Sandstones

Ravenstonedale Group

SILURIAN

Basal Carboniferous
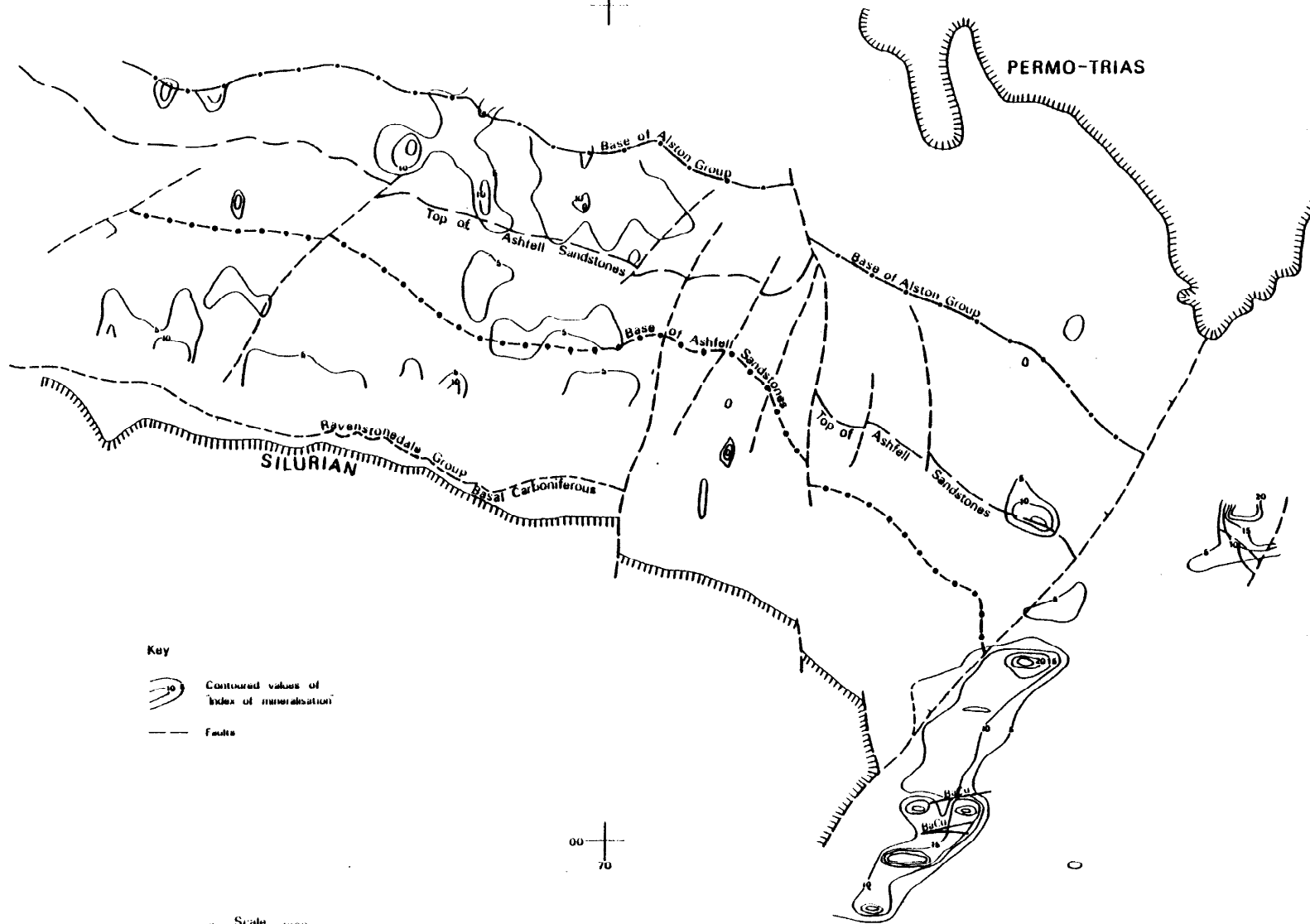
Key

Contoured values of
"Index of mineralisation"

— — Faults

BaCu

0   Scale   1000

Metres

Fig 5   "Index of Mineralisation"-contours of values

Table 2 Dispersion of Zn and Pb in Scandal Beck

Sample No.	53	85	86	87
Zn (ppm)	470	370	300	210
Pb (ppm)	140	140	140	110
Distance down-stream (in km)	0	1.5	2.5	3.5

has been considered but discounted, as there is little glacial material on this topographically high ridge and the analysed soils gave no evidence of transport.

A small group of four anomalous samples (B) occurs on the eastern margin of the area investigated, at Birkett Common. This occurrence is of interest since it coincides in general with anomalous data obtained from VLF investigations over the area (Figure 9), which have been interpreted as indicating a pair of approximately north-west/south-east faults. The presence of the anomalous geochemical values in this vicinity suggests that there may be minor mineralisation associated with these structures.

A well-defined group (C) of anomalous soil samples is located in the northern part of the area on the north-facing slope of Crosby Garrett Fell overlooking the valley of Potts Beck. The cause of this anomaly is not immediately apparent as there are no known indications of mineralisation recorded at surface. The anomalous values obtained in the soils here are generally of the order of 1.5 times background, with maximum values of 2, 3 and 5 times background for Cu, Pb and Zn respectively. The anomaly has been confirmed and more precisely defined by further soil sampling at intermediate points on the original grid.

The high soil values appear to coincide with the outcrop of the limestones, part of the Orton Group, which occur between the massive 'D' zone limestones above and the Ashfell sandstones below. They form the lower part of the Knipe Scar Limestone and are characterised by relatively thinly bedded fossiliferous limestones with abundant coral heads, frequently in the position of growth, and beds composed of detrital organic fragments. The development of chert both as thin lenticular bands and as discrete nodules has been noted particularly in the outcrops on Hazzler Brow Scar in a unit which may well represent the base of the 'D' zone limestones in this area (Garwood, 1913). Iron staining was also noted in the area from which the anomalous values were obtained, both on the eastern side of Weather Hill and also Hazzler Brow Scar.

The fourth group (D), Windy Hill, consists of three samples taken from an area of carbonate sediments in the Orton Group, stratigraphically equivalent to the limestone sequence upon which the anomaly C at Crosby Garrett Fell lies. Values at Windy Hill for zinc are at 2 and 10 times background levels with lead at 1.2 and 2 times background. There is little evidence at surface to indicate the cause of these relatively high soil levels at this location. The values are in keeping with the data to be expected from the minor mineralisation of joints and fractures and the small local extent of the anomaly is also consistent with such an interpretation.

Of the four groups of anomalous soils described, two (A and C) were followed up with detailed geophysical surveys, whilst for group B geophysical data were already available.

INDEX OF MINERALISATION MAP

The contour map (Figure 5) produced by using the mineralisation index has value in identifying the areas of interest as it appears to identify, more clearly than Figure 2, directional trends in the anomalous areas (although this parameter has to be used with caution as contouring can be rather too subjective an approach).

This method of data treatment has identified the known mineralised features as well as the extensions and additional areas shown by the single elemental approach. It also indicates the probable directional trends of the structures causing the soil anomalies which in the case of the Stennerskeugh Clouds area is confirmed by the observed geological data.

ROCK SAMPLES

Eight rock samples from the area near to Crosby Garrett Fell were analysed by XRF techniques for a number of elements, the data from which are shown on Figure 6. Of these samples, four lie close to or within the area of anomalous soil values. There is nothing exceptional about the analytical data obtained, the range of values being generally in accord with published data relating to the metal content in carbonate rocks (Levinson, 1974).

GEOPHYSICAL SURVEYS AND INTERPRETATION

Detailed geophysical surveys following up geochemical anomalies were carried out at two localities; Stennerskeugh Clouds and Crosby Garrett Fell. They were aimed at obtaining any indication of mineralisation or of any geological features, such as faulting or facies change, to which it might be related. The surveys are described in detail below, and the results of an earlier survey at Birkett Common are summarised. Brief reference is first made to related large-scale geophysical surveys.

Airborne geophysical surveys were carried out at a number of localities in Great Britain as part of

Sample No.	ppm						Ca %
	Ba	Pb	Cu	Zn	Mn	Fe	
4	11	2		2	100	740	46.6
5	25		2	2	330	1540	44.2
3	17			2	160	800	44.8
2	104	9		7	490	9350	44.8
6	23	4	2	1	70	910	42.1
1	16	5	1	29	130	1580	40.8
8	11	12			100	460	45.0
9	28	7	2	4	170	780	44.8

Limestone } Alston Group

Limestone Shale } Orton Group

Sandstone }

Approx. area of soil anomaly

Fault

Boulder clay

Bedding dip

0   0.5 km
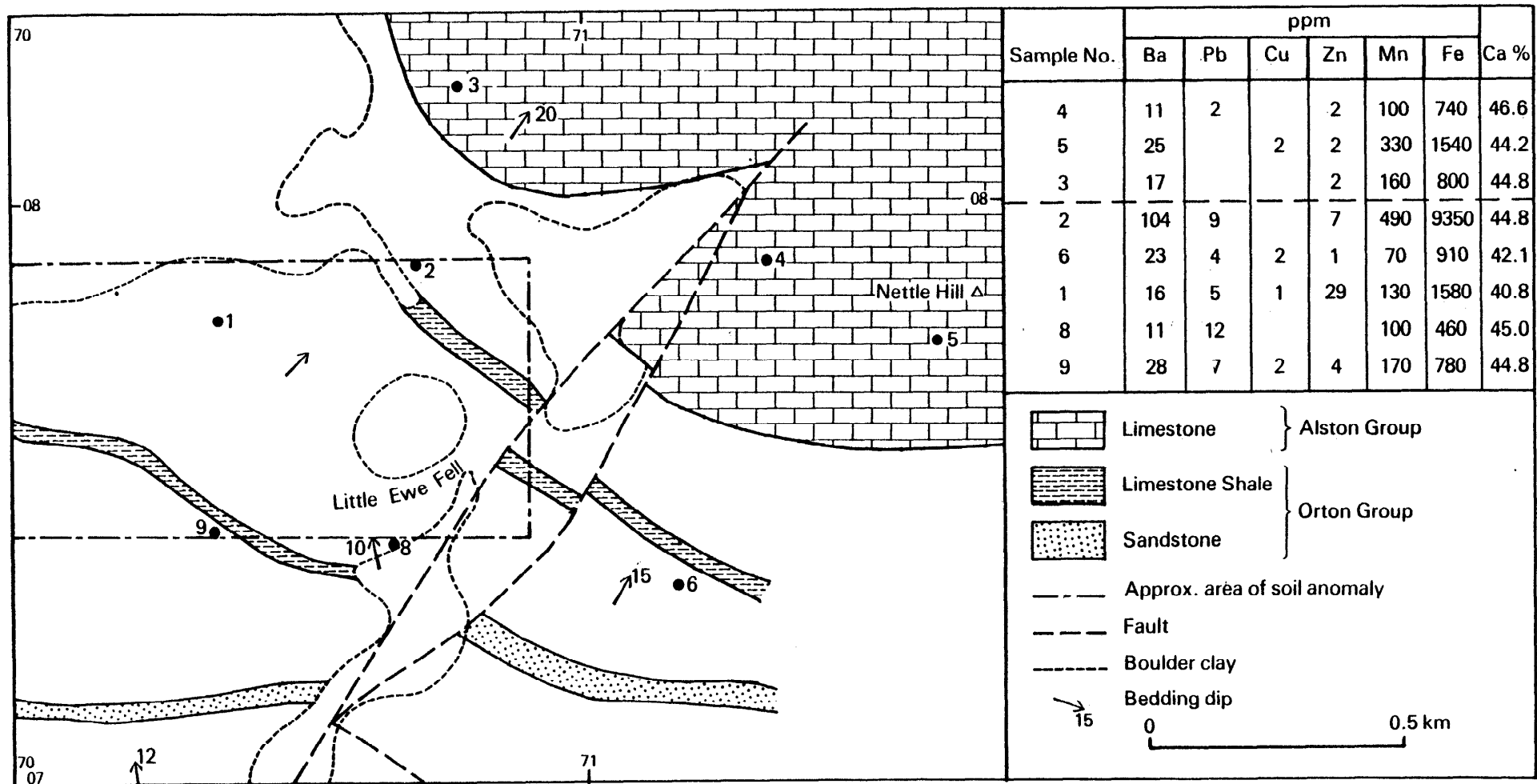
Nettle Hill △

Little Ewe Fell

Fig.6 Rock samples, relation to geology and geochemical analyses, Crosby Garrett Fell

the Mineral Reconnaissance Programme in 1973 (Burley and others, 1978). Parts of four of these areas, all basin-margin areas on the flanks of the Pennine blocks, fall within some ten miles of the Ravenstonedale geochemical survey area. These are the Lunedale Fault area (Cornwell and Wadge, 1980), the Dent and Augill Fault areas (Cornwell and others, 1978), and the Stockdale Monocline (Swaledale) area (report in preparation). The area of the Dent Fault airborne survey overlaps partially with the Ravenstonedale geochemical survey (Figure 1), and at Birkett Common geophysical work had already been carried out as follow-up to the airborne survey prior to the geochemical survey.

As part of this earlier investigation of the Dent Fault line, the regional gravity coverage was improved to an average station density of one per km² in the Kirby Stephen area, and part of this work falls within the area of the Ravenstonedale geochemical survey. The results of the gravity survey are described by Cornwell and others (1978).

Both the regional gravity and aeromagnetic maps (Institute of Geological Sciences, 1977, a and b) show Ravenstonedale (the area between Tebay and Kirkby Stephen) to be a quiet area. To the south the gradient of the magnetic field increases strongly towards the major Ribblehead anomalies while to the west another sharp anomaly is associated with the Shap granite. Ravenstonedale lies in a quiet area of the gravity map, falling between the important lows of the Shap, Weardale and Wensleydale granites. However, the gravity contours do reflect the sharp change in the direction of the margin of the Cumbrian massif, from ESE to SSW where the Silurian—Carboniferous unconformity in the Lune Valley meets the Dent line.

STENNERSKEUGH CLOUDS

The location of the geophysical traverses at Stennerskeugh Clouds is shown in Figure 7. The east-to-west traverses were measured with both the IP and VLF—EM methods. The NNE traverses were measured with the VLF—EM method only. The survey was aimed at examining the limestone immediately to the east of the Dent Fault for mineralisation which might be responsible for the geochemical anomalies, this possibly being trapped at depth in the anticlinal structure which accompanies the fault on its east side. Traverses were confined to the area of high ground known as Stennerskeugh Clouds, which carries little or no drift. The lack of promising results from this area discouraged extension of the survey area to cover the geochemical anomalies to the north, where the drift, possibly thick, would in any case have reduced the effective depth penetration of the IP method. As has become customary in such surveys, the IP traverses were also measured with the VLF—

EM method to provide additional information on near-surface conductivity discontinuities, to assist interpretation of the IP data. The VLF—EM traverses aligned 012° were aimed at locating any significant features cross-cutting the strike which could be missed by the east-to-west traverses; the known mineral veins, for example, occupy small dip faults with this trend.

Locating extensions of the known mineral occurrences was not a consideration in planning the surveys, the minimal level of development of old workings suggesting there would be little to expect in this direction. Similarly, coverage of the Dent Fault itself was omitted as the geochemical samples taken nearest the fault line are generally not anomalous. Also, the fault is drift-covered, and is closely followed by a main road; features that would probably hamper a satisfactory study of the structure.

Except in the vicinity of High Stennerskeugh Farm and in the valley bottom between Street and Coldkeld Farms, the area is rough pasture and free of man-made features likely to influence geophysical observations.

Time-domain IP equipment was used for the survey, measuring both apparent resistivity and chargeability, using a dipole-dipole array. The method is described in detail by Burley and others (1978). Chargeability was measured as the area under the secondary voltage decay curve over the period between 240 and 1140 ms after primary current switch-off. Fifty-metre dipoles were used, with the transmitter dipole positioned to the east of the receiver dipole throughout. On four of the traverses (375N, 0, 550S, 1125S) dipole spacings of n = 2, 3, 4 and 5 were used, i.e. distances between dipole centres of 100, 150, 200 and 250 m respectively. On traverses 300S and 825S, readings were at n = 3 and 4 only, since equipment failures had reduced the time available for completion of the survey. The high apparent resistivities over most of the area gave a high signal-to-noise ratio, permitting measurements at the wider dipole spacings to be achieved easily.

The NNE-aligned VLF—EM traverses show no anomalies indicative of significant east-west features, and these results are not discussed further. The VLF—EM and IP/resistivity data from the east-to-west traverses show anomalies which can be accounted for by the known geology. The VLF—EM profiles and IP/resistivity pseudo-sections for traverse 0 are shown in Figure 8. These results are typical; the broad pattern of anomalies is repeated on each of the other traverses.

Anomalous chargeability values would be the most likely indicator of sulphide mineralisation concealed at depth in the Great Scar Limestone. However, the chargeability values recorded over the outcrop of this limestone are uniformly low, generally not more than 4 ms. Between 50W and 100E on traverse 0 a zone of slightly increased chargeability occurs, with some values
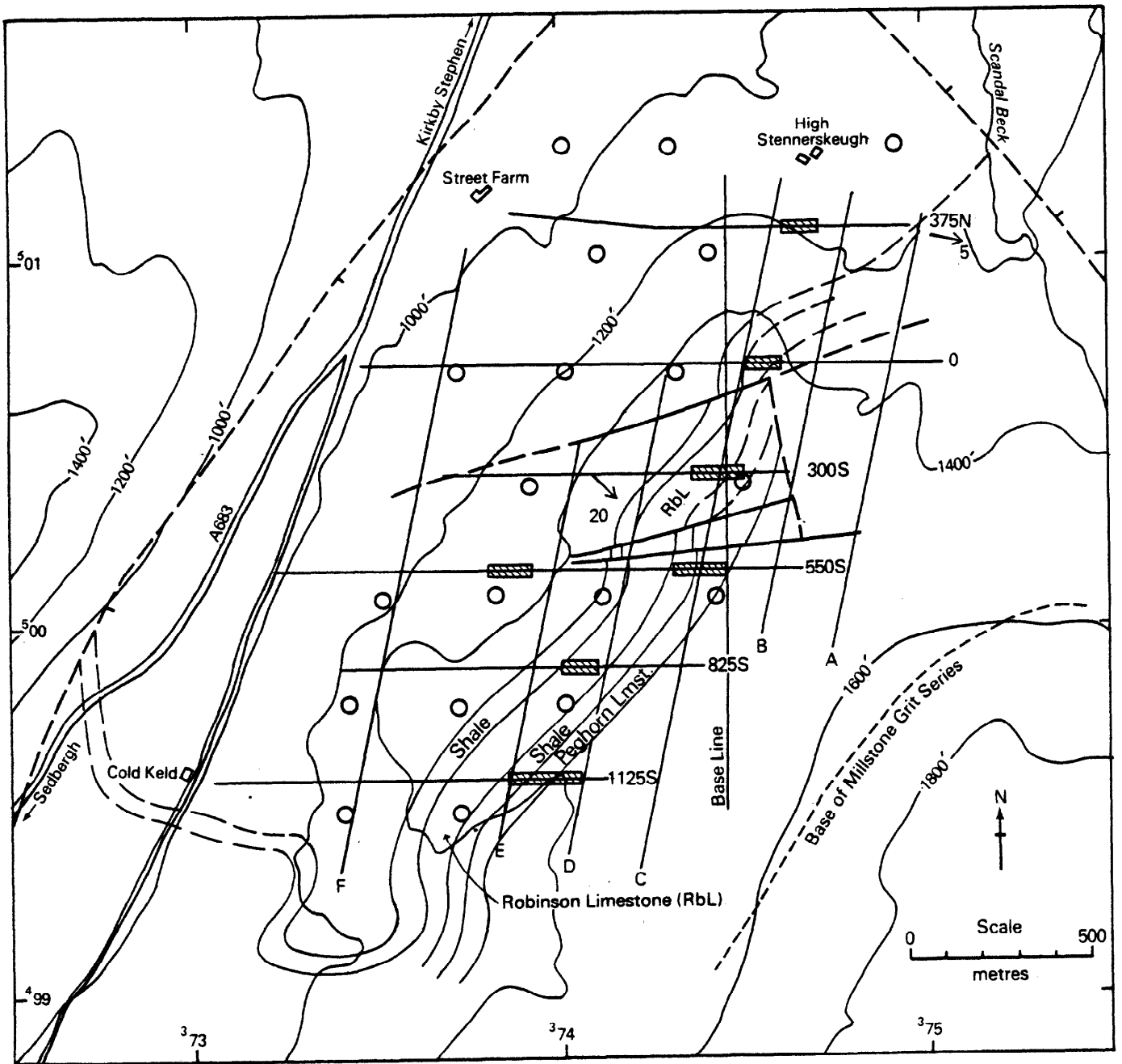
11

Fig. 7 Stennerskeugh Clouds: Location of geophysical traverses, showing areas of anomalous chargeability

+ 50
+ 40
+ 30
+ 20
+ 10
0
- 10
- 20

A

1000W   600W   200W   200E   600E

B

11•3
13.5
26•2 11•5
6.0
10
6.0
6.0

← Average chargeabilities 1.5-3.5 milliseconds →   ← Average chargeabilities 3.5-5.5 milliseconds →

C

← Average apparent resistivities 2000-3000 ohm-metres →

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KEY: A: VLF-EM Profile   •—•—• in-phase   ⊶—⊶—⊶ out-of-phase   Values in per cent

B: Chargeability pseudo-section   Contours at 6ms and 8ms   Actual values are shown where these exceed 10ms

C: Apparent Resistivity pseudo-section   Horizontal hatching = values below 500 ohm-metres   Vertical hatching = values 500-1000 ohm metres
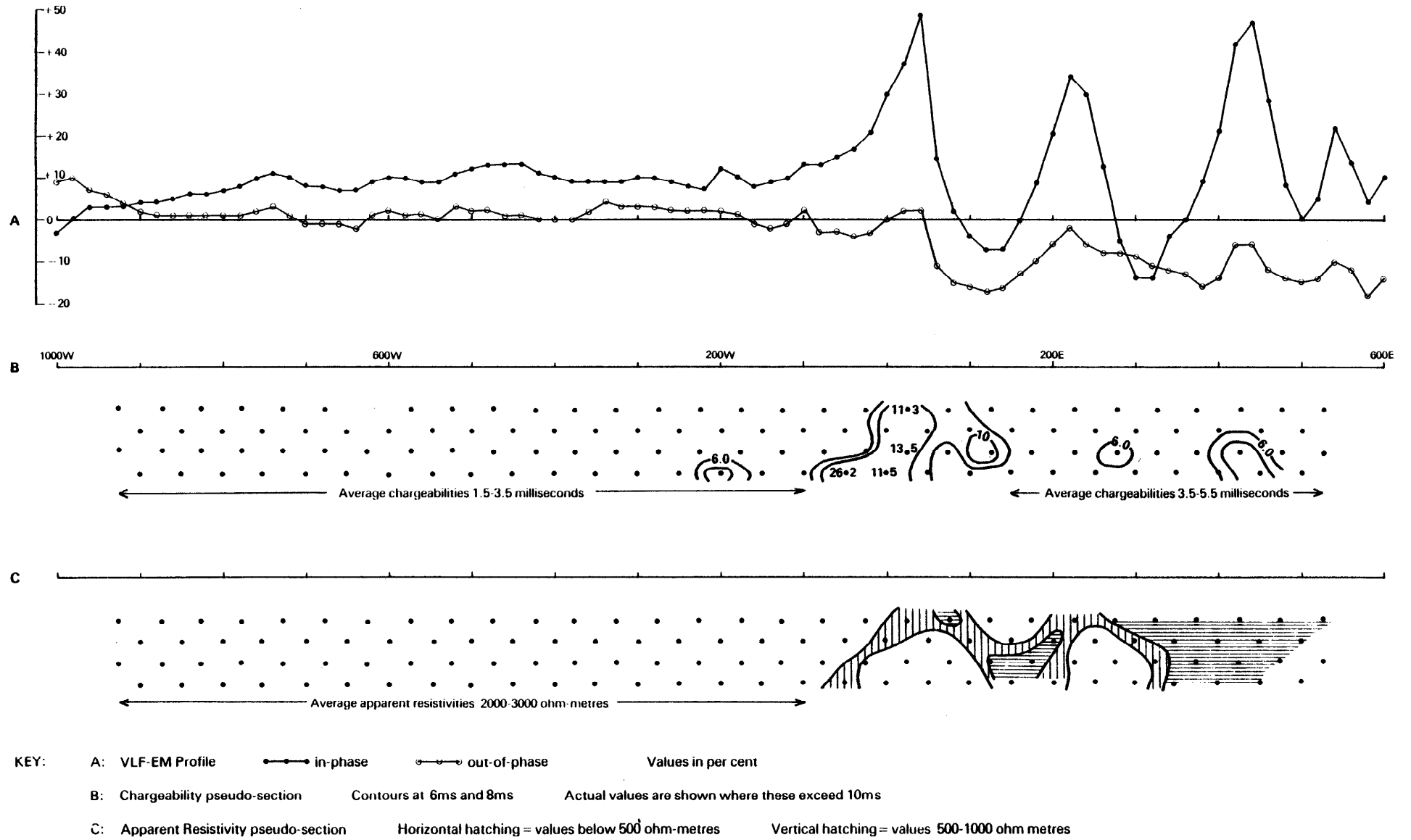
Fig 8 Stennerskeugh Clouds geophysical survey :Results of VLF-EM and IP/Resistivity measurements on traverse ON

exceeding 10 ms (Figure 8). Comparable charge-ability anomalies are seen on each of the other traverses, and their positions are shown in Figure 7. The VLF profile for each traverse indicates a significant conductor present at, or just west of, the position of the anomalous chargeability zone. This coincidence of electrical and electromagnetic anomalies with a similarly linear distribution of geochemical anomalies suggests that the cause may be a mineralised fault zone, which would thus run approximately parallel to the Dent Fault. This is, however, considered unlikely for several reasons. With the good exposure in the area, it is doubtful that such a fault would remain undetected, whilst the workings on the Clouds Vein should have intersected such a fault, if present. The geochemical anomalies are confined to ground west of the line of geophysical anomalies and show no consistently higher values in those samples closest to that line. Furthermore, the VLF anomalies are characteristic of the 'edge effect' of a shallow-dipping conductor, and give no indication of the presence of a steeply-dipping conductor such as an open fault zone.

The surface position of the feature causing the chargeability anomalies is approximately the position of the Robinson Limestone; but accurate resolution of the feature is not possible because the length of the electrode array greatly exceeds the width at outcrop of the stratigraphic units. The Robinson Limestone is the first of a series of thin, shallow-dipping limestones, overlying the Great Scar Limestone, separated from each other by thin shale horizons. The known geology thus offers the most satisfactory explation of the geophysical anomalies. The succession of VLF anomalies on each traverse, of which the profile in Figure 8 shows a typical example, mark the surface positions of each of the thin shales above the Great Scar Limestones. The anomalies result from the marked conductivity contrast between the two alternating lithologies. The chargeability anomalies are considered to be related to the shale unit separating the Robinson and Great Scar Limestones with, in some instances, a contribution from the shale separating the Robinson and Peghorn Limestones. Less anomalous are the shales at the eastern end of each traverse, which give charge-ability values only slightly above those for the Great Scar Limestone. This difference in the chargeability responses of the shale units is considered to be due to lithological differences; in pyrite content, for example. In this respect, it is of interest that the airborne geophysical survey of the Dent Fault (Figure 1) located significant anomalies at Little Longrigg Scar (802 084) (Cornwell and others, 1978) which were shown by ground surveys to be related to the shale units adjacent to the Robinson Limestone. These anomalies were exceptional amongst the other air-borne anomalies in being clearly aligned along the local strike over almost 1 km.

It can be seen from Figure 7 that the charge-ability anomaly on traverse 375N does not conform to the interpretation suggested above. However, the mapped lithological boundaries in this area are conjectural, and the VLF anomalies on this traverse suggest that the local strike maintains a more northerly trend. Indeed, it is suggested by Dunham and Wilson (in prep.) that the Stennerskeugh Clouds area may be a dome feature, involving a change in strike direction back into the Dent Fault.

The interpretation given above does not exclude the possibility that minor mineral occurrences, sufficient to account for the geo-chemical anomalies, occur in the area. It is possible that higher chargeability values are due in part to local concentrations of sulphides. The presence of shale in the waste from the Clouds Vein adit indicates that mineral working was located in horizons above the Great Scar Limestone. However, the geophysical traverses are too widely spaced, and the electrode array too large, to be able to confirm the presence of minor pockets of sulphides.

Finally, an isolated chargeability anomaly occurs at approximately 600W on traverse 550S. This is considered to be due to a local accumulation of boulder clay in a hollow in the limestone escarpment and it is probably coincidental that it lies close to a possible westward extension of one of the mapped mineral veins.
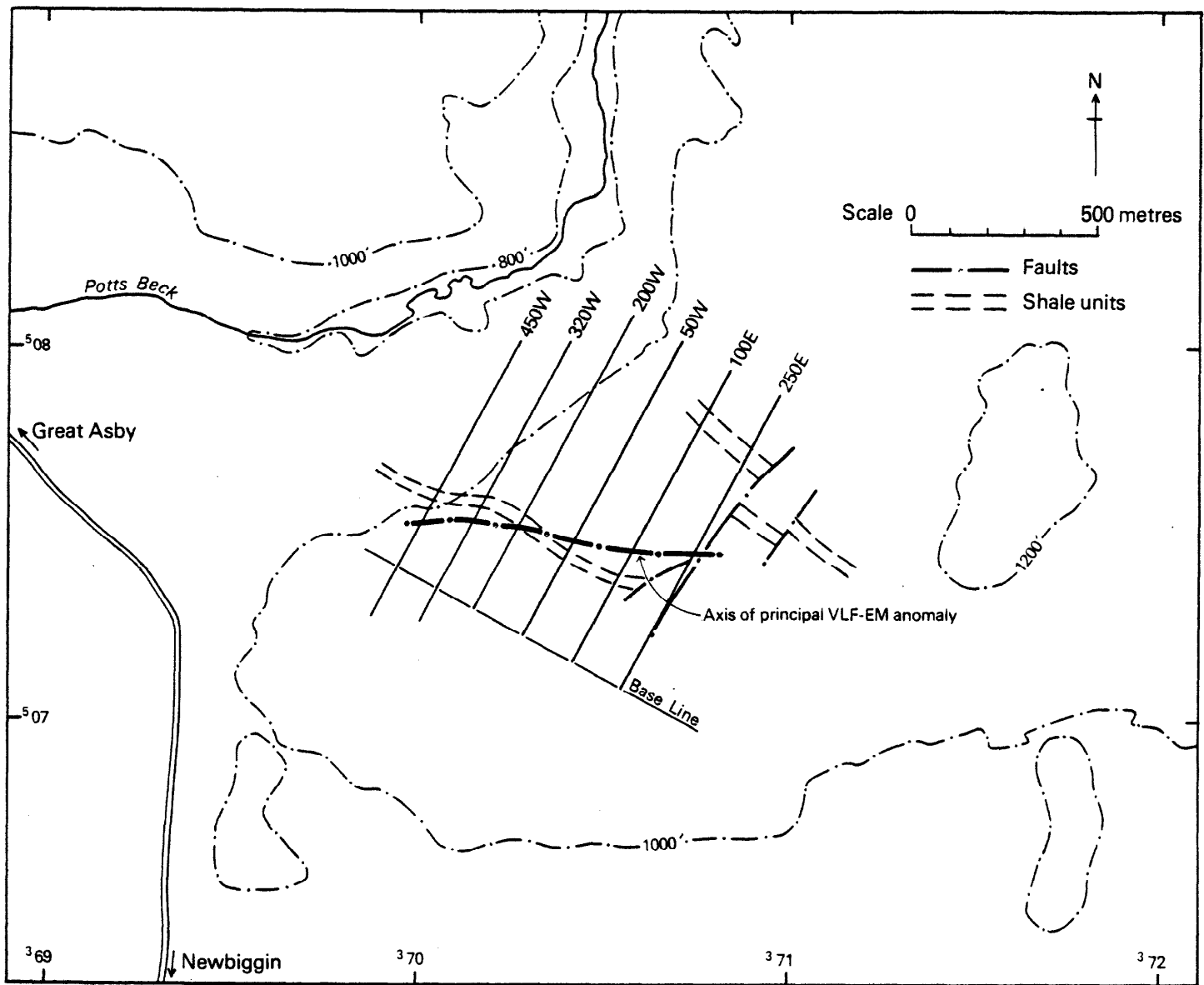
CROSBY GARRETT FELL

The location of the geophysical traverses at Crosby Garrett Fell is shown in Figure 9. Traverses 200W, 50W and 100E were measured with the IP method and all traverses with the VLF—EM method. The IP traverses were measured as described above for Stennerskeugh Clouds, but at the n = 2, 3 and 4 dipole spacings only. The transmitter dipole was positioned to the south of the receiver dipole throughout. VLF—EM measurements were taken at 20 m intervals throughout. This survey was aimed at obtaining any evidence of mineralisation which would account for the geochemical anomaly described above. The geophysical traverses were aligned approximately normal to the local strike, which the geochemical anomaly appears to follow.

The area is rough pasture and free from sources of artificial geophysical anomalies.

Anomalies were identified in both the IP/resistivity and VLF—EM data but none is consider-ed to be indicative of mineralisation, since they can be explained satisfactorily in terms of the known geology. The results from traverse 100E demonstrate the IP/resistivity and VLF—EM anomaly characteristics most clearly (Figure 9). Comparable but less clearly defined anomalies are also seen on each of the other traverses.
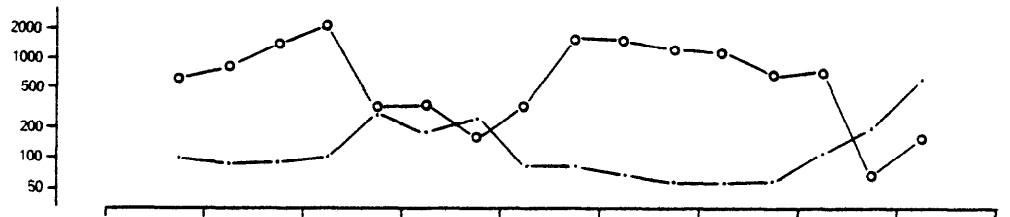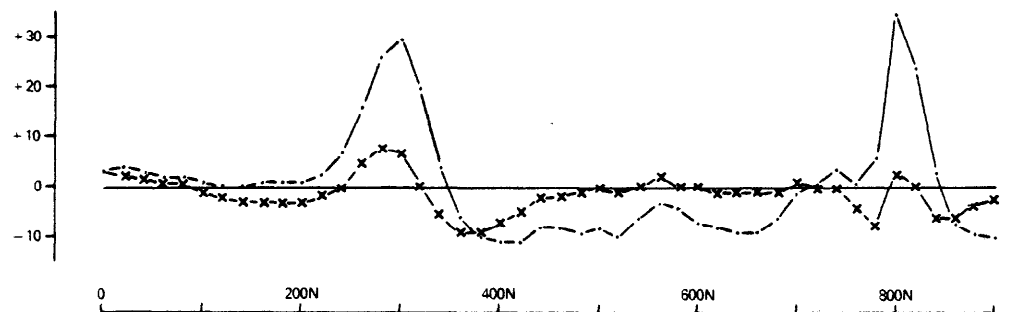
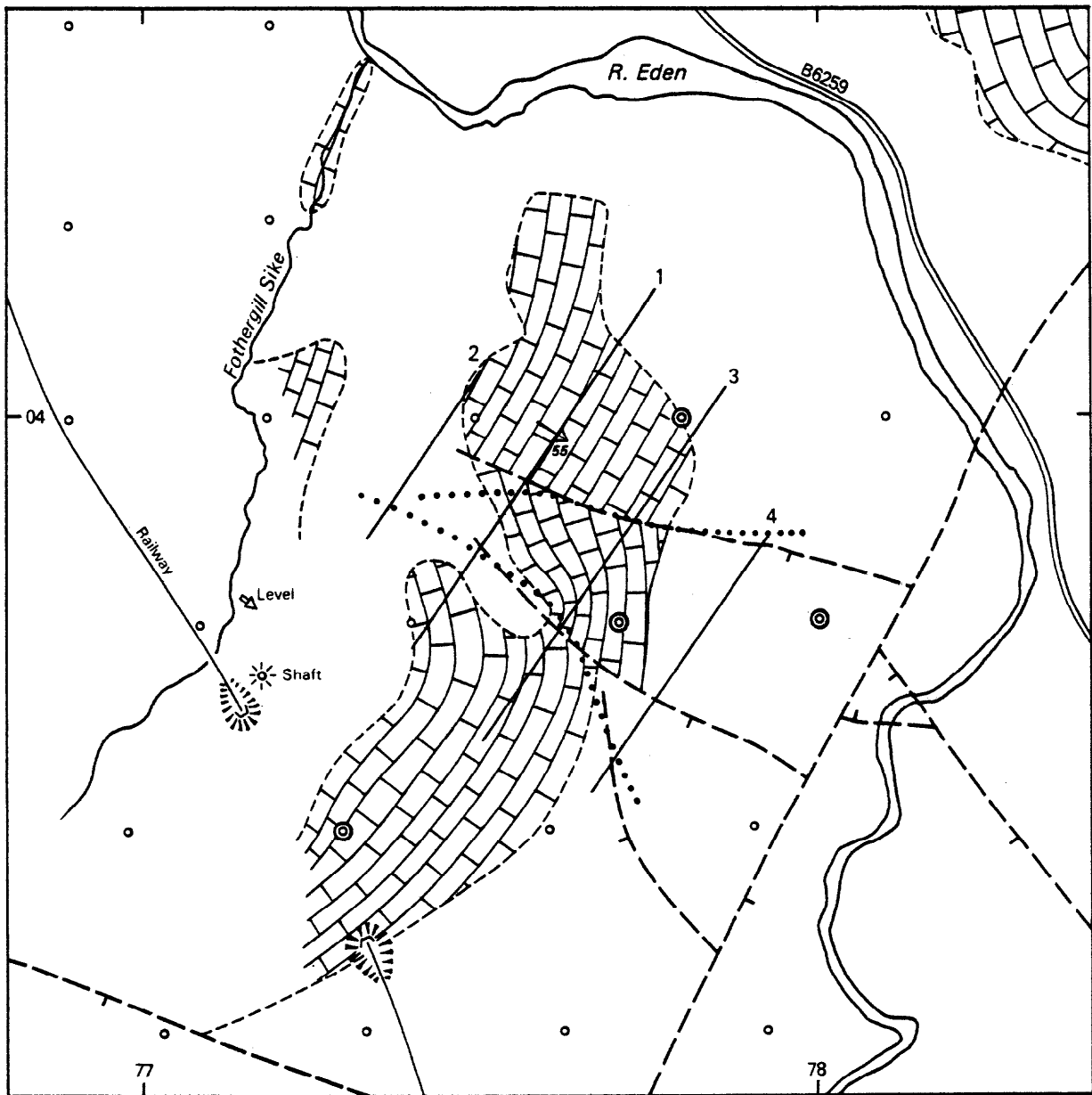On traverse 100E, at approximately 325N,

Fig. 9 Crosby Garrett Fell: Location of geophysical traverses and results of VLF-EM and IP/Resistivity measurements on Traverse 100E.

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Key

| o | Approx. sites of geochem. samples |
| ◎ | Anomalous geochem. samples |

•••• Axes of ULF maxima

1 2 3 4 VLF-EM traverses

Scale 0 _____ 300 metres

Fig10 Birkett Common-Geophysical and Geochemical Data.

the VLF–EM profile indicates a conductor at, or close to, surface which has a shallow northerly dip. The resistivity profile supports this, showing a marked low for the three positions where such a conductor would be beneath or between the dipoles. At these three positions the chargeability values are approximately double the background values observed to the north and south. The geophysical data correlate well with the geological map (Figure 9) which shows a north-dipping shale cropping out in the vicinity of 300/350N on traverse 100E. Similar VLF–EM and IP/resistivity anomalies at the northern end of the traverse indicate a second such shale, again shown on the geological map. Thus the geophysical anomalies, as at Skennerskeugh Clouds, are best explained as an expression of the particular physical properties of the different lithologies known to occur in the area.

BIRKETT COMMON

This locality falls within the area of the airborne geophysical survey of part of the Dent Fault, and follow-up ground geophysical surveys had already been carried out here prior to the Ravenstonedale geochemical survey (Cornwell and others, 1978). Weak airborne EM anomalies occur over the area and are of uncertain origin; the anomalies appear to be more significant on the flight profiles than on the contoured map of in-phase response.

Test ground traverses were measured with the Slingram and VLF–EM methods, with traverses at various orientations. The only significant results were obtained from a set of four VLF–EM traverses aligned N 035°, giving anomalies which show some correlation with the known faulting (Figure 10), as described by Cornwell and others (1978). The incidence of a small group of geochemical anomalies on Birkett Common (Figure 10) suggests that the faults indicated by the geophysical anomalies may be mineralised. The geophysical and geochemical anomalies occur on the north-east flank of the hill of Birkett Common. On the north-west flank the Fothergill Sike Vein was tried from a shaft and a level after the vein was intersected in construction of the railway cutting (Dunham and Wilson, in prep.). This lends support to the possibility that the geochemical and geophysical anomalies are related to other unrecorded mineralised structures; but these are not considered of sufficient potential size to warrant further investigation.

CONCLUSIONS

The data produced from this reconnaissance investigation allow some conclusions to be reached with respect to the mineralisation likely to occur in the area. Stream sediment data, almost entirely

relating to the Silurian rocks, do not indicate major mineralisation, there being only three sample sites with anomalous values. It is concluded that there is little evidence to justify further work in this area. The anomalous stream sediments from Scandal Beck relate to the known mineralisation in the carbonate rocks of the Alston Group and provide an indication of the distance of transport of Cu, Pb and Zn under the conditions developed in streams flowing from the carbonate environment of the Stennerskeugh Clouds.

The majority of the data obtained from the soil samples are at the background values expected, but those that are anomalous identify discrete areas which have been discussed separately in the text. It is concluded that the geochemical data indicate an extension of the mineralisation from Stennerskeugh Clouds for some 3–4 km to the north-east. The effect of glacial transport is considered to be minimal in this area.

The small group of samples at Birkett Common identify possible minor mineralisation associated with faulting, of a type similar to that known at Stennerskeugh Clouds. Conclusions are rather less easily drawn from the anomalous data at Crosby Garrett Fell and Windy Hill. In neither locality was any surface indication of mineralisation seen, and the few rock analyses from the former location do not indicate enrichment of metals. The data obtained from both of these locations is, however, consistent with the presence of local minor mineralisation.

Geophysical data from Stennerskeugh Clouds and Crosby Garrett Fell are interpreted as reflecting lithological (argillaceous) units in the stratigraphical succession. In the case of Birkett Common, they are interpreted as identifying fault zones. There is no evidence from the geophysical data which can be interpreted as indicative of massive sulphide mineralisation.

It is regarded as significant in exploration terms that those samples taken close to the Dent Fault Zone contain only background values of metals. This may indicate that the fault zone was too tight a structure along this part of its length to allow ready access by mineralising fluids and may, in fact, have constituted a barrier.

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