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BRITISH GEOLOGICAL SURVEY

Mineral Reconnaissance Programme Report





This report relates to work carried out by the British Geological Survey on behalf of the Department of Trade and Industry. The information contained herein must not be published without reference to the Director, British Geological Survey.

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No. 77

**Follow-up mineral
reconnaissance investigations
in the Northumberland Trough**

BRITISH GEOLOGICAL SURVEY
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**Follow-up mineral reconnaissance
investigations in the Northumberland
Trough**

Geology and Geochemistry

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Geophysics

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- 32 Investigations at Polyphant, near Launceston, Cornwall
- 33 Mineral investigations at Carrock Fell, Cumbria. Part 1—Geophysical survey
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Bibliographic reference

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SUMMARY

As a result of the data obtained from the Regional Mineral Reconnaissance of the Northumberland Trough, several areas were defined, largely on the basis of the total field magnetic data, for further investigation. Bateson and others (1983) have reported on the first phase of this work. The present report covers a further four areas. Soil geochemistry of each was examined in samples obtained from a regular grid together with ground magnetic measurements. In one area, Brown Moor, a programme of exploratory drilling (4 holes) was also undertaken.

At Todridge Fell, Wheathill and Brown Moor the surface geochemical data indicate that faulting in the Whin Sill, is accompanied by mineralisation. The amount and type of such mineralisation is, however, not determinable except in the case of Brown Moor where the short drilling programme indicates alteration of the Whin accompanied by identifiable mineralisation particularly with respect to Mn, Ba and Pb.

The work undertaken at Ewesley resulted in the definition in soils of a linear zone enriched in Ba with associated higher than background values of Pb and Zn. A weak linear magnetic feature does not coincide with the surface geochemical "highs". The data cannot be used conclusively to determine the origin of these highs; mineralisation associated with a fault structure or a stratabound concentration are possible. As with the occurrences at Todridge and Wheathill, the source of the geochemical anomalies could only be determined by drilling.

The work in these four areas, together with the data obtained at Newbrough (Bateson and others, 1983), indicates that in areas underlain by the Whin Sill magnetic methods can be used to identify fault structures affecting this basic body, with which alteration and mineralisation may be associated.

INTRODUCTION

Following reconnaissance investigations undertaken in large Carboniferous depositional trough underlying Northumberland, several small areas were investigated in detail. Results for the areas at Melkridge, Newbrough, Settlingstones and Torney's Fell have been reported already (Bateson and others, 1983). The remaining areas are described here. Of these, Todridge Fell/Grindstonelaw, Wheathill and Brown Moor were identified on the basis of the geophysical data obtained initially from the 1978 airborne survey (Evans and Cornwell, 1981); the area at Ewesley was selected primarily on the basis of high barium values recorded in stream samples and minor barium mineralisation seen in the area. Of the four areas, drilling was carried out at only one, Brown Moor. The other three were investigated by means of detailed ground geophysics and soil geochemistry. The location of the four areas is shown on Figure 1 together with the outcrop of the Whin Sill.

A standard approach for these investigations was adopted, a grid of traverse lines being set out at approximately 200-250 m intervals with sampling and magnetometer observations at 50 m and 10 m intervals respectively; where possible the geophysical and soil sample lines were coincident, with additional geophysical traverses being inserted where appropriate. The traverses were oriented approximately normal to the strike of the

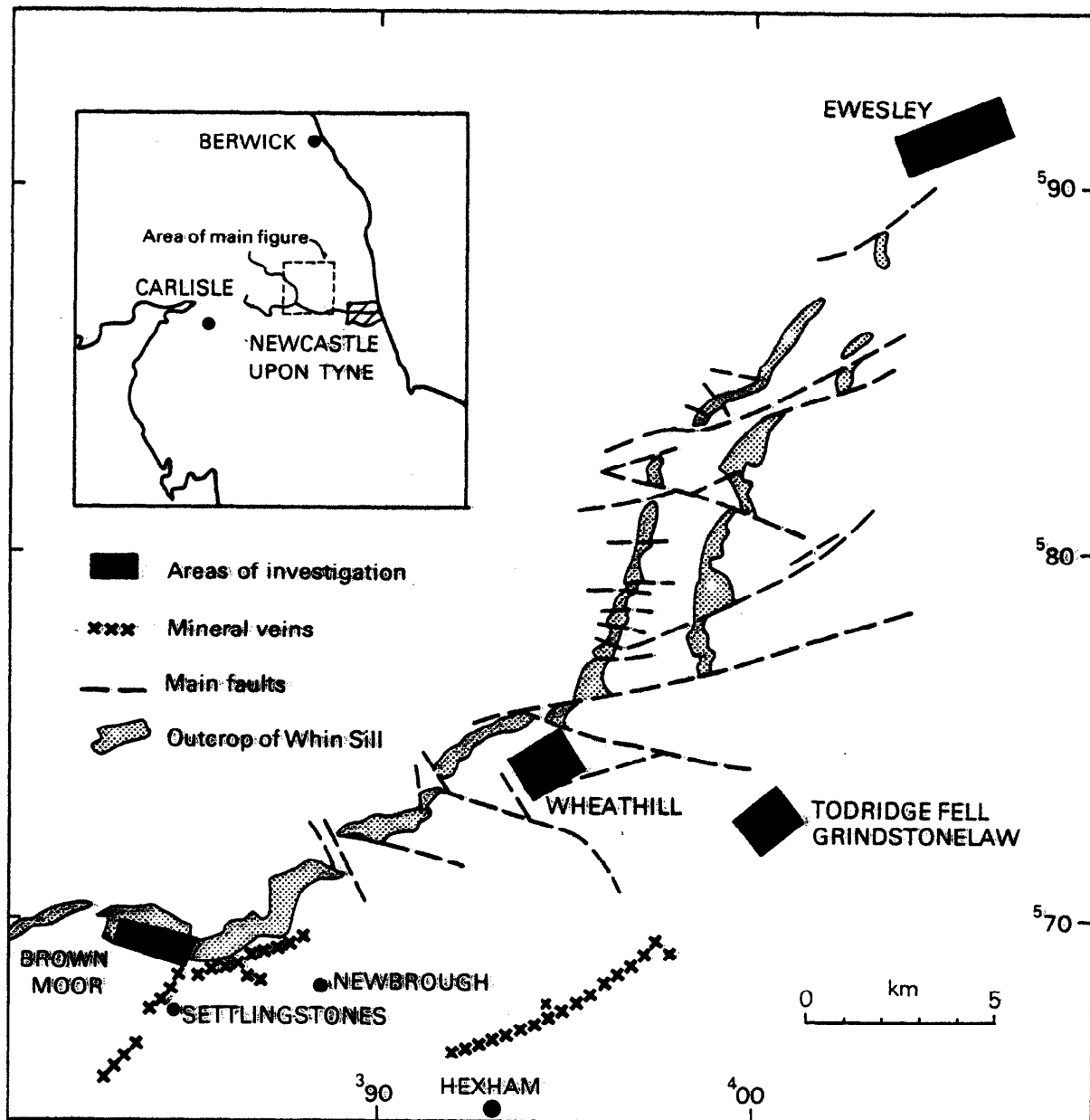


Fig. 1 Location of survey areas

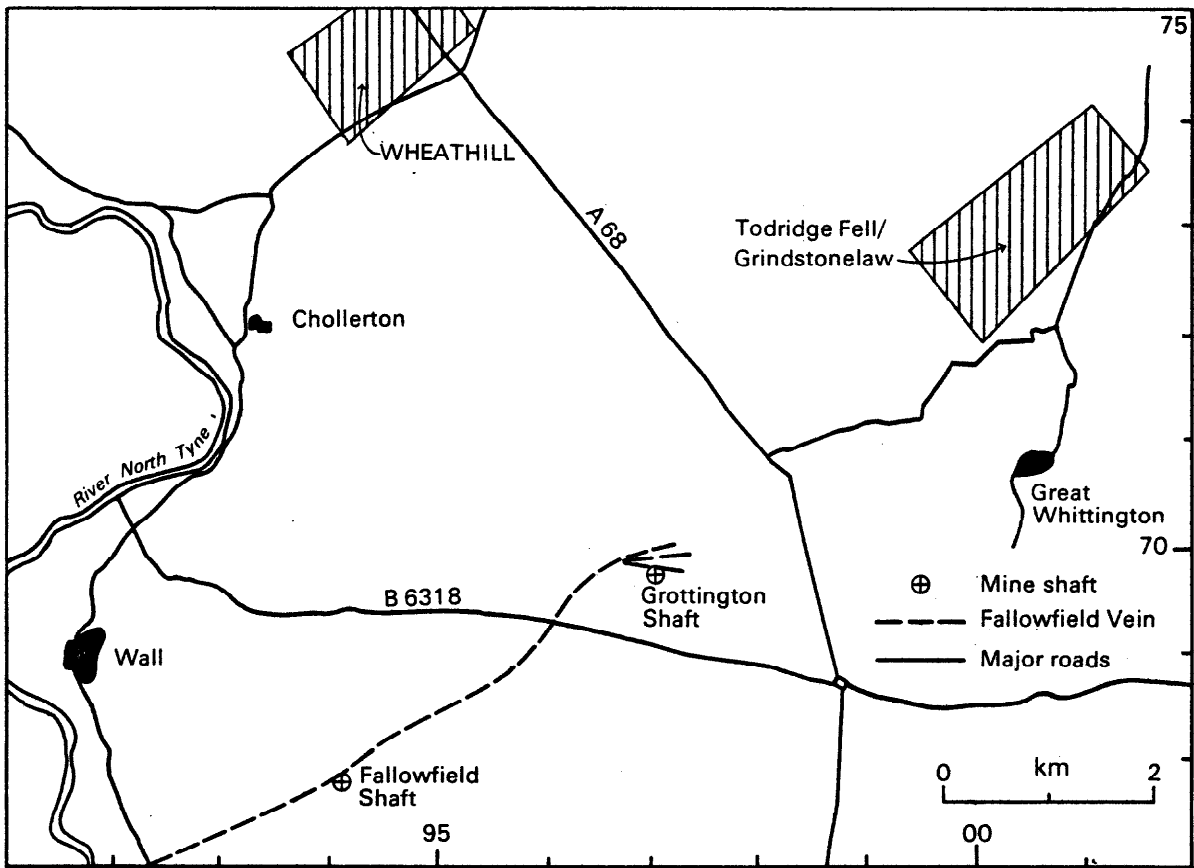


Fig. 2a Location of Wheathill and Todridge Fell – Grindstonelaw

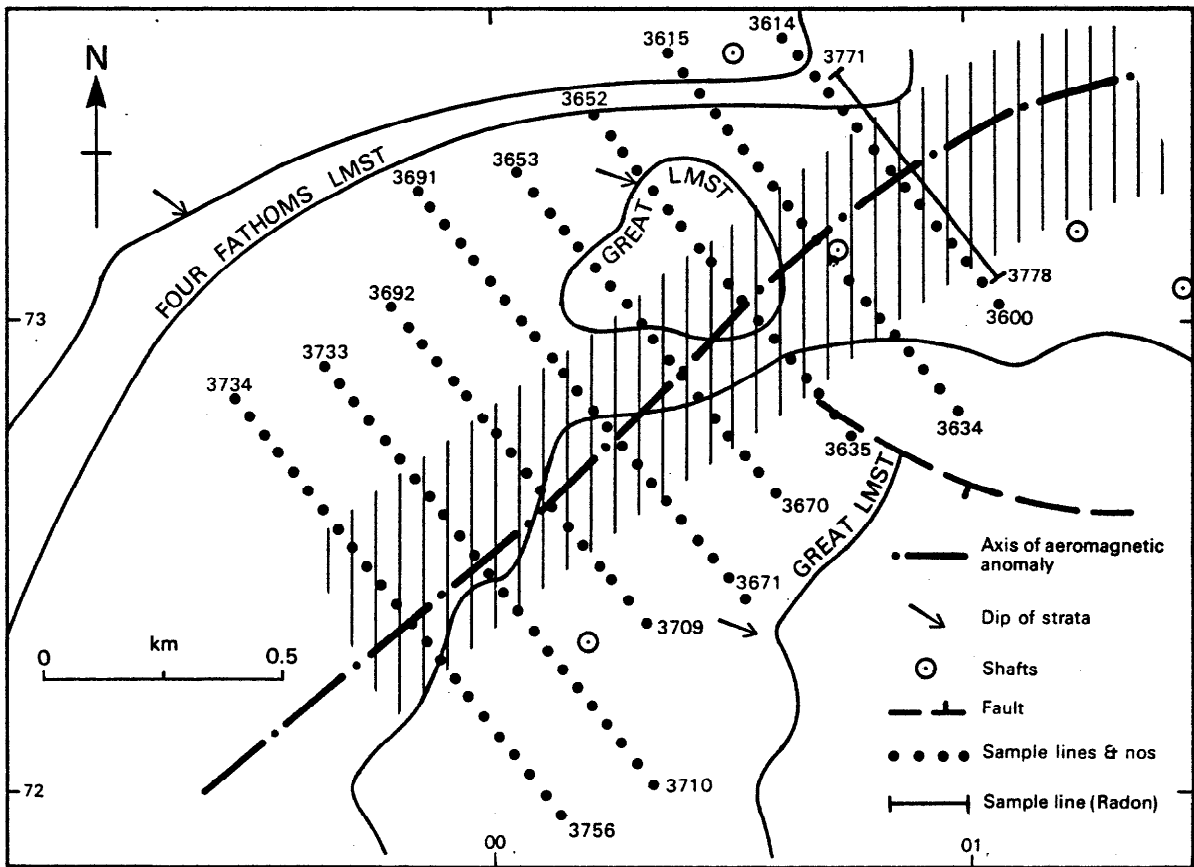


Fig. 2b Geology of Todridge Fell and Grindstonelaw

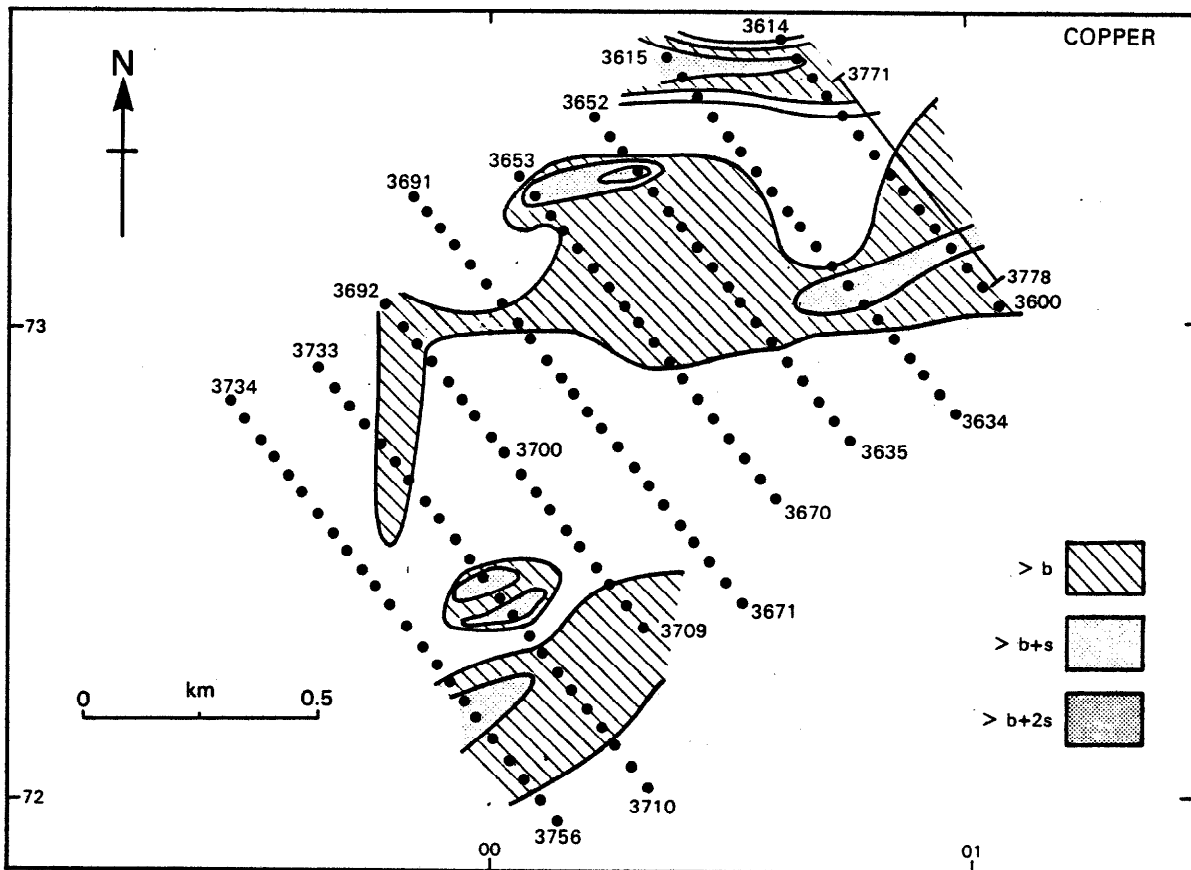


Fig. 3a Distribution of copper—Todridge Fell and Grindstonelaw

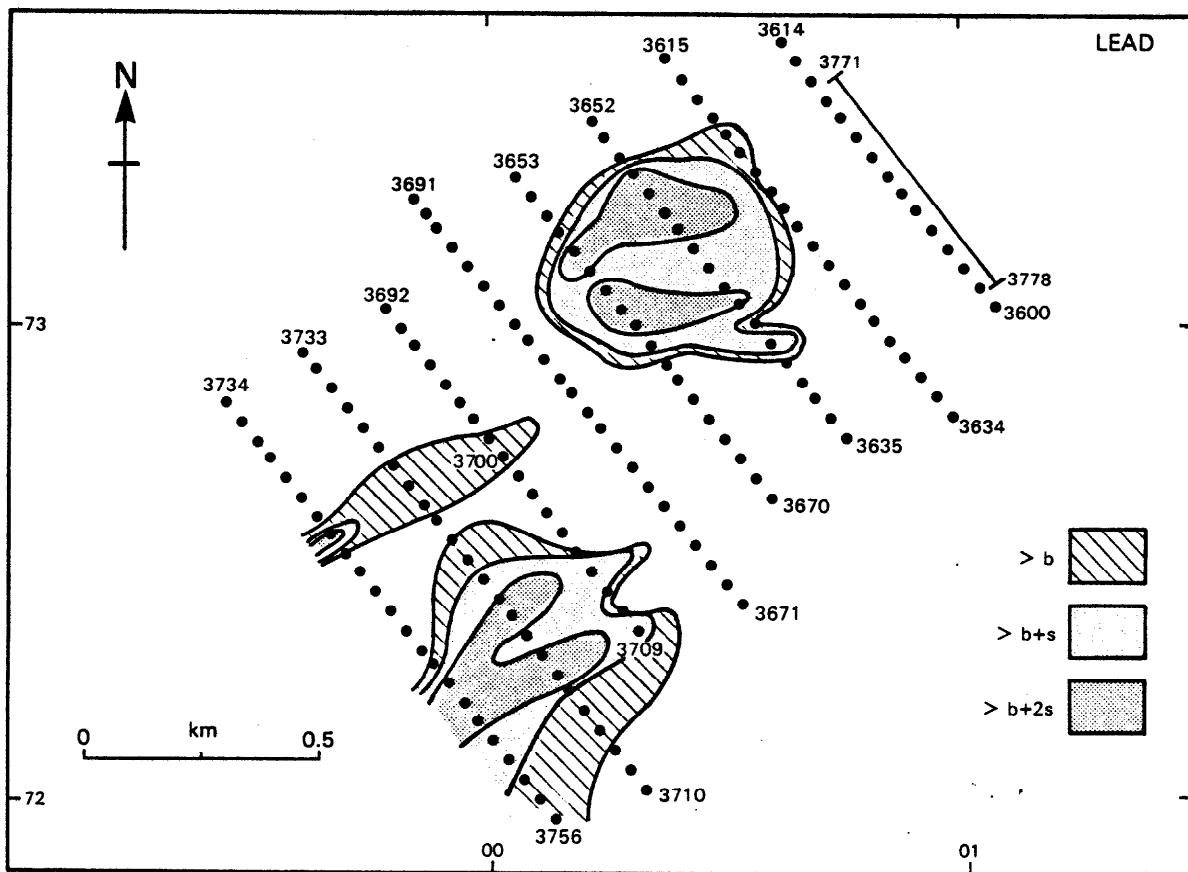


Fig. 3b Distribution of lead—Todridge Fell and Grindstonelaw

anticipated anomalies. The soil samples were taken, using a hand auger, from the horizon beneath the humus layer - generally at depths of 30-50 cm.

In all cases the geochemical data were examined by means of cumulative frequency plots from which the levels of the geometric mean (b) and anomalous values (b+2s) were identified by inspection at the 50% and 97.5% population levels.

TODRIDGE FELL AND GRINDSTONELAW

Introduction

The work in this area took place as a result of a study of the airborne magnetic data, which show a linear negative anomaly trending NE between the villages of Bingfield and Great Whittington, and extending for a distance of at least 4 km (Figure 5). The anomaly is significant because it lies in close alignment with the trend of the very productive Fallowfield Pb/Ba vein (Smith, 1923; Wilson and others, 1922), which extends SE for 6 km from the Grottingham shaft (Figure 2a); the anomaly may therefore be due to faulting in the Whin Sill occupied by an extension of that vein.

An area of approximately 400 x 1000 m covering the best-defined part of the magnetic anomaly was selected for ground magnetic survey and soil sampling.

Geology

The geology underlying the follow-up area as indicated on the published map (Sheet 14) consists of a sequence of calcareous mudstones/shales and sandstones lying between the Four Fathom Limestone below and the Great Limestone above (Figure 2). The sediments dip gently to the SE; faulting is indicated affecting the Great Limestone. The area investigated lies approximately 4 km to the NE of the Grottingham shaft, the most northeasterly point at which the Fallowfield Vein was tested. A number of disused shafts occur in the general vicinity of the area of investigation, but most of these were sunk during exploration for thin coal seams that occur in this part of the succession.

Geochemical survey

Samples were collected with a hand auger at 50 m intervals along lines 200 m apart oriented approximately normal to the strike of the magnetic anomaly. For comparative purposes a single line of 20 holes were deepened in order to collect deep basal till samples from depths between 1.4 and 5 m. From these sites radon in soil gas was also determined.

The soil samples were analysed, after suitable drying and sieving. The copper, lead, zinc and manganese results were plotted on cumulative frequency curves, from which the values of b, b+s, and b+2s (equivalent respectively to the 50%, 84% and 97.5% population levels) were estimated and used in the construction of the contoured maps (Figures 3 and 4).

The values determined are given in the table below (values in ppm):-

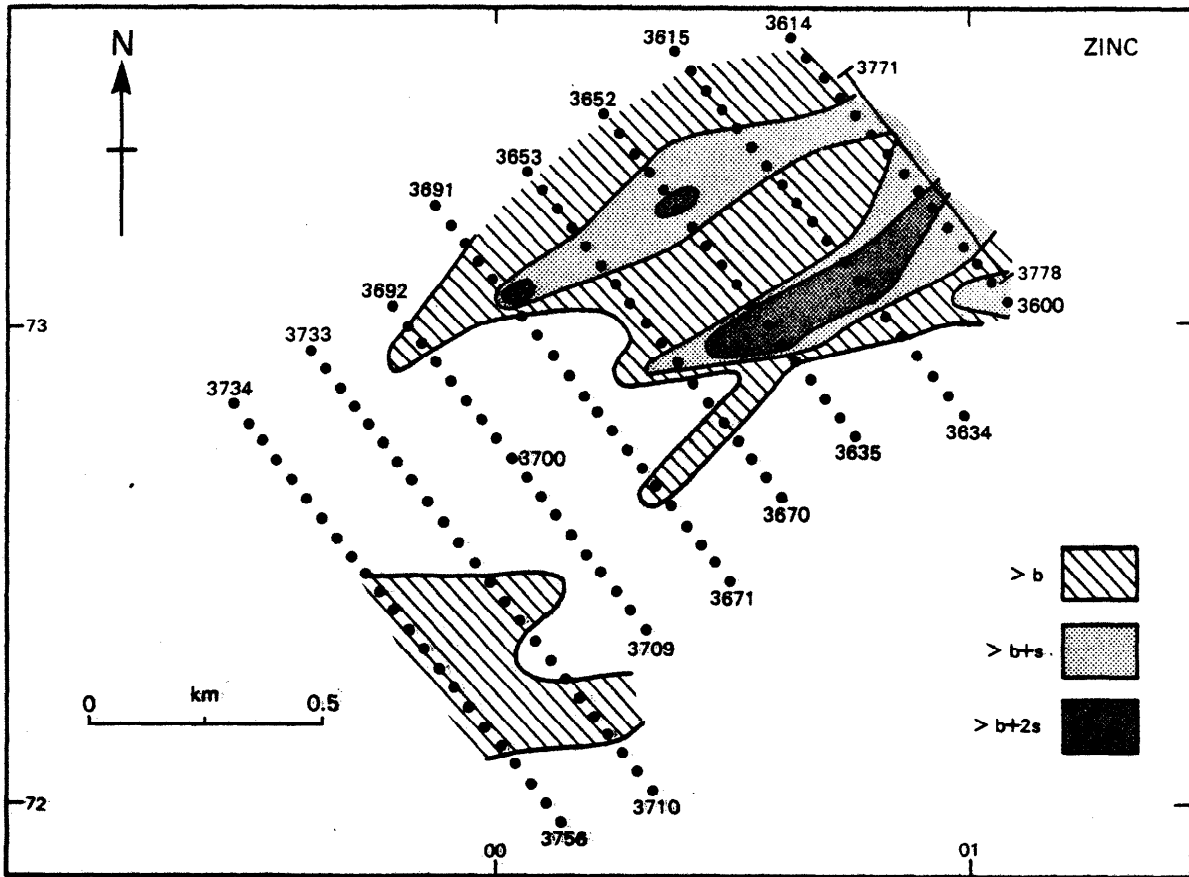


Fig. 4a Distribution of zinc—Todridge Fell and Grindstonelaw

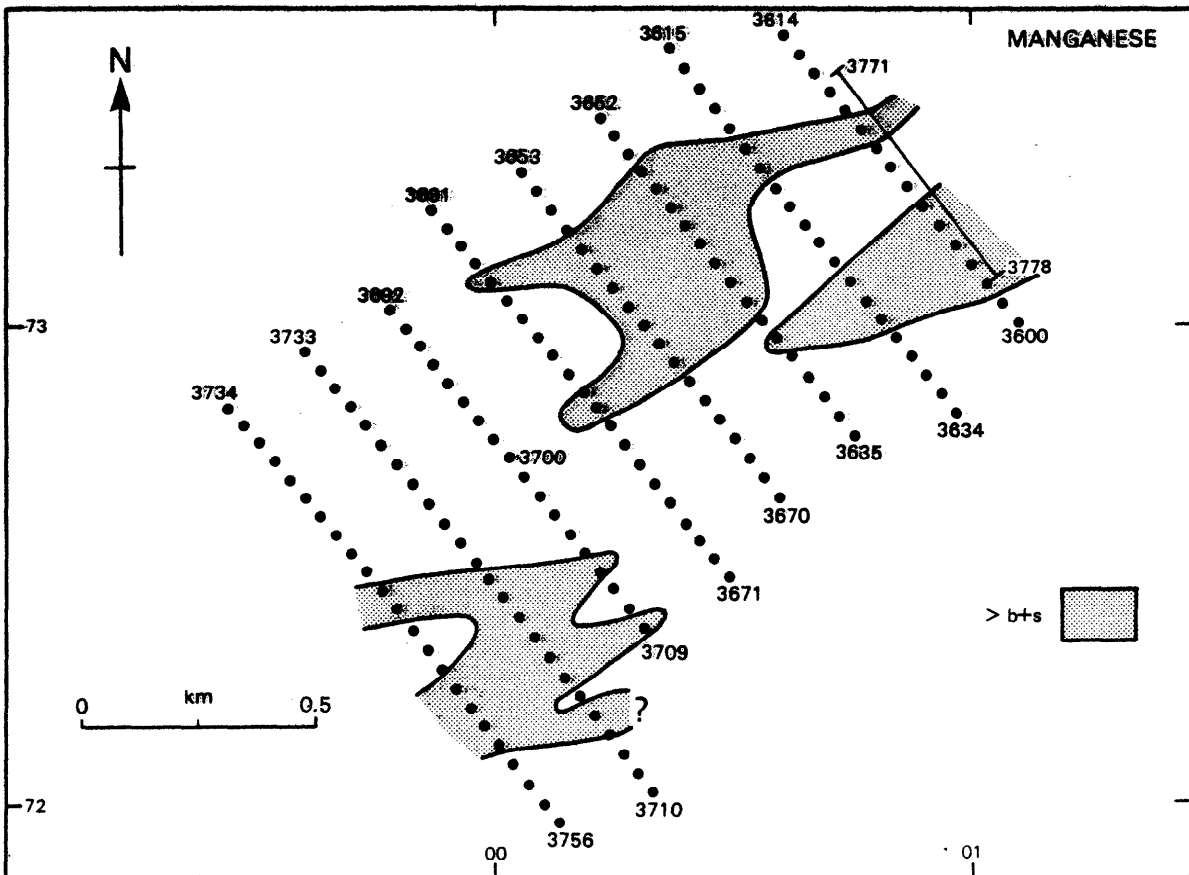


Fig. 4b Distribution of manganese—Todridge Fell and Grindstonelaw

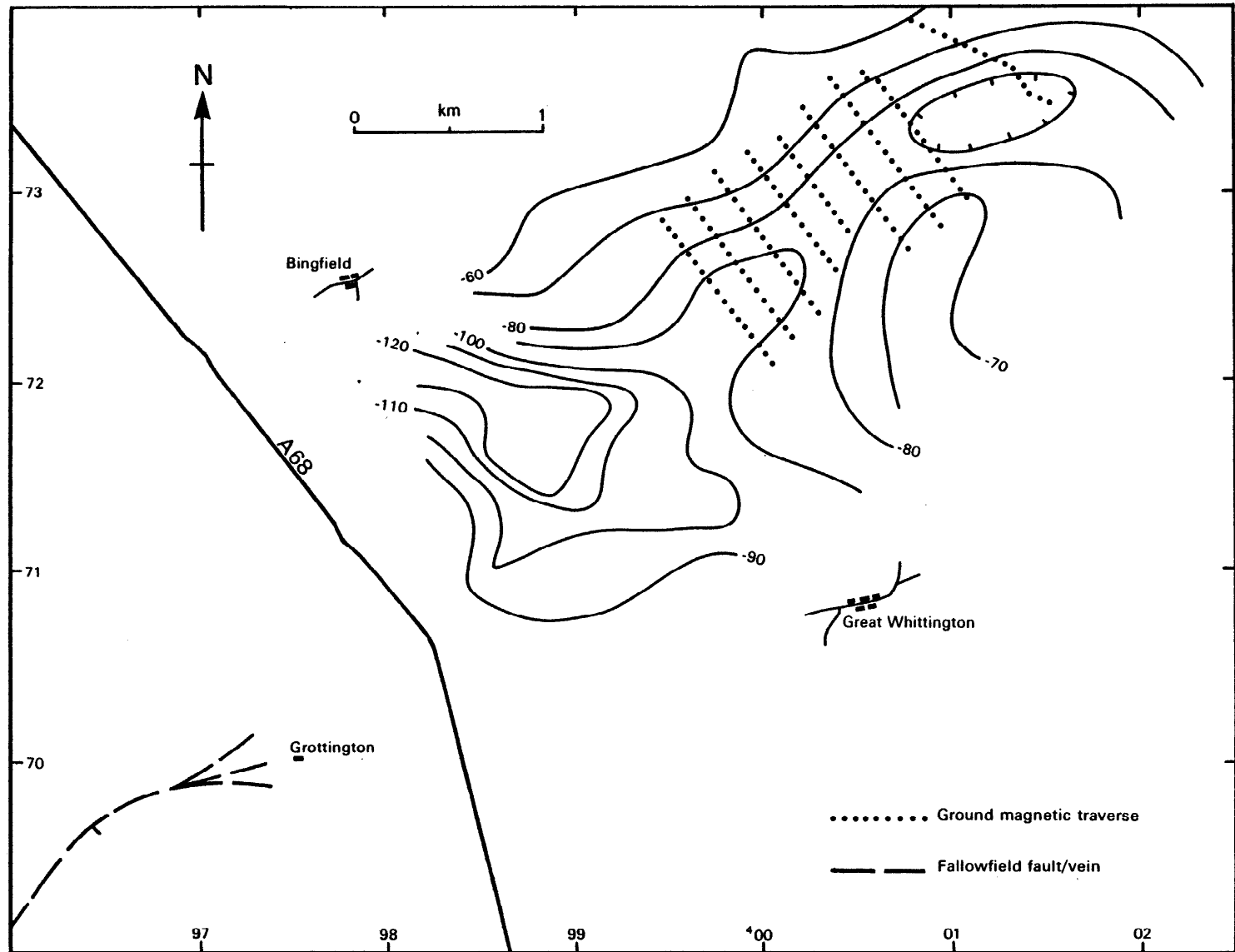


Fig. 5 Contours of aeromagnetic anomaly (values in nT) for the Todridge Fell and Grindstonelaw area and location of ground magnetic traverses

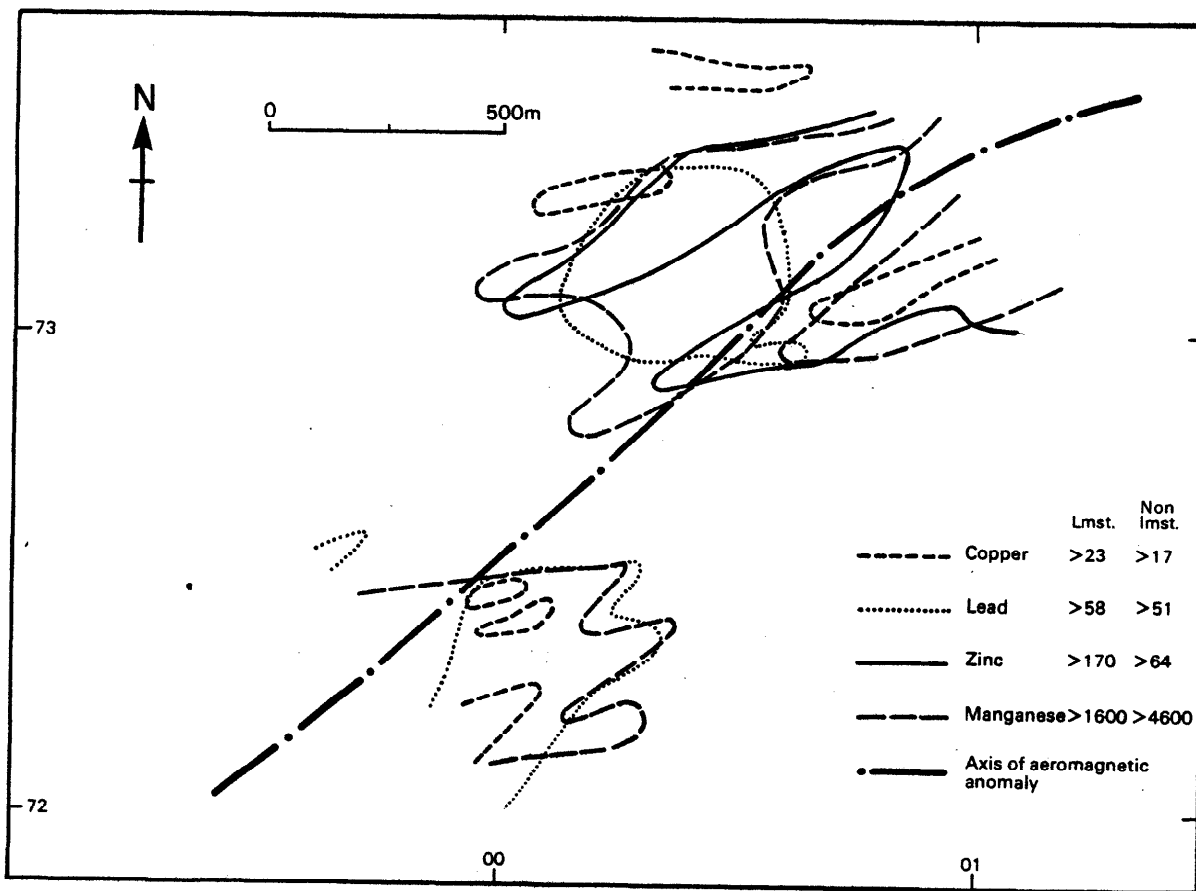


Fig. 6 Combined geochemical and geophysical anomalies—Todridge Fell and Grindstonelaw

	Copper		Lead		Zinc		Manganese	
	Lmst	Non-Lmst	Lmst	Non-Lmst	Lmst	Non-Lmst	Lmst	Non-Lmst
b	16	10	41	36	108	48	790	790
b + s	23	17	58	51	170	64	1600	4600
b + 2s	34	30	82	73	280	85	3200	(10000+)
Range of values	1-26	0-31	17-128	13-113	2-174	5-297	3-459	1-499

Geophysical survey

The aeromagnetic contours (total field) are shown in Figure 5, at 10nT intervals; the NE-trending negative anomaly is clearly seen. There is a sharp change in trend at the NE end of the anomaly, but this is not adequately defined as it occurs where the anomaly reaches the boundary of the airborne survey area. The southern part of the anomaly is disturbed by a separate anomaly, running ESE from Bingfield, this anomaly being the combined effect of the Whin Sill displaced by the Barrasford Fault, and of the Tertiary Bingfield Dyke which is intruded along that fault (Frost and Holliday, 1980).

The ground magnetic survey covered the central portion of the NE-SW anomaly, with the SW-most traverse located c. 6 km from the nearest well-developed part of the Fallowfield Mine at Codlaw Hill. Traverse locations are shown in Figure 5.

Discussion

Geochemical results

A compilation map (Figure 6) indicating main areas of anomalous geochemical values (at the > b + s level) shows that the higher values lie in two distinct areas. Both of them are closely related to the areas underlain by the Great Limestone - the more northerly grouping coinciding with the outlier of this limestone and the anomalous group to the SW with a part of the main crop of the Great Limestone.

In detail the distribution of the high values for Cu, Zn and Mn in the more northerly of the anomalies shows SW/NE linear trends which are parallel to, but some 200 m to the north of, the margin of the zone of low magnetic values.

Values from deep till samples collected along a single traverse some 50 m to the north of the main sample grid show a distribution of maximum values that is different from those identified from the soil survey data (Figure 7). Not only is the range of values for Zn, Pb and Cu in the till samples greater than in the soils but also the positions of the maxima with respect to the boundaries of the magnetic low zone are different, tending in the tills to be further away from the zone margins.

It is not possible on the basis of these limited till data to draw any firm conclusions but it does not seem that the till data are more useful than the data obtained from the shallow soil samples.

In addition to the analysis for selected metal elements, the soil gas in the deeper holes was analysed for radon - the most significant value

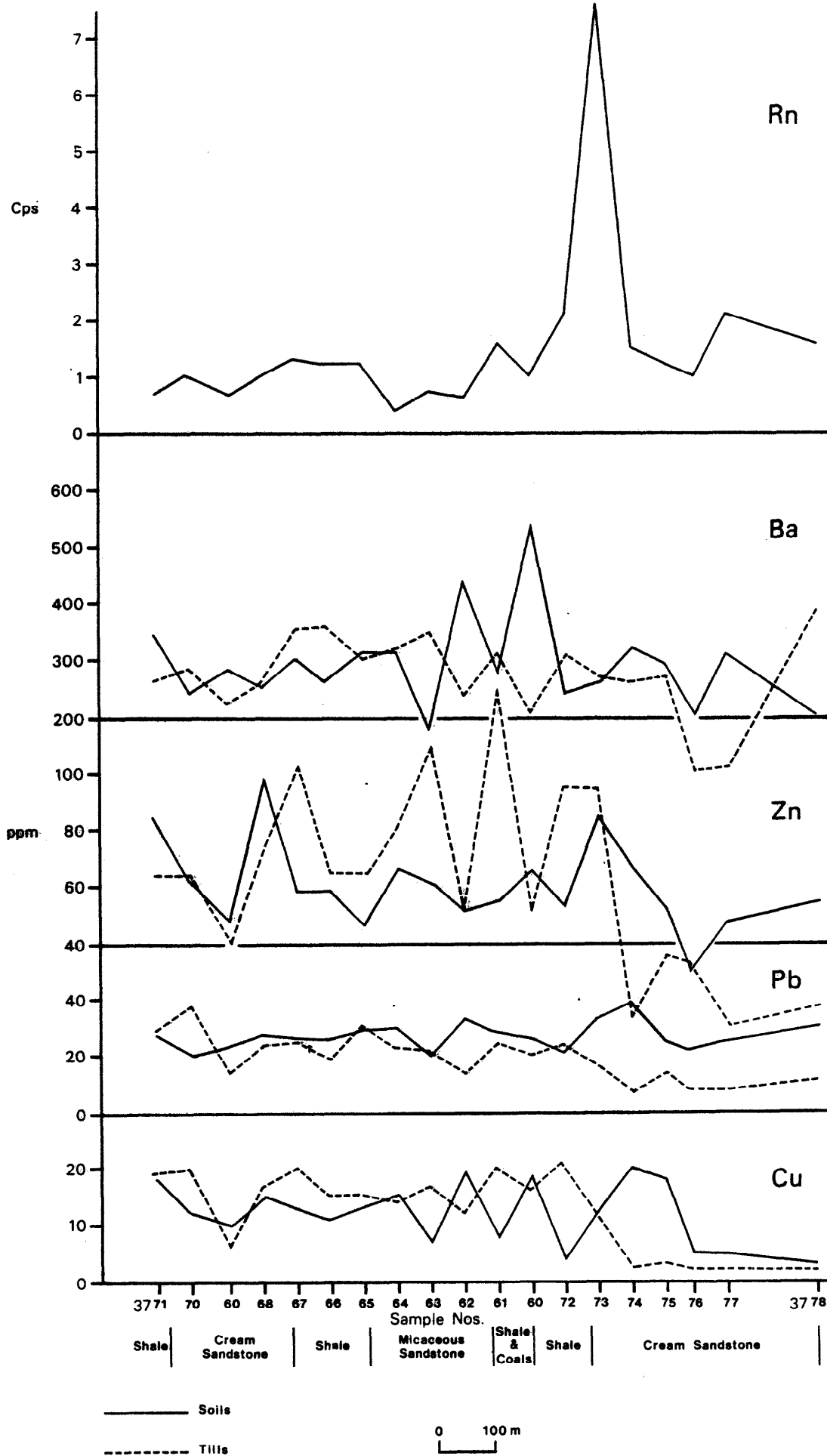


Fig. 7 Distribution of copper, lead, zinc, barium and radon in soils and tills—Todridge Fell and Grindstone law

occurring approximately 150 m from the zone margin, where a value of 7.6 cps was recorded (in contrast to a background level of 1.4 cps). The cause of this anomaly is uncertain but it may represent Rn degassing, via the fault structure interpreted from the geophysical data.

Geophysical results

The ground traverses confirmed the location and trend of the magnetic anomaly indicated by the airborne data. The ground and airborne anomalies are comparable in terms of amplitude and wavelength, suggesting a distance from source (i.e. the Whin Sill) of 300-400 m. A depth of this order is consistent with depths estimated from the average separation of the Great Limestone and Whin Sill in the local succession. As the anomaly is negative, and approximately symmetrical, a S-downthrow fault in the Whin Sill is indicated as a probable cause, by analogy with the Newbrough anomaly (Bateson and others, 1984). The fault occupied by the Fallowfield Vein also throws down to the south, supporting the suggestion that an extension to this structure has been located. The magnetic anomaly is too broad for the position of its axis to be accurately defined, and use of the magnetic data to site boreholes accurately to intersect the indicated fault in the Whin Sill would not be possible.

Conclusions

The geochemical anomalies defined in this area, although demonstrating in broad terms a positive relationship to the Great Limestone (most markedly shown in the case of lead), in detail show also a linear distribution spatially related to the margins of the area of low magnetic values. It seems, therefore, reasonable to conclude that the results indicate mineralisation associated with a faulted zone affecting the Whin Sill at depth, as suggested by the magnetic data. Although not conclusive, the high values of Rn in soil gas (from a single traverse only) may also be interpreted as indicating the presence of a fault structure at depth along which the gas migrates.

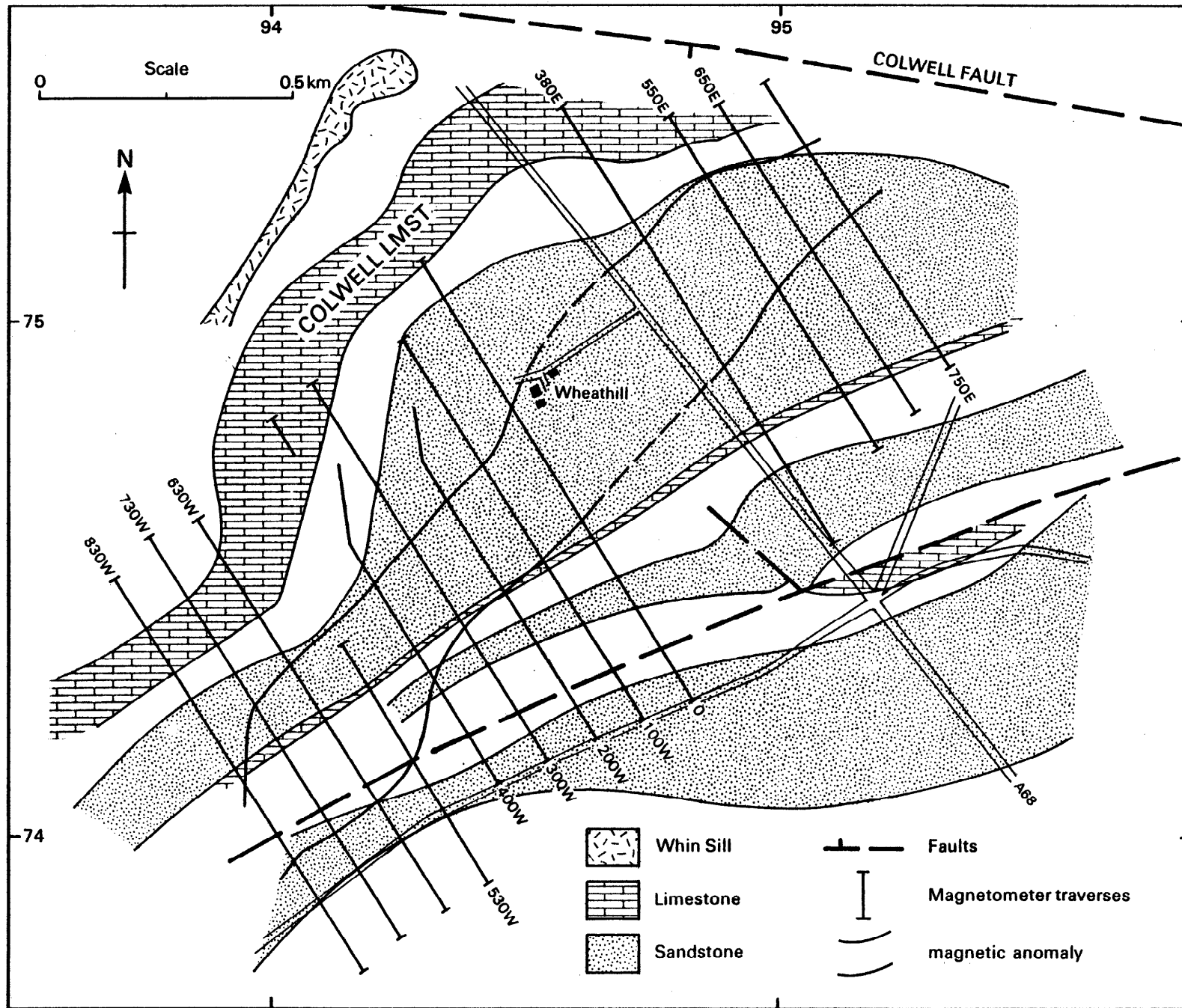
The type and extent of any mineralisation cannot be determined from the available data; this can only be achieved by drilling to intersect the Whin Sill where it is affected by faulting - at a depth likely to be in excess of 300 m.

WHEATHILL

Introduction

The follow-up work undertaken at Wheathill was the direct result of the assessment of the airborne magnetic data, which revealed a negative magnetic anomaly several km in length trending through the area in a NE-SW direction, (Figure 12). There are no mapped geological features with this trend in the immediate vicinity. Evans and Cornwell (1981) suggest the possibility of NE-trending structures in south Northumberland contributing to the control of mineralisation, and point out that the Wheathill anomaly may be due to such a structure. It is also notable that the magnetic anomaly lies very close to the extensive linear feature identified on the Landsat imagery (Bateson, 1985) along which are distributed a number of mineral veins.

Fig. 8 Geology of Wheathill, and location of magnetic traverses and anomaly



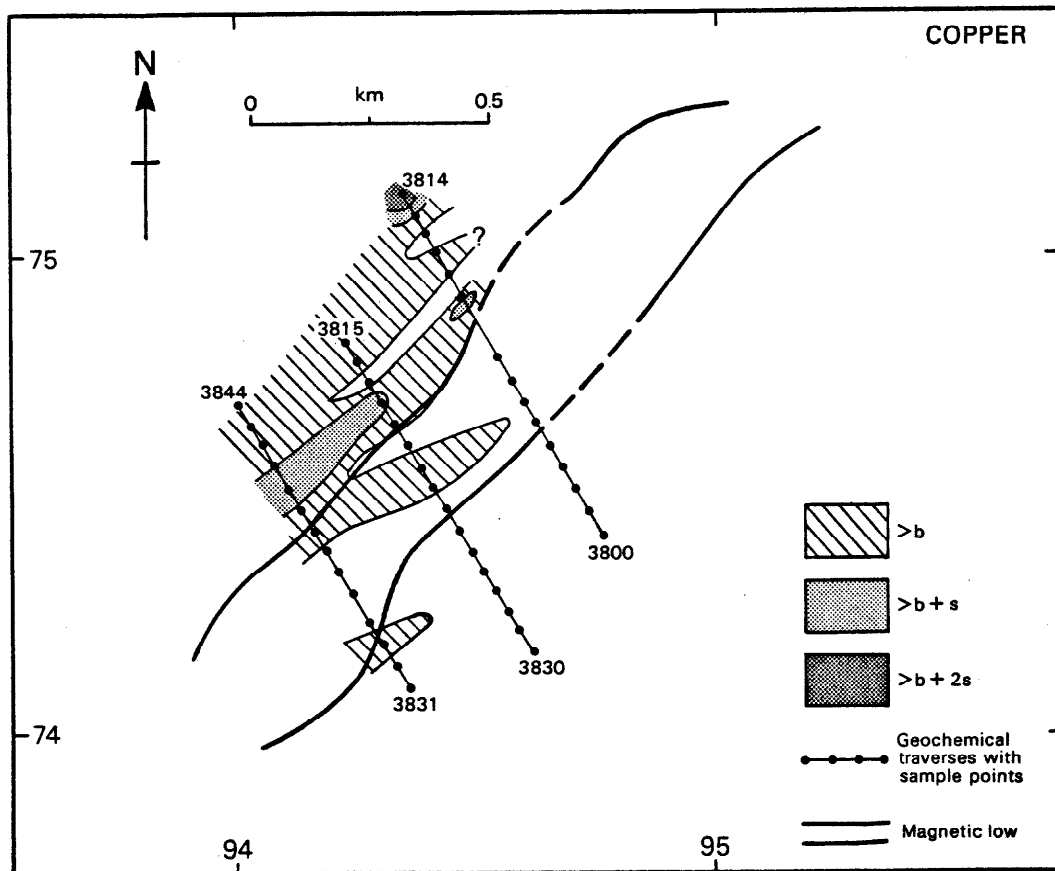


Fig. 9a Distribution of copper—Wheathill

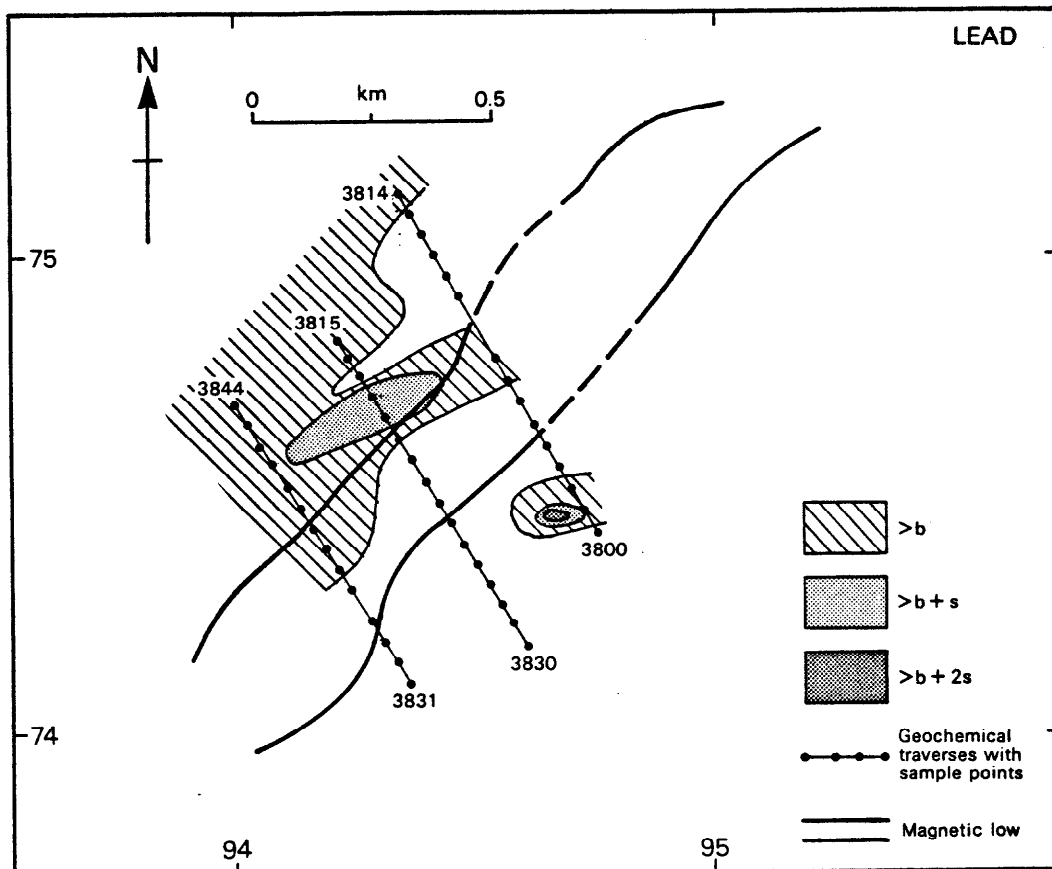


Fig. 9b Distribution of lead—Wheathill

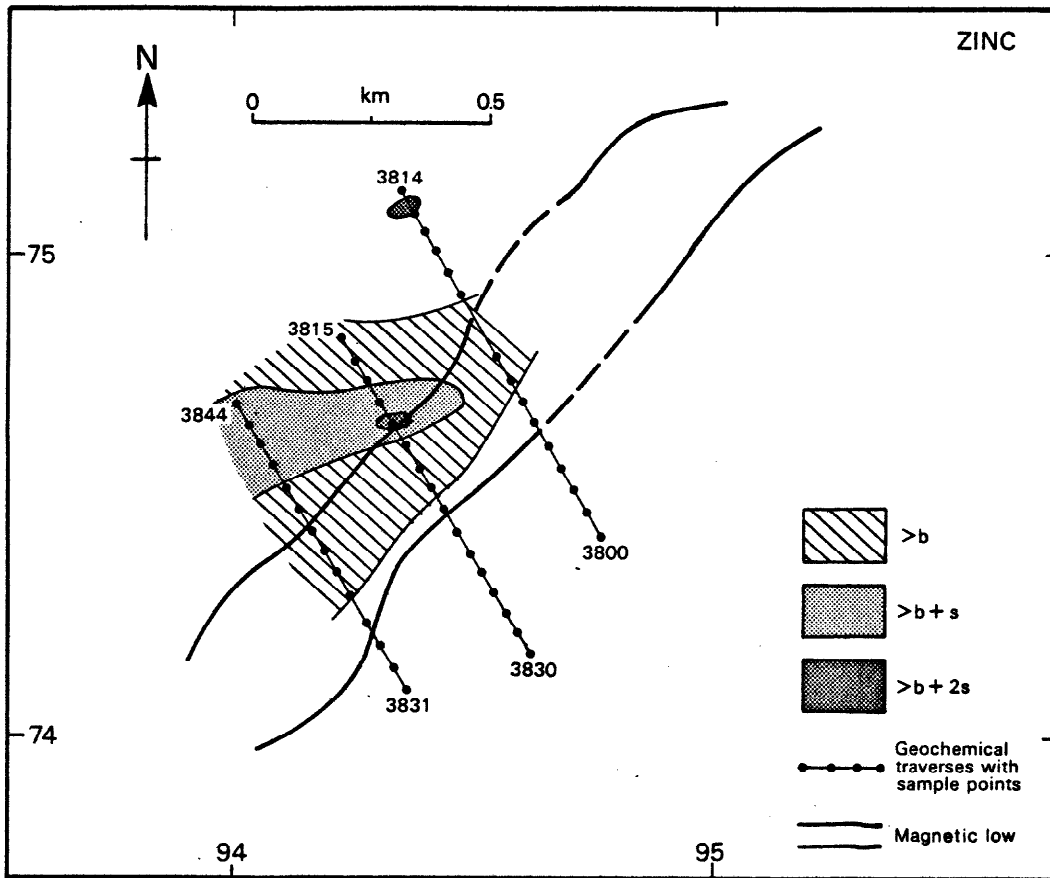


Fig. 10a Distribution of zinc—Wheathill

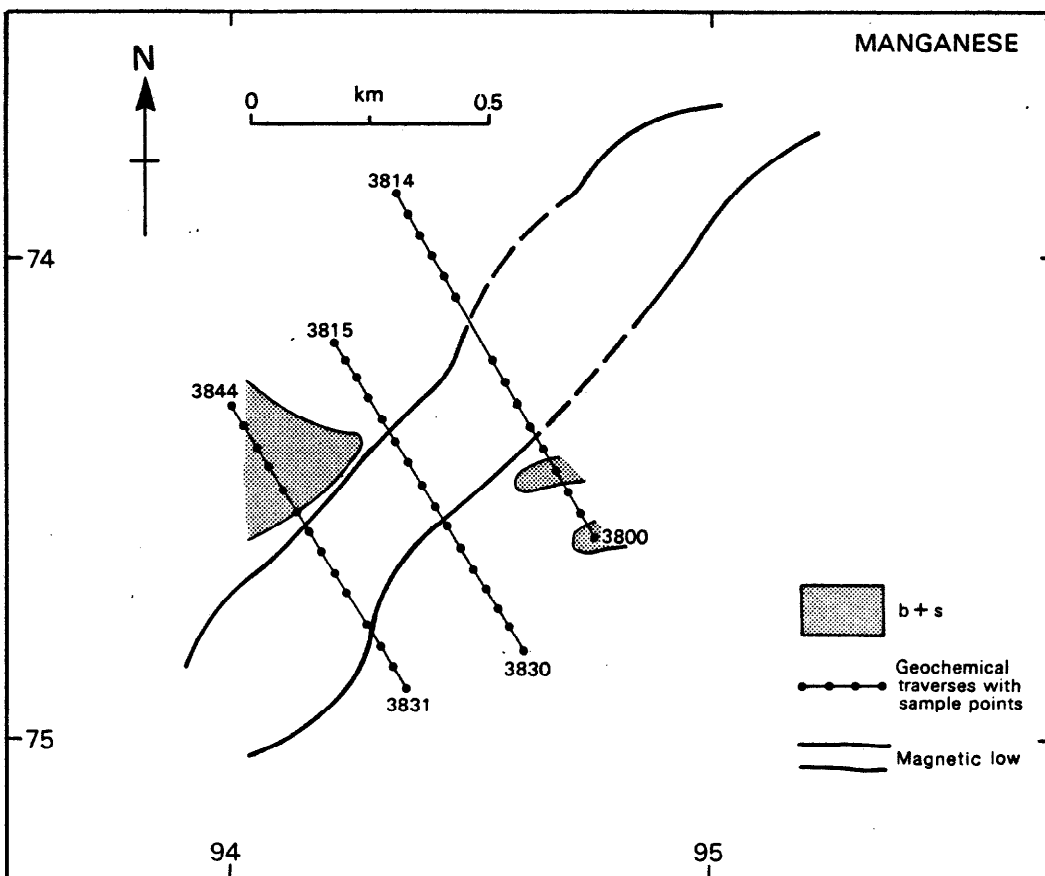


Fig. 10b Distribution of manganese—Wheathill

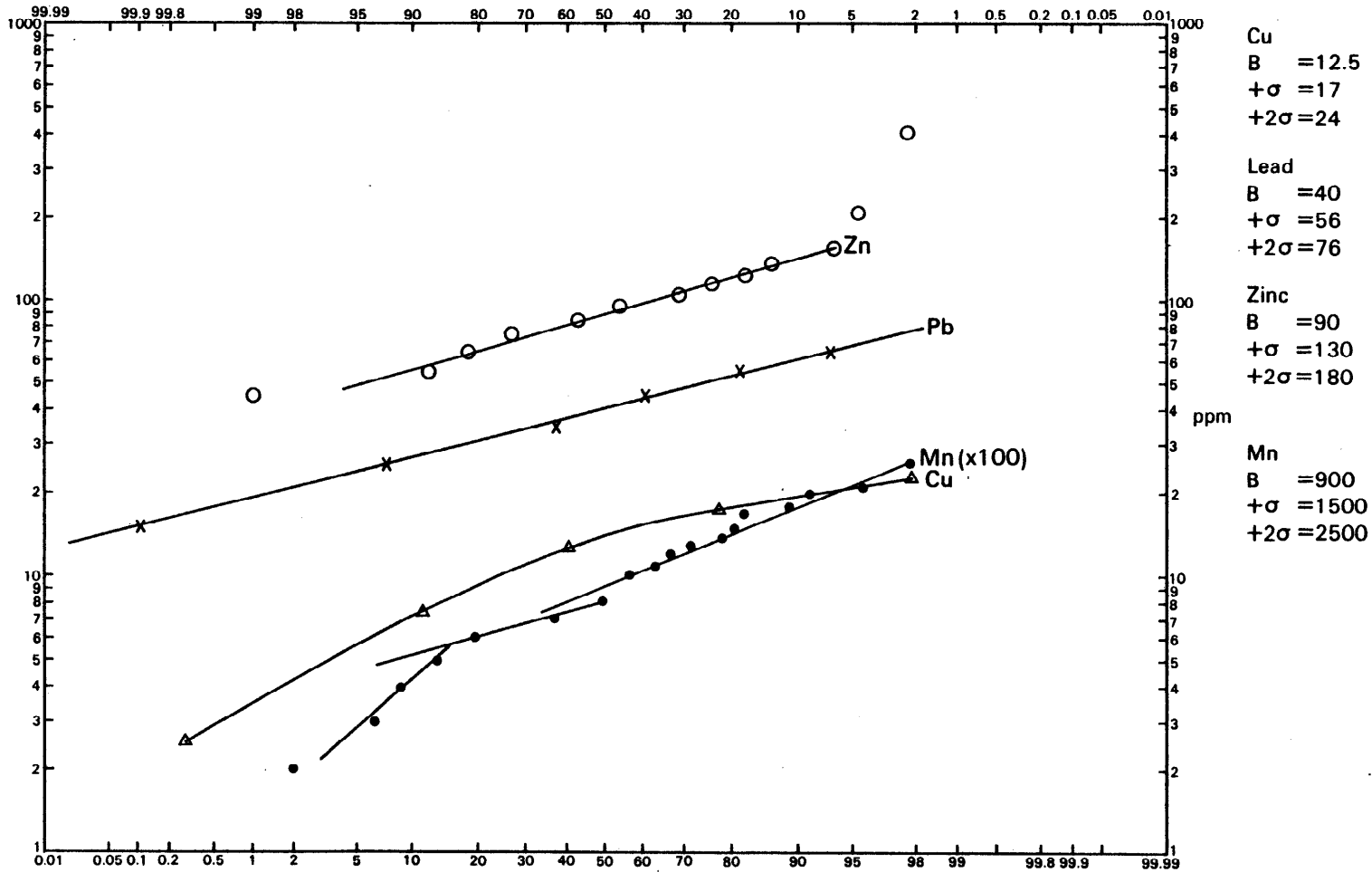


Fig. 11 Cumulative frequency curves for copper, lead, zinc and manganese—Wheathill

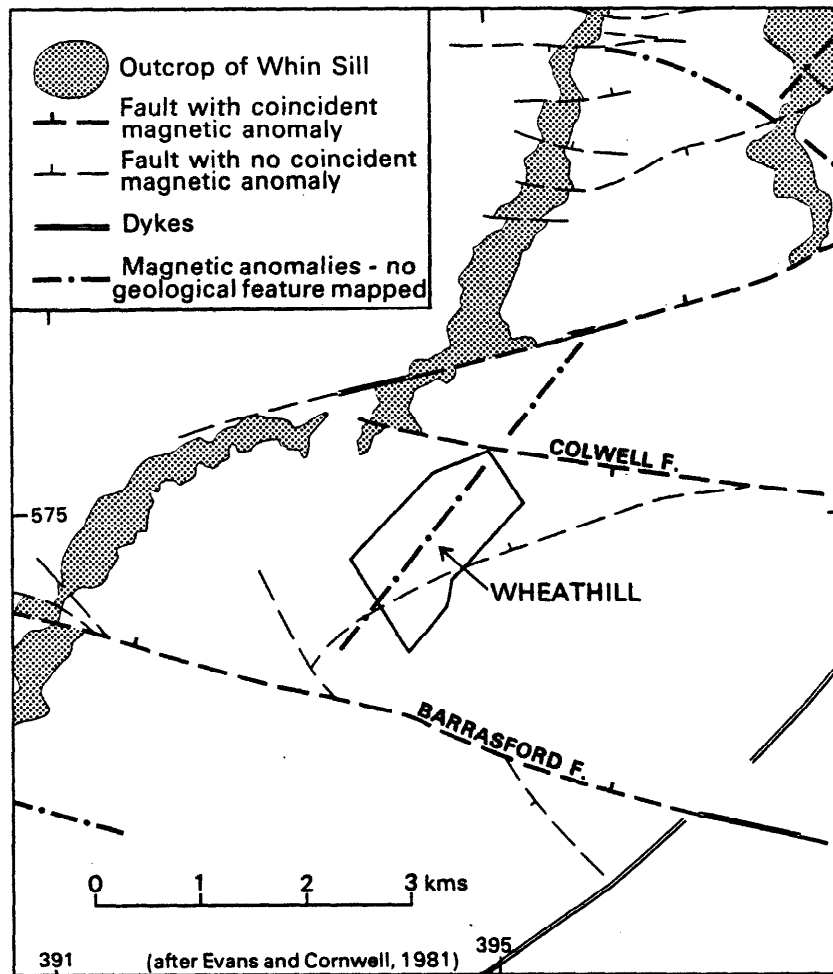


Fig. 12 Relationship of Wheathill area to aeromagnetic features

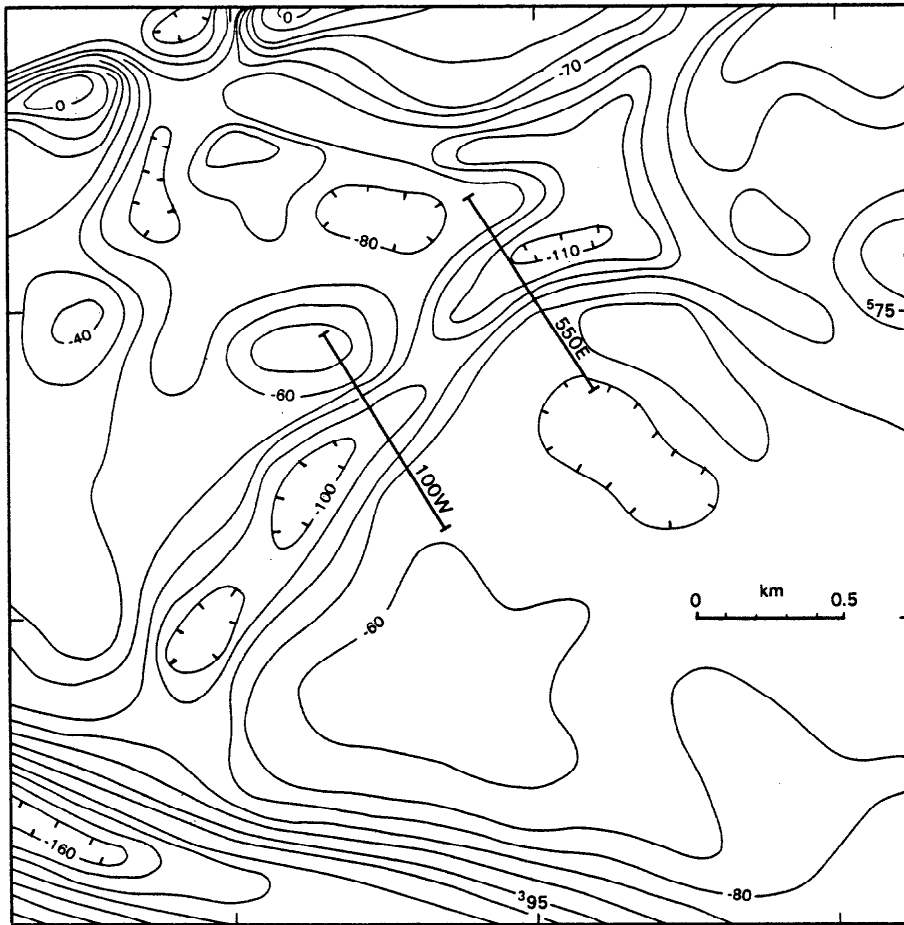


Fig. 13a Contours of airborne magnetic anomaly (10 nT interval) – Wheathill

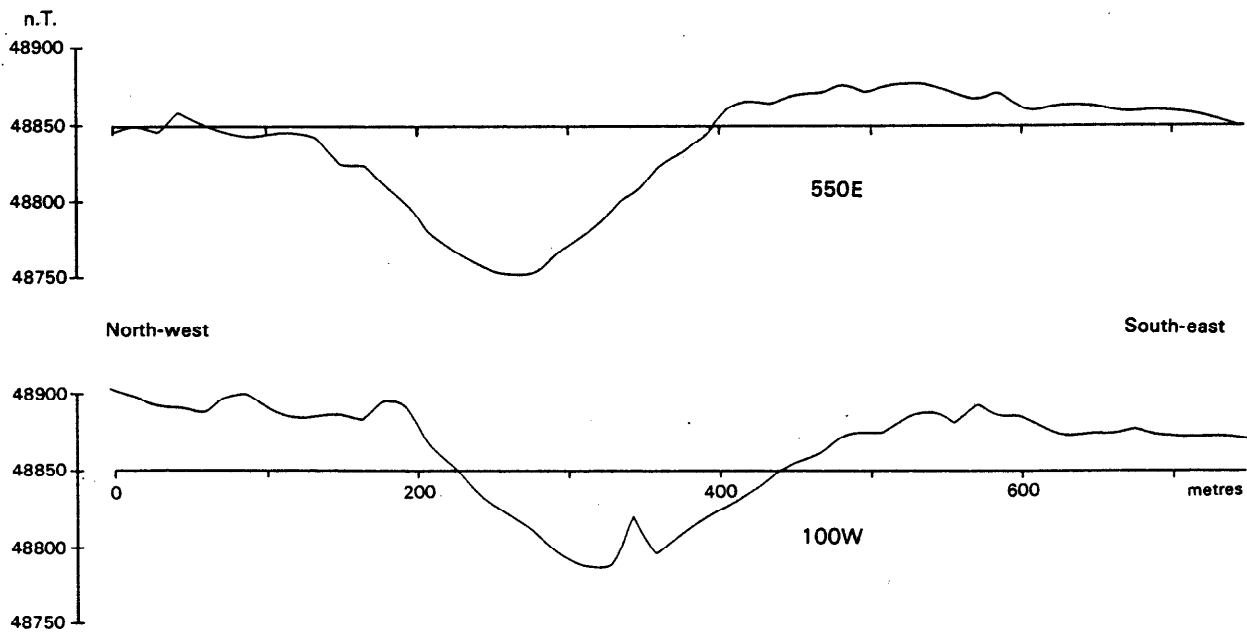


Fig. 13b Magnetic profiles for traverses 550E + 100W – Wheathill

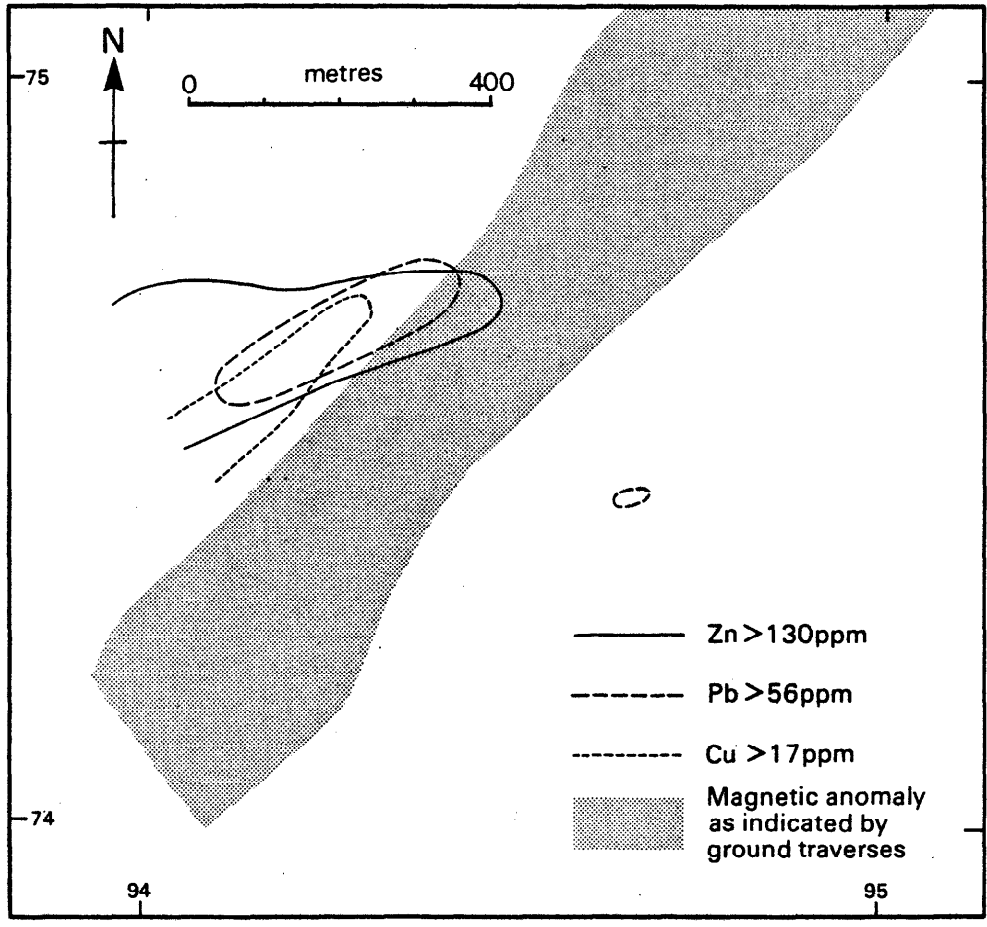


Fig. 14 Combined geochemical/geophysical anomalies—Wheathill

Geology

The geology of the area of investigation is taken from the 1:50 000 Sheet 13 Bellingham (Figure 8).

Three sandstones within the Upper Liddesdale Group (Dinantian) are separated by thin limestones and shale horizons. Just to the north of the area sampled the more persistent Colwell Limestone occurs. The sediments have a south-westerly strike with a shallow dip to the SE. The area lies between the Colwell Fault in the north and a NE-trending fault that merges with the Colwell Fault a kilometre or so to the east of the area; these faults are shown as having their downthrow side in opposite directions, to form a graben structure.

Geochemical survey

Soil samples for analysis were collected from centres 50 m apart along three lines oriented approximately normal to the trend of the magnetic anomaly.

The soil samples collected from beneath the humus-rich upper horizon, by hand auger, were analysed by XRF techniques for 15 elements, at the BGS laboratories, of which Cu, Pb, Zn and Mn have been considered in detail.

For each of these elements the values for the total population have been plotted on a cumulative frequency graph, from which the values of b, b + s and b + 2s were determined (at the 50%, 84% and 97.5% population levels). These values (in ppm) are given in the table below and were used to produce contour maps of the data (Figures 9, 10).

	Copper	Lead	Zinc	Manganese
b	12.5	40	90	900
b + s	17	56	130	1500
b + 2s	24	76	180	2500

The cumulative frequency curves (Figure 11) indicate that the data may be considered as single populations; variations in the bedrock geology do not appear to have a significant effect upon the geochemical characteristics.

Geophysical survey

The airborne magnetic anomaly is some 4 km in length, with an indication of a continuation a further 3 km to the NE (Figure 12). Figure 13a shows that to the south the anomaly is terminated against a strong ESE anomaly (due to the Barrasford Fault and Bingfield Dyke), while further north it is disturbed by the anomaly due to the Colwell Fault. The ground survey was, therefore, restricted to the area around Wheathill. Traverse locations are shown in Figure 8.

Discussion

The ground survey magnetic data confirm the location and trend of the airborne anomaly. Typical profiles are shown in Figure 13b. The limits of the magnetic low are clearly seen, and the anomalous zone thus delimited is shown on Figure 8. The magnetic data are consistent with a displacement of the Whin Sill by a fault with a downthrow to the south; the well-defined

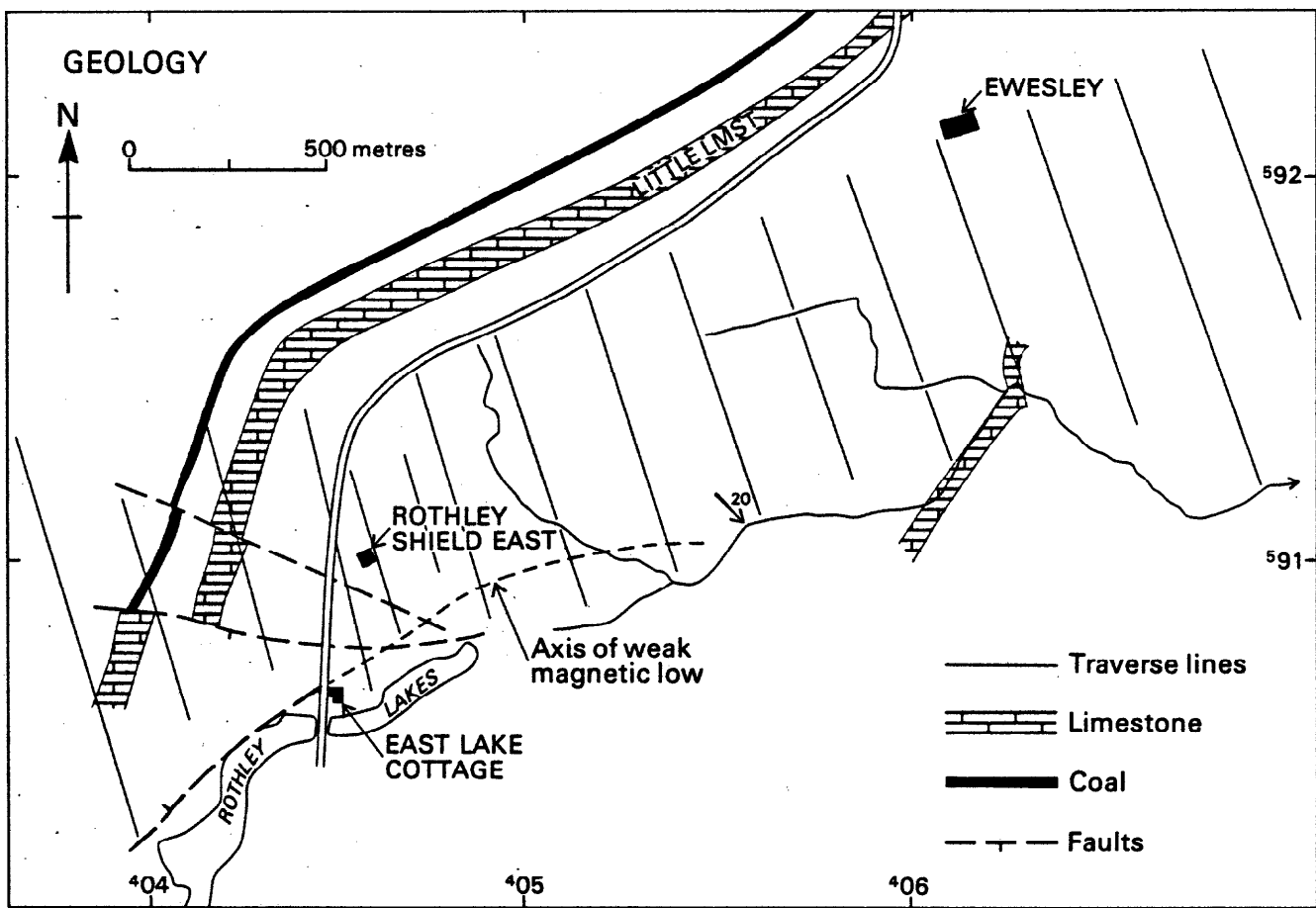


Fig. 15 Geology of Ewesley area

symmetrical anomaly is analogous to that tested at Newbrough (Bateson and others, 1984). A WSW trending fault which passes through the southern part of the survey area (Figure 12) cannot be configured to intersect the sill beneath the magnetic anomaly, and it is therefore concluded that the cause of the anomaly is an additional fault that has not been recognised at the surface. It is of interest that this would occur where there is a considerable thickening in the mapped outcrop of the sandstone, which could be due to repetition by faulting.

The geochemical data for the area, when contoured, identify well-defined anomalous zones for each of the elements which show good spatial correlation with each other (Figure 14).

The geochemical anomalies occur along a trend that parallels the strike of the low magnetic zone, and lie just to the NW of the zone which coincides with the lower part of the main sandstone unit that underlies much of the area investigated.

Values for the four elements examined are generally at levels similar to those obtained at Todridge Fell and Grindstonelaw and also in the case of the Pb and Zn of a similar order to those obtained from Newbrough, Settlestones (Bateson and others, 1983) and Brown Moor. From this limited investigation it has not been possible to close any of the anomalies to the SW.

Conclusions

It seems likely that, as was found both at Newbrough (Bateson and others, 1983) and Brown Moor (see p. 29 this report), the zone of low magnetic values represents the effect of faulting (with downthrow to the south) with possibly some alteration and demagnetisation, in the Whin Sill. As in the two previously cited examples such changes are likely to result from the passage of mineralising fluids which it would seem in this case have moved up dip through the lower part of the sandstone to reach the surface soils.

The extent and quality of any mineralisation in this structure cannot be determined from the present data. A series of exploratory diamond drill holes would be required to furnish this information.

EWESLEY

Geology

The geology of this area is generally very poorly exposed, but outcrops in small tributaries flowing to the Ewesley Gill reveal a succession of sandstones and shales of the Upper Limestone Group, dipping gently to the SE (Figure 15). Thin coal seams occur in the NW of the area; minor barium mineralisation is known from joints and small veinlets in some of the exposures.

Geochemical survey

A small area to the SW of the original sample area (Bateson and others, 1983) at Ewesley was included in the follow-up work in the Northumberland Trough in order to close the anomalies defined by the earlier work. Soil samples were collected at 50 m intervals along four traverses approximately 250 m apart oriented NNW.

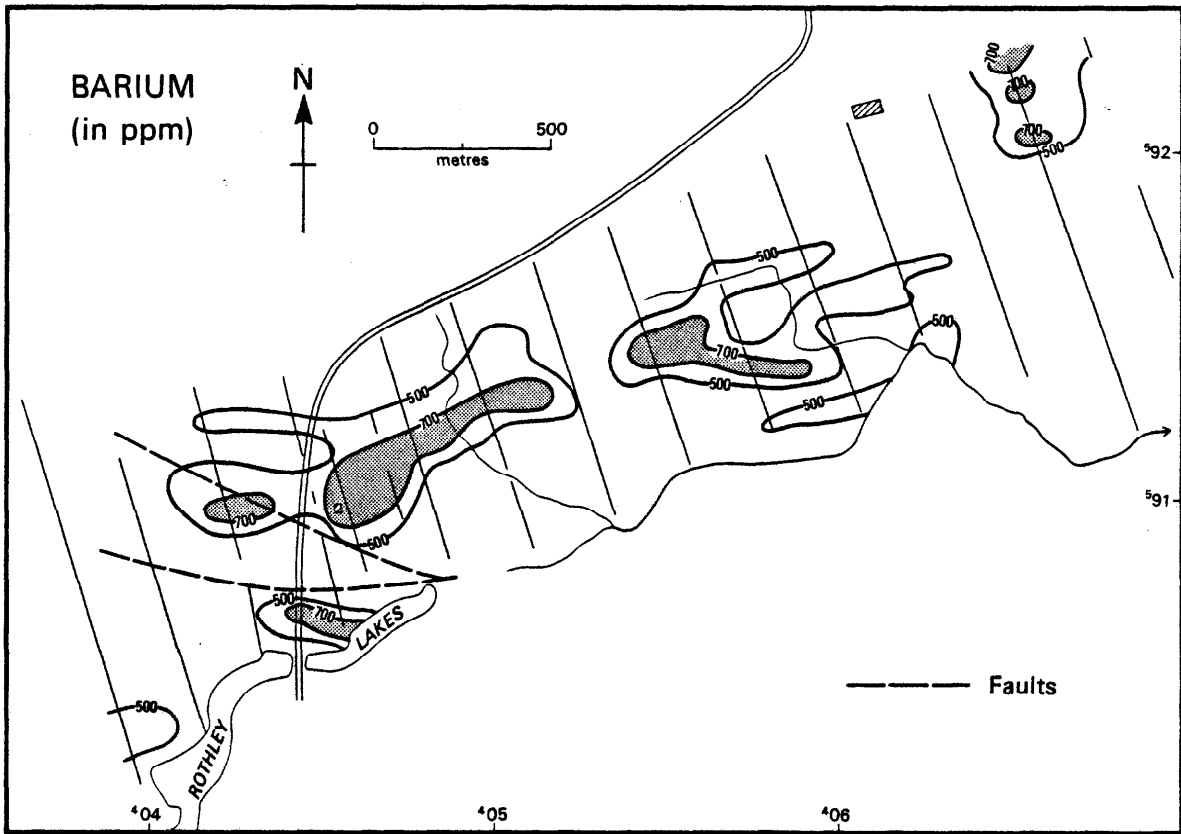


Fig. 16a Distribution of barium—Ewesley

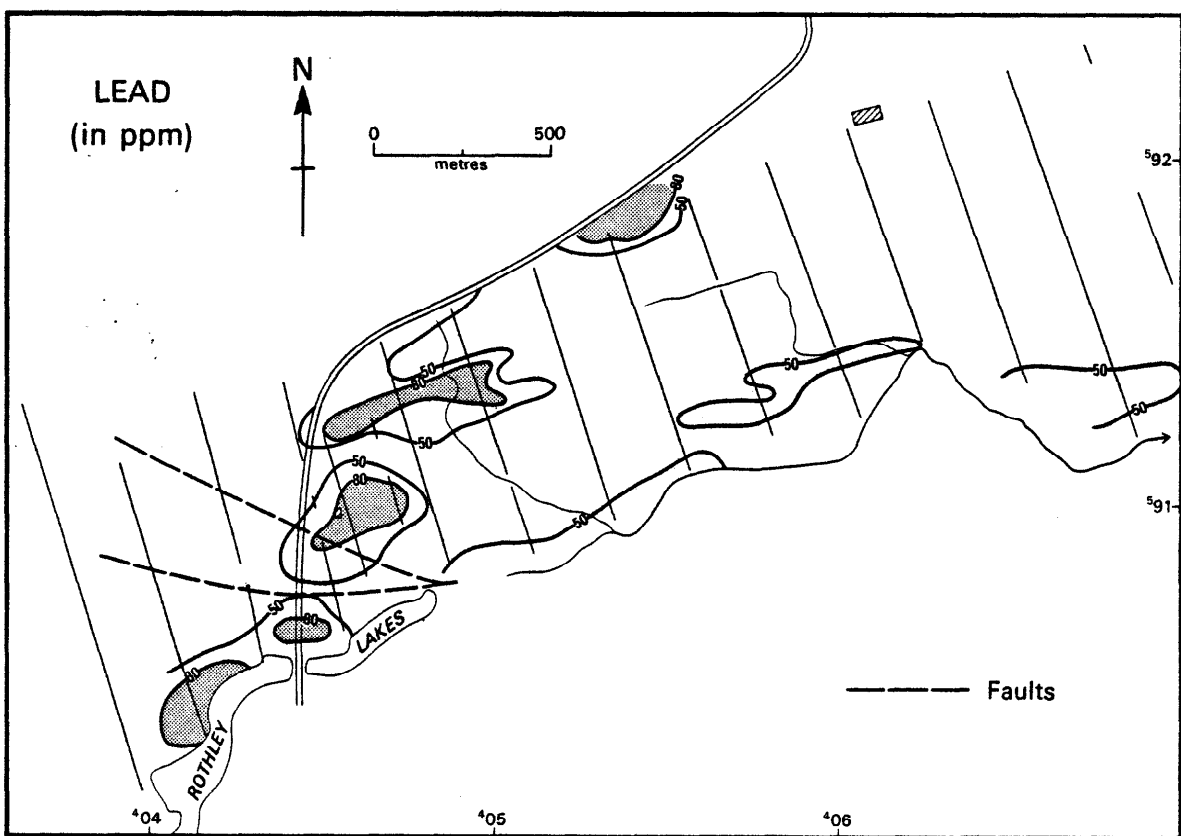


Fig. 16b Distribution of lead—Ewesley

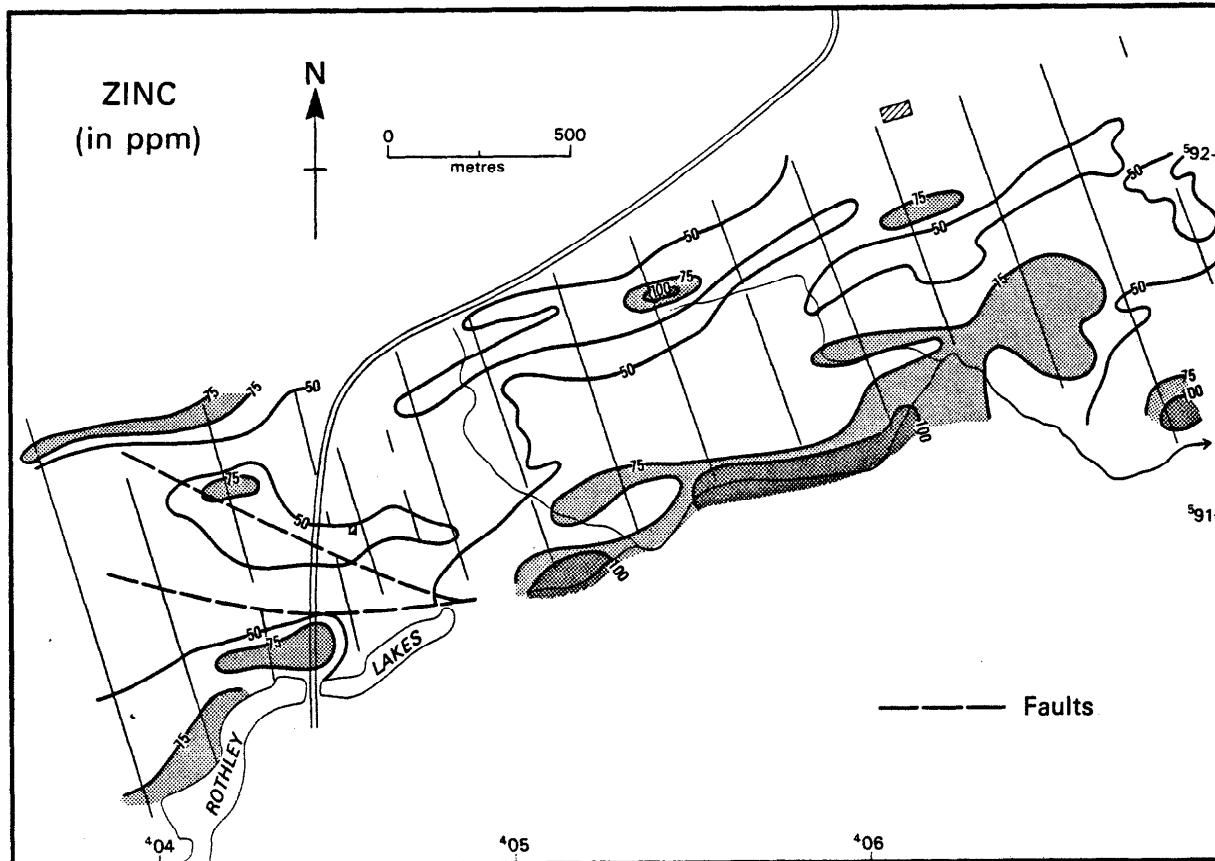


Fig. 17a Distribution of zinc—Ewesley

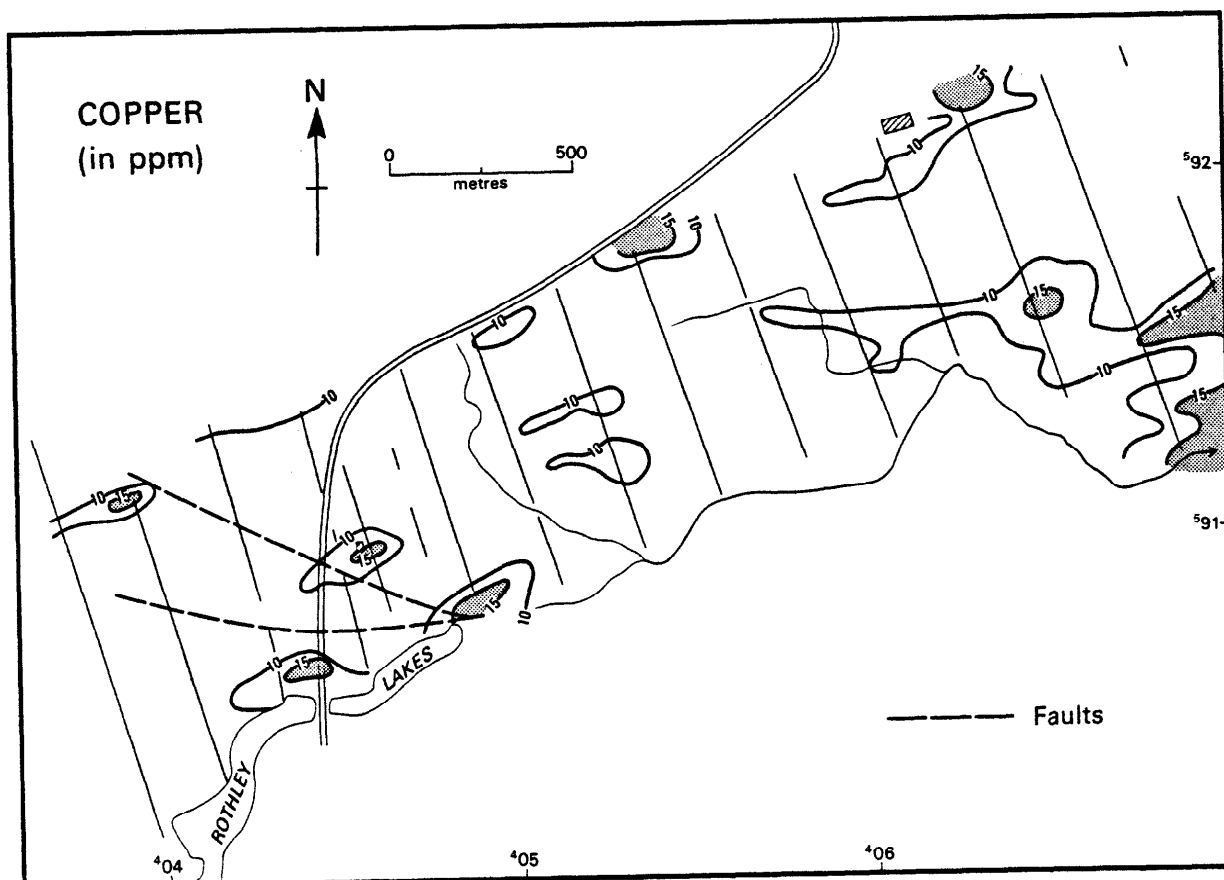


Fig. 17b Distribution of copper—Ewesley

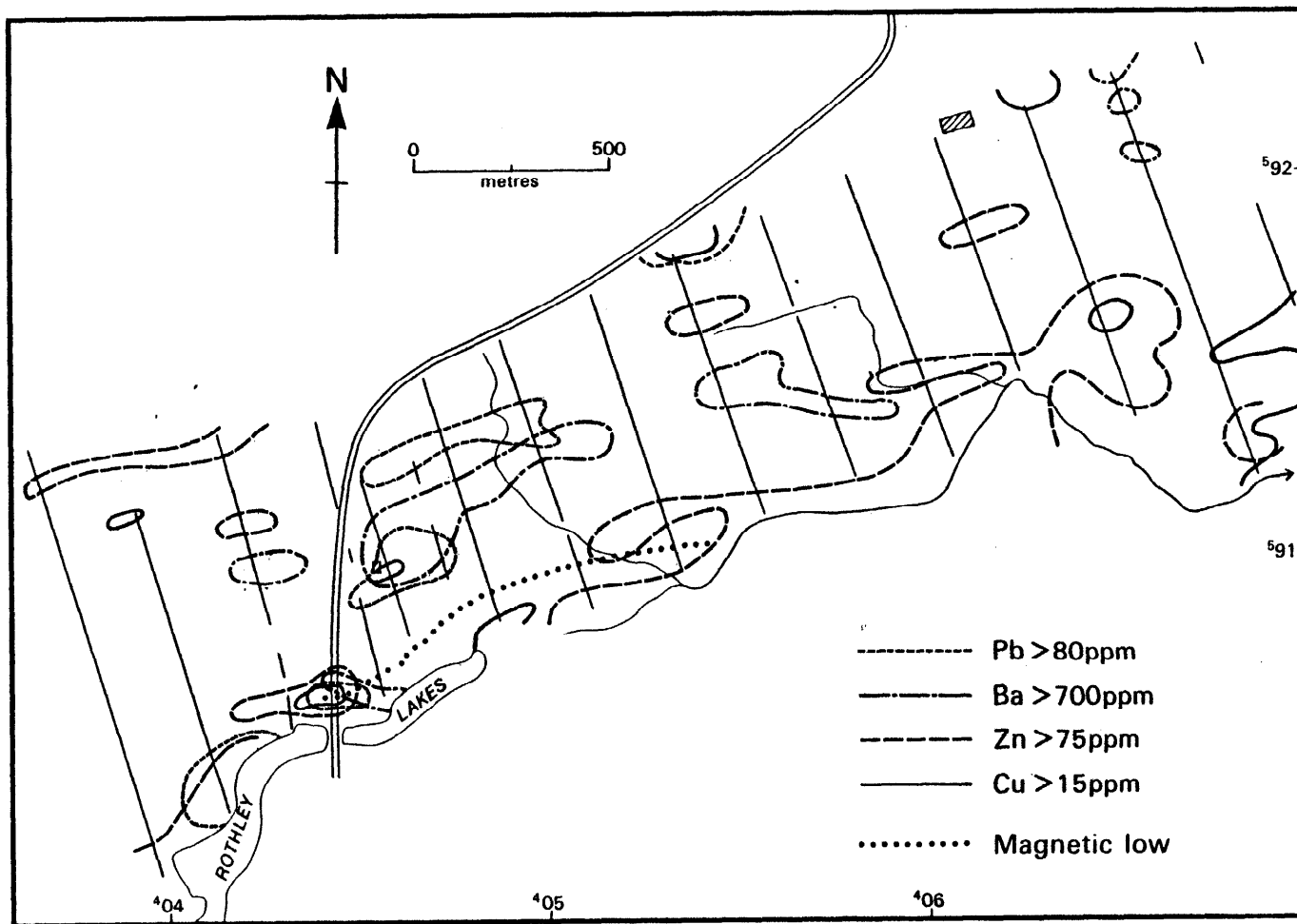


Fig. 18 Combined geochemical/geophysical anomalies—Ewesley

Table 1 Summary statistics, follow-up soil samples, Ewesley (in ppm)

	No. of samples	Pop.	%	b	b + 2s	b - 2s
	70					
Barium		A	76	310	480	210
		B	18	630	600	540
Lead		A	94	35	72	9
		B	6	170	230	140
Zinc		A	97	44	125	15
		B	3	215	-	-
Copper		A	93	6.5	23	2
		B	7	27	34	21

The soils were analysed by XRF techniques for 18 elements, of which Ba, Pb, Zn and Cu are reported here (Figures 1, 16, 17; Table 1).

Barium (Figure 16a)

The population ranges in value from 180 ppm to 2.4% Ba; cumulative frequency plots of the data show two distinct populations, the lower of which represents 76% of the samples with a background value of 310 ppm and a (b + 2s) value of 480 ppm. Values for Ba in excess of this figure occur as isolated samples with the exception of two small groups that are found in the most southerly part of the soil area close to the lake side.

Lead (Figure 16b)

Although a cumulative frequency plot indicates that there are two populations for the Pb distribution, the higher of these represents only 6% of the sample population, with the three samples that make up this data set each having values in excess of 120 ppm. The distribution of those samples with values in excess of 72 ppm (the b + 2s value of the larger population) occur close to the NW shore of the Rothley Lakes - and are mainly in the areas enclosed by the 80 ppm contour.

Zinc (Figure 17a)

The zinc data partition into two very unequal populations, the higher one of which represents only 2.8% of the total population. The larger population has a background level of 44 ppm with anomalous values (b + 2s) defined in excess of 125 ppm. The highest values for zinc in this follow-up area are found in the area immediately to the north of the Rothley Lakes.

Copper (Figure 17b)

Values for copper are low, 80% of the population containing less than 10 ppm. The partitioning of the copper data shows that some 83% of the population fall in the main group with three samples only (5%) comprising a highly anomalous minor population. The larger population has a background value of 6.5 ppm and an anomaly level (b + 2s) of 23 ppm which accounts only for 5% of the total population. The highest values lie in a small area in the area north of the Rothley Lakes.

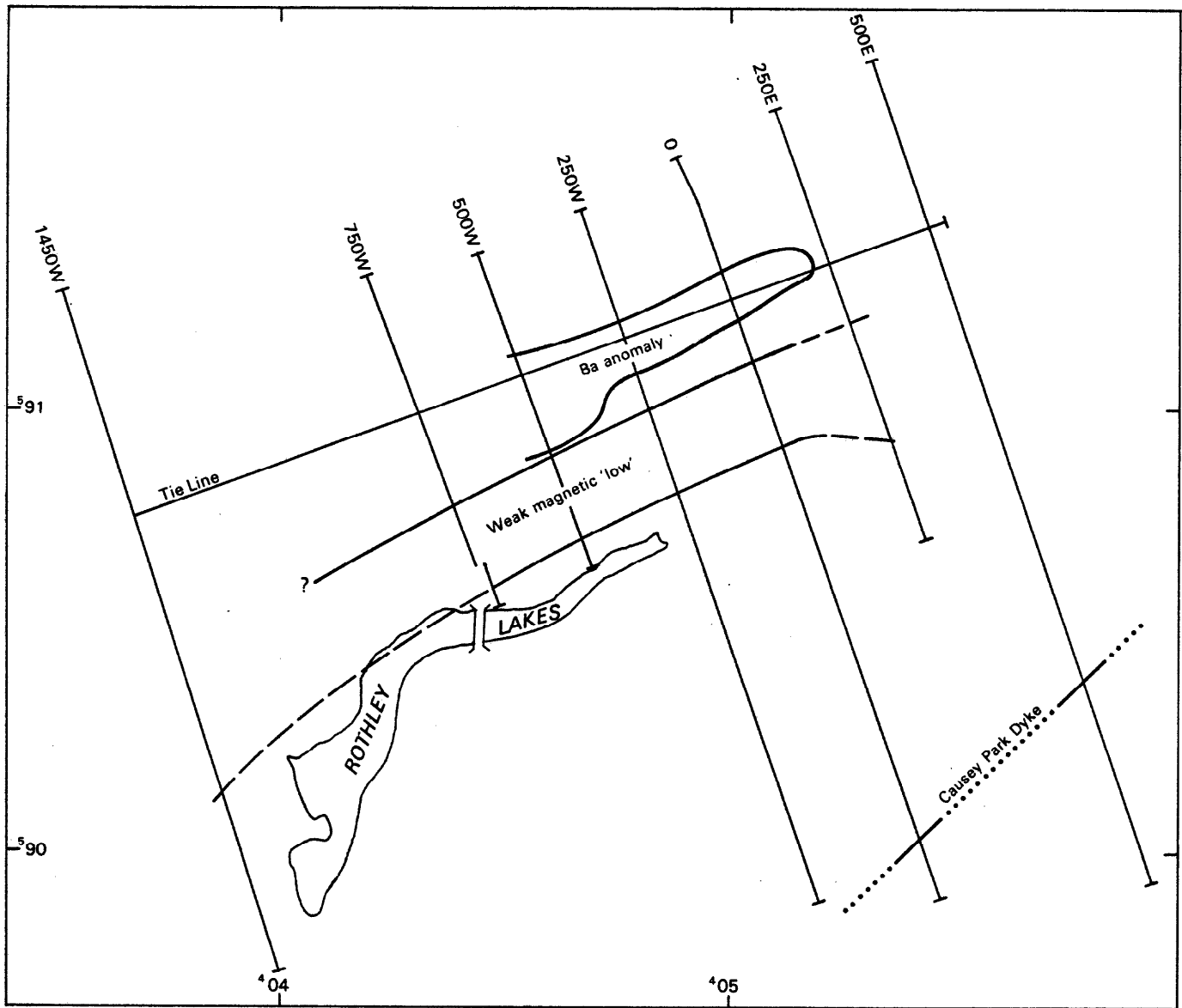


Fig. 19 Relationship of magnetic low to main barium anomaly – Ewesley

Synthesis

The contoured figures (16 and 17) show the distribution of the various elements, combining the old data (Bateson and others, 1983) together with the new data. For simplicity the contour intervals used in the earlier phase of this investigation have not been modified for the data from the follow-up area in the vicinity of the Rothley Lakes.

The Figure (16a) shows that the linear zone of Ba enrichment, identified in the earlier investigations, can be shown to extend westwards beyond the line of the B4362. A smaller area of Ba enrichment trends WNW in the area of East Lake Cottage.

This phase of follow-up soil work has also closed to the west the small areas with higher than average Pb values and shown up a further pair of small highs close to the northern shore of the Rothley Lakes.

The new data for zinc show up a discontinuous area of high values coincident with those close to the shore of the lake referred to above. Values for copper are generally at background level and show a small high in the vicinity of the East Lake Cottage; the small copper anomaly defined in the area of Rothley Shield East from the earlier soil sampling does not extend further to the west.

There is a general coincidence in the location of anomalous values for Pb and Ba and to a lesser degree Cu in the area examined around Rothley Shield East, with Zn anomalies coinciding with, but being rather more extensive than, Pb and Cu in the area to the north. These relationships are shown on Figure 18.

Geophysical survey

Six traverses were measured with a magnetometer across the area (Figure 19) in which soil values anomalous for barium had been located from the earlier work. It was thought that the linear ENE trending Ba anomaly may reflect mineralisation of a fault in the Whin Sill, here at only a few tens of metres depth.

The magnetic results show no clearly defined features that can be used to account for the barium anomaly. A weak magnetic low is seen, extending ENE for a few hundred metres from the north shore of Rothley Lake. The southern margin of the anomaly is better defined than the northern margin.

Strong positive anomalies on traverses 500E and 0 indicate the position of the Causey Park Dyke (Figure 19).

Discussion

The weak zone of low magnetic values, trending in an ENE direction from the vicinity of East Lake Cottage at the NE end of the Rothley Lakes, runs parallel to and somewhat south of the linear Ba anomaly. The magnetic low is aligned with a fault mapped from Gallows Hill (approximately 3 km to the SW) (Figure 15) that is shown displacing the outcrop of the Whin Sill, and is interpreted as being due to an extension of this fault.

The two small faults trending NW and WNW (Figures 16 and 17) which converge near to the eastern end of Rothley Lakes do seem to have the effect of cutting off the anomalous zones identified by Cu, Ba and Pb values.

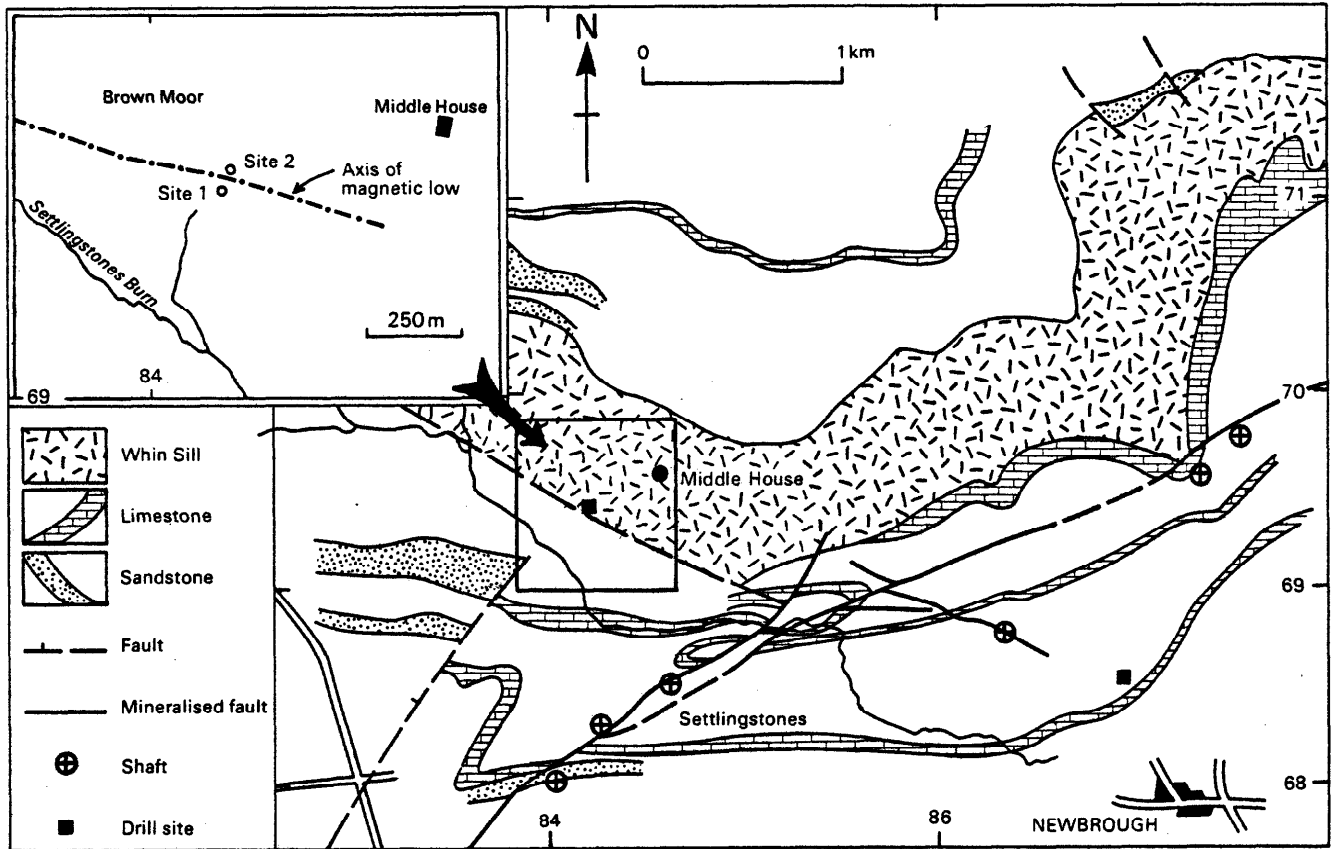


Fig. 20 Geology of Brown Moor and Settlingstones mining area

Conclusions

The precise cause of the magnetic feature has not been determined but it is likely that it represents a continuation of the fault between Rothley Shield East and East Lake Cottage - a feature that could be responsible in part for the direction of the eastward flowing Rothley Gill.

The geochemical anomalies are reasonably consistent in maintaining a trend parallel to the strike of the sediments in this area. There is insufficient direct evidence, from either the exposed geology or available geophysical data, to be certain that this distribution is related either to faulting or to lithological control.

BROWN MOOR

Introduction

On the basis of the airborne magnetic data (Evans and Cornwell, 1981) and the drilling programme undertaken at Newbrough (Bateson and others, 1984), it was recognised that the area of Brown Moor (1 km to the NW of Settlingstones) be considered as a promising drilling target (Figure 20).

Ground geophysical follow-up work confirmed the existence of the linear magnetic low (Bateson and others, 1983, page 52) and provided information that enabled a drilling target to be identified.

Four holes were drilled from two sites, separated by 28 m; three of the holes passed through the entire thickness of the Whin Sill and into the sediments beneath. The Whin Sill dolerite was sampled to give a representative set of geochemical data, analyses being undertaken for Pb, Ba, Ce, Zn, Cu, Ca, Ni, Fe, Mn, Ti, Rb, Sr and Zr.

Discussion of geochemical data

The distribution of selected elements (Ba, Pb, Rb, Sr and Zn) in the holes is shown in Figures 21 and 22 and a plot of the calculated mean value (\bar{X}) and range of values in comparison with the data obtained from the Newbrough drilling programme is given in Figure 23 (Bateson and Johnson, 1984). From this it is possible to recognise the distribution of individual elements in relation to alteration of the Whin Sill.

The data from Brown Moor indicate that Zn, Pb, Cu, Ca, Ti, Fe, Ce and Zr are present at levels that are close to those recorded in the "normal" (i.e. unaltered) dolerite at Newbrough. Ba, Sr and Mn show a much wider range of values than would be expected in the "normal" Whin, and Ni and Rb are closer to the levels recorded in the altered sill at Newbrough. Observations made on the core material show that the Cu and Zn levels coincide reasonably well with the values from the normal Whin Sill at Newbrough but the Pb values show a rather higher mean value and a smaller range than in the Newbrough cores; a few small grains of galena are noted in the Brown Moor core.

Examination of the Brown Moor core shows that much of it has been affected by movements that have produced considerable shattering, some zones of which show considerable gouging and slickensides. Magnetic susceptibility values measured on the dolerite core confirm that significant parts have been altered which coincide with observed physical features

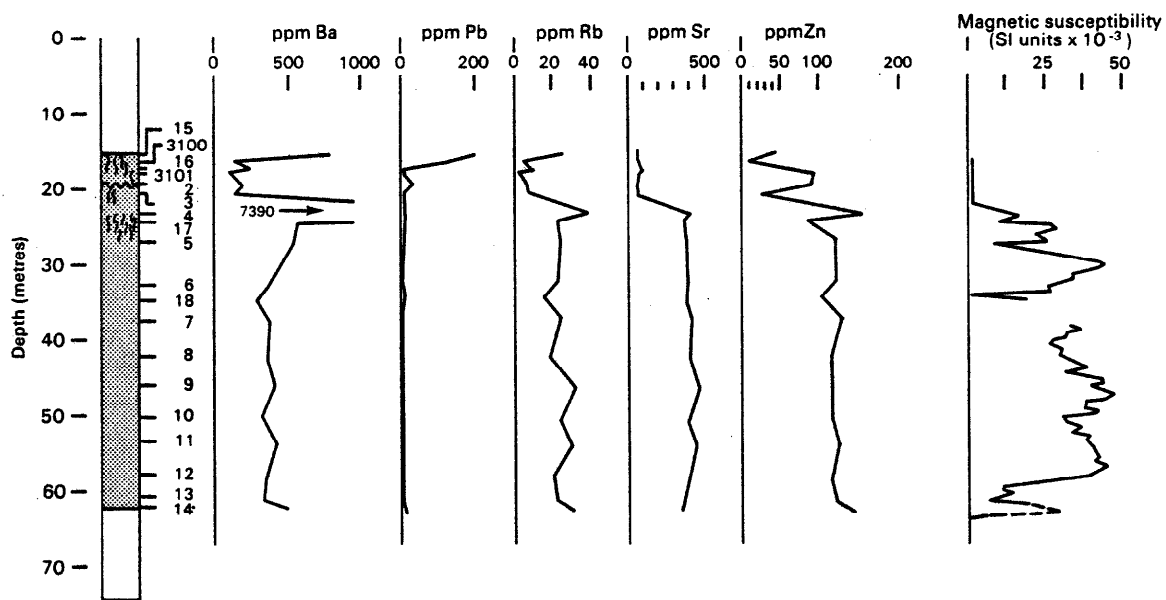


Fig. 21a Lithology, geochemistry and magnetic susceptibility—Borehole 1 Brown Moor

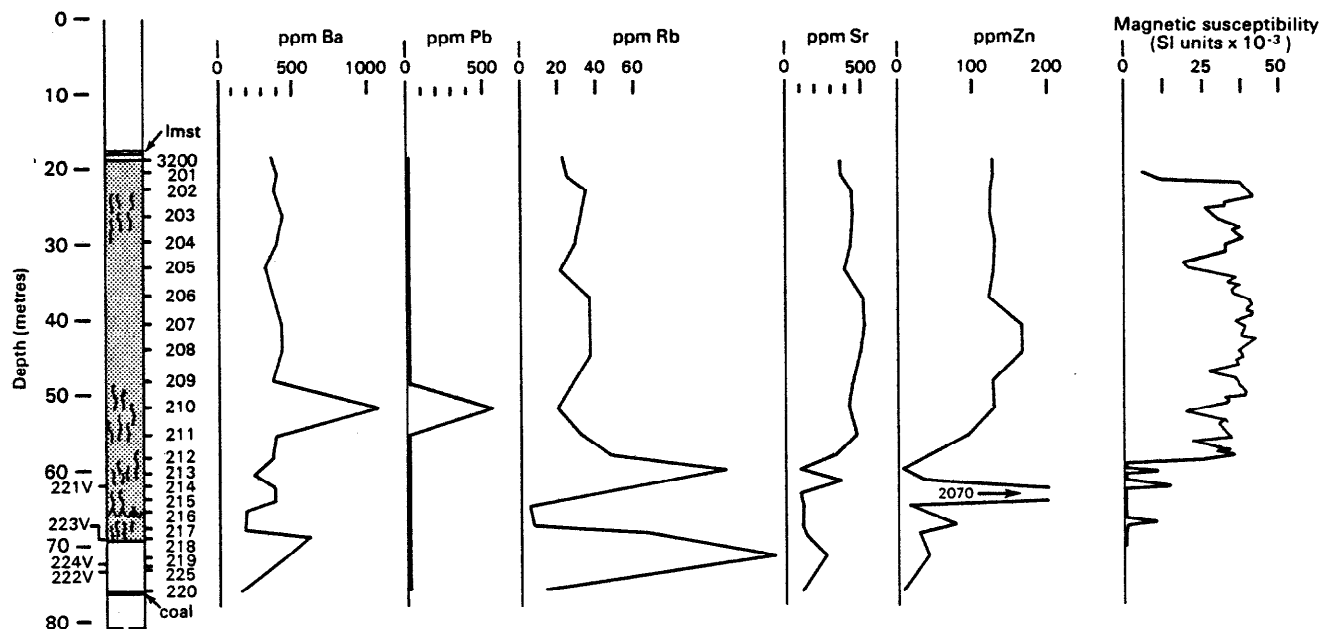
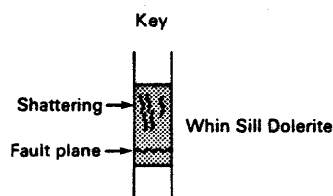


Fig. 21b Lithology, geochemistry and magnetic susceptibility—Borehole 2 Brown Moor

Fig. 22a Lithology, geochemistry and magnetic susceptibility—Borehole 3 Brown Moor

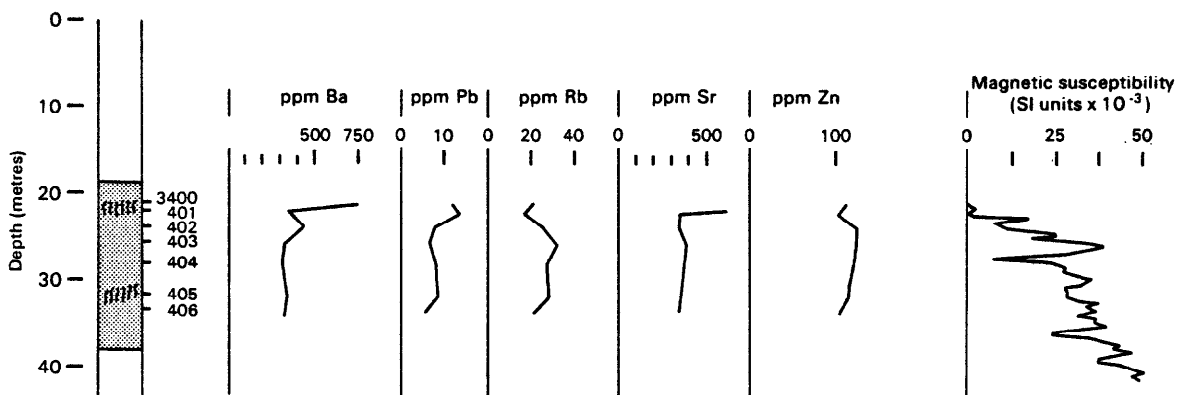
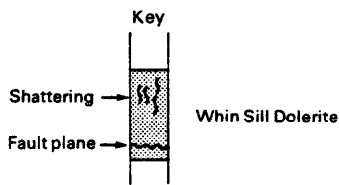
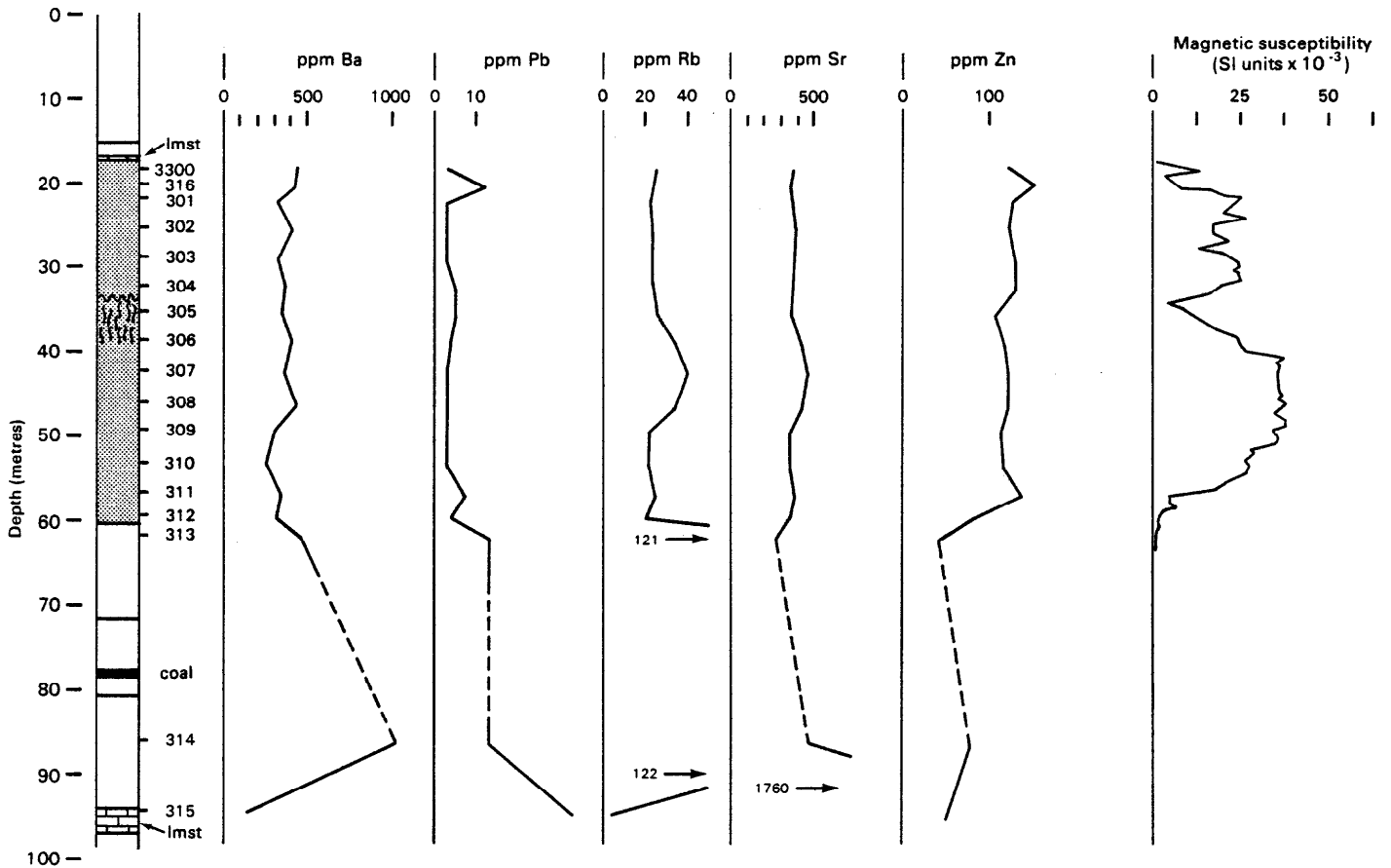


Fig. 22b Lithology, geochemistry and magnetic susceptibility—Borehole 4 Brown Moor

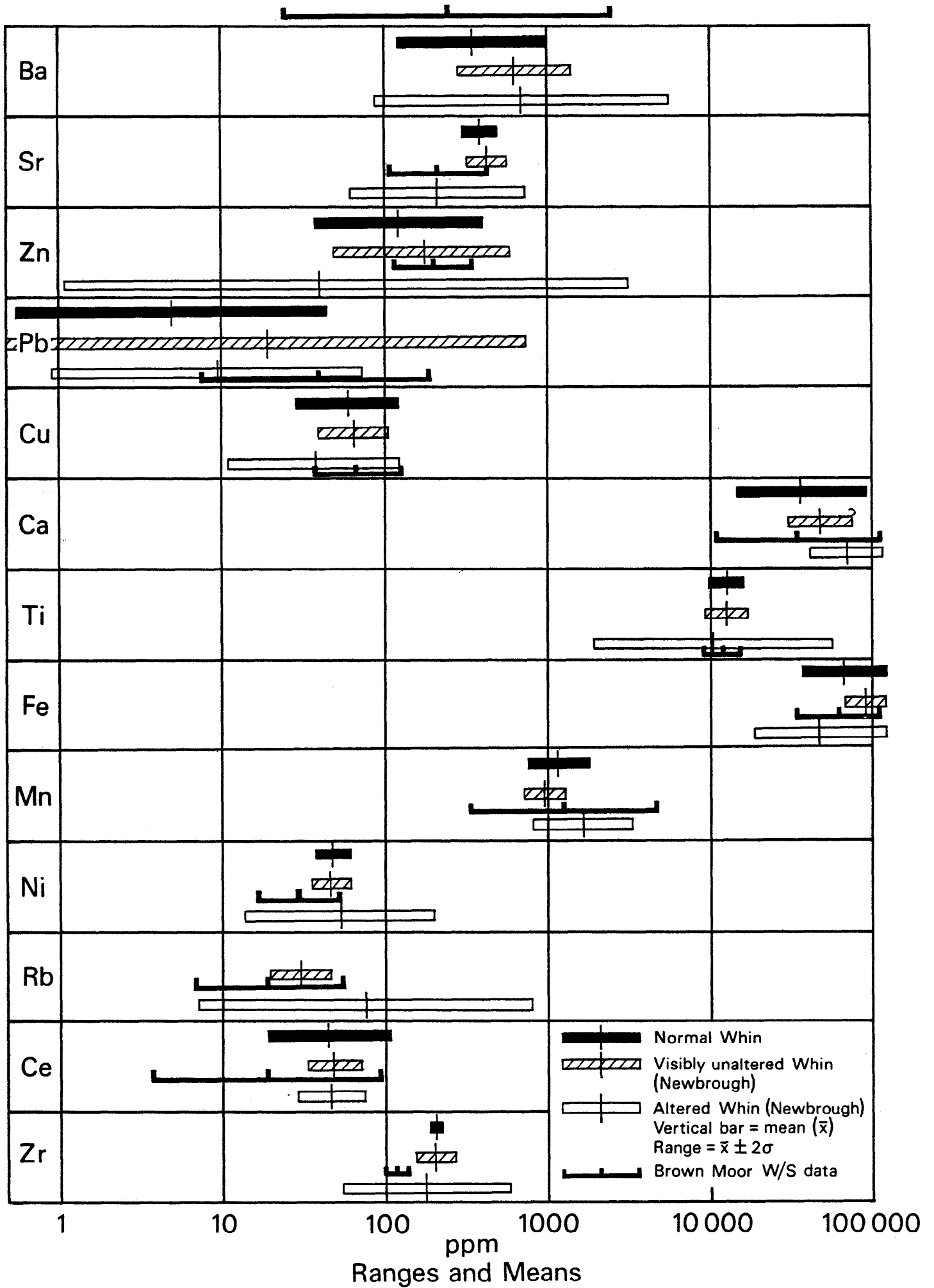


Fig. 23 Ranges and means of elemental values in Whin Sill at Brown Moor and Newborough

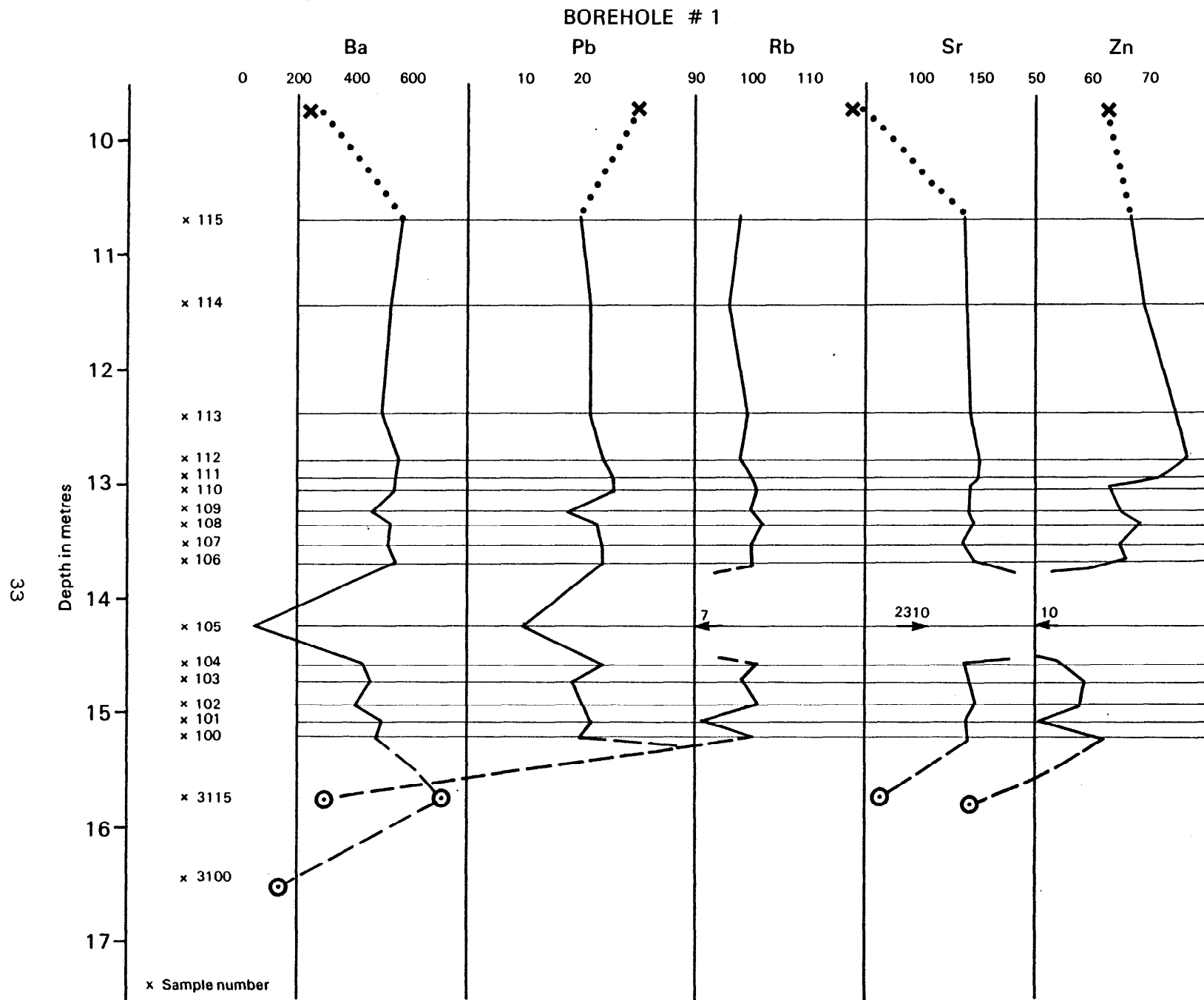


Fig. 24 Variations in elemental distribution in till samples—Borehole 1 Brown Moor

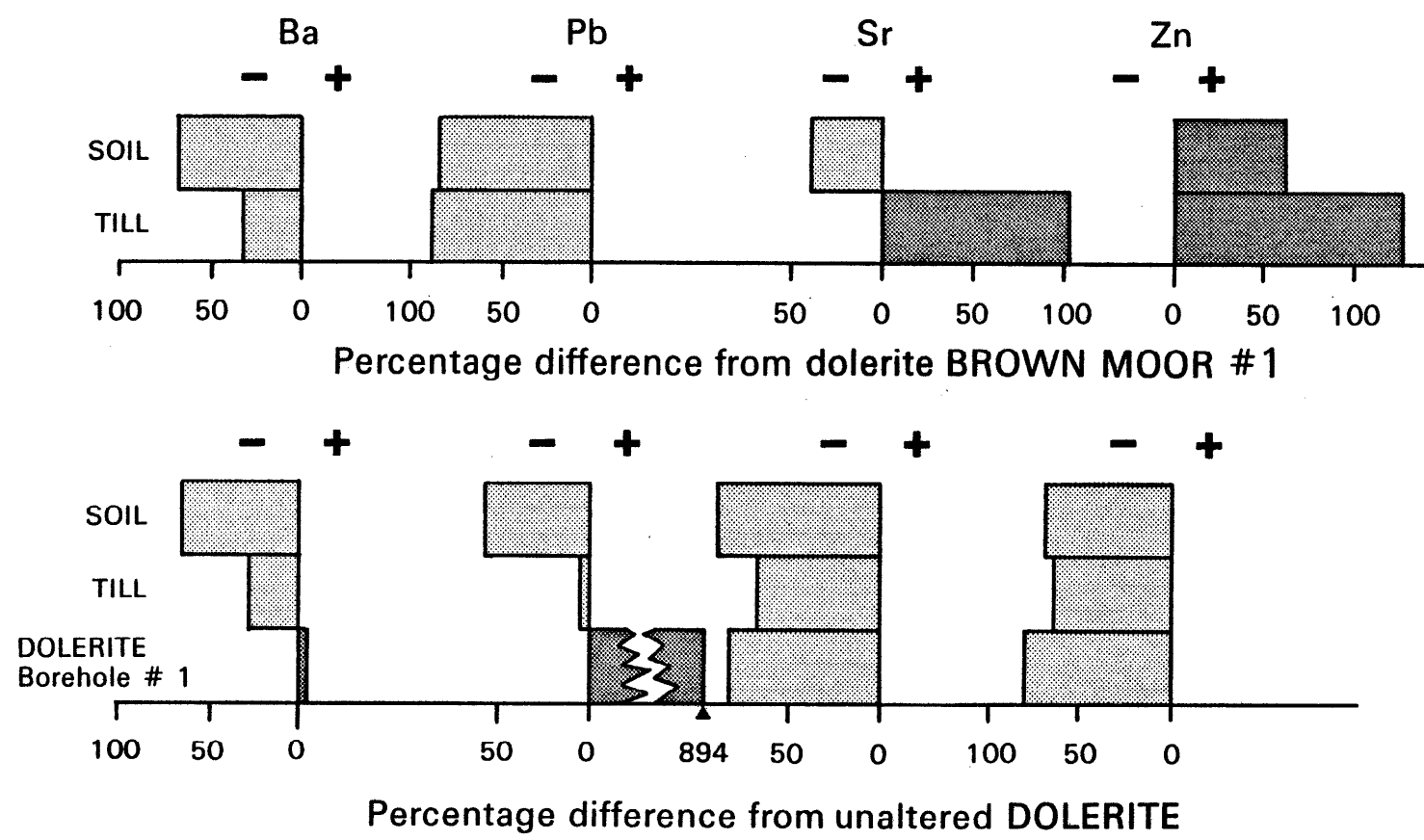


Fig. 25 Elemental variation: bedrock dolerite - till - soil. Brown Moor

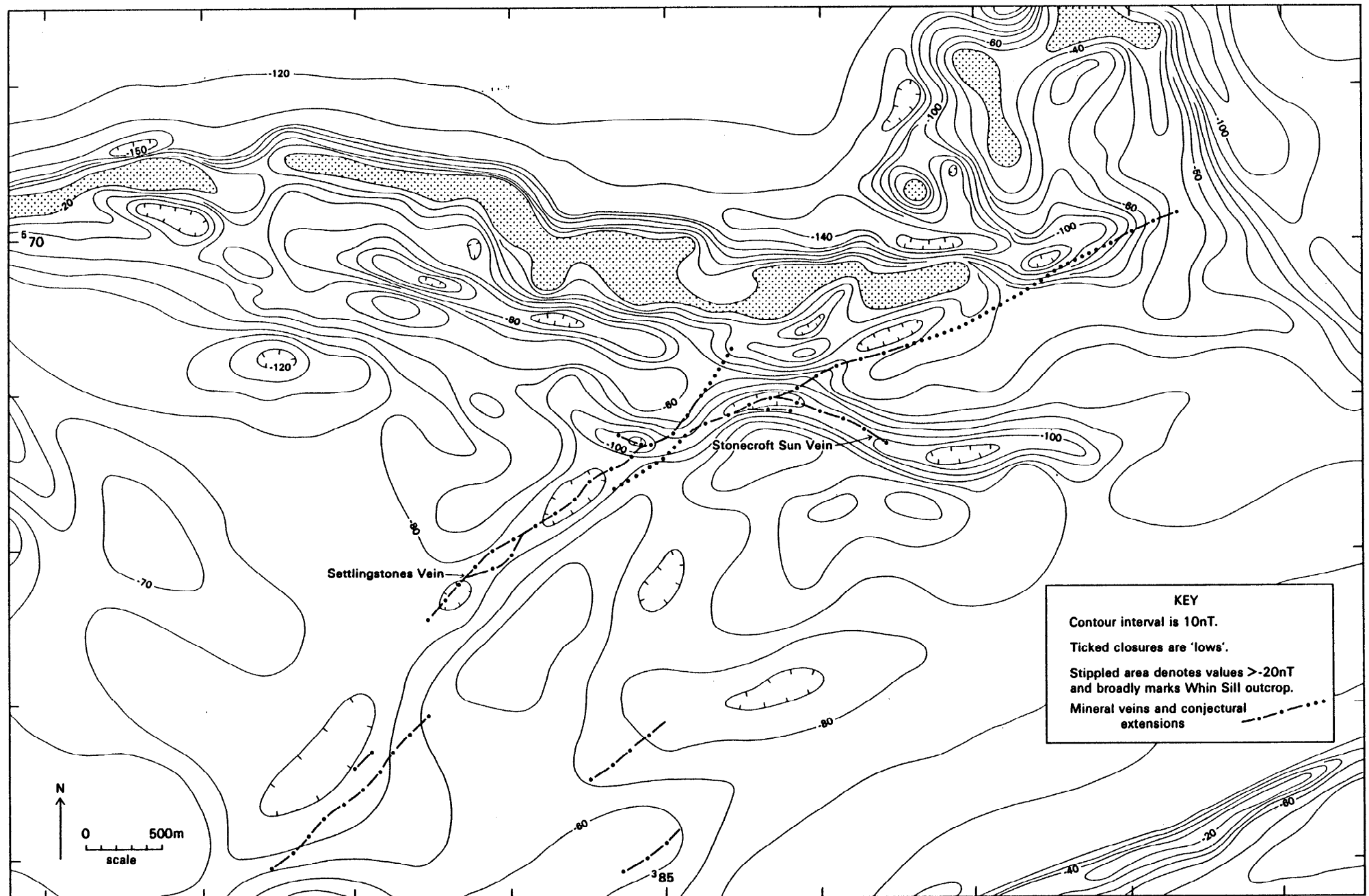


Fig. 26 Aeromagnetic contour map: Settlingstones Mine and surrounding area

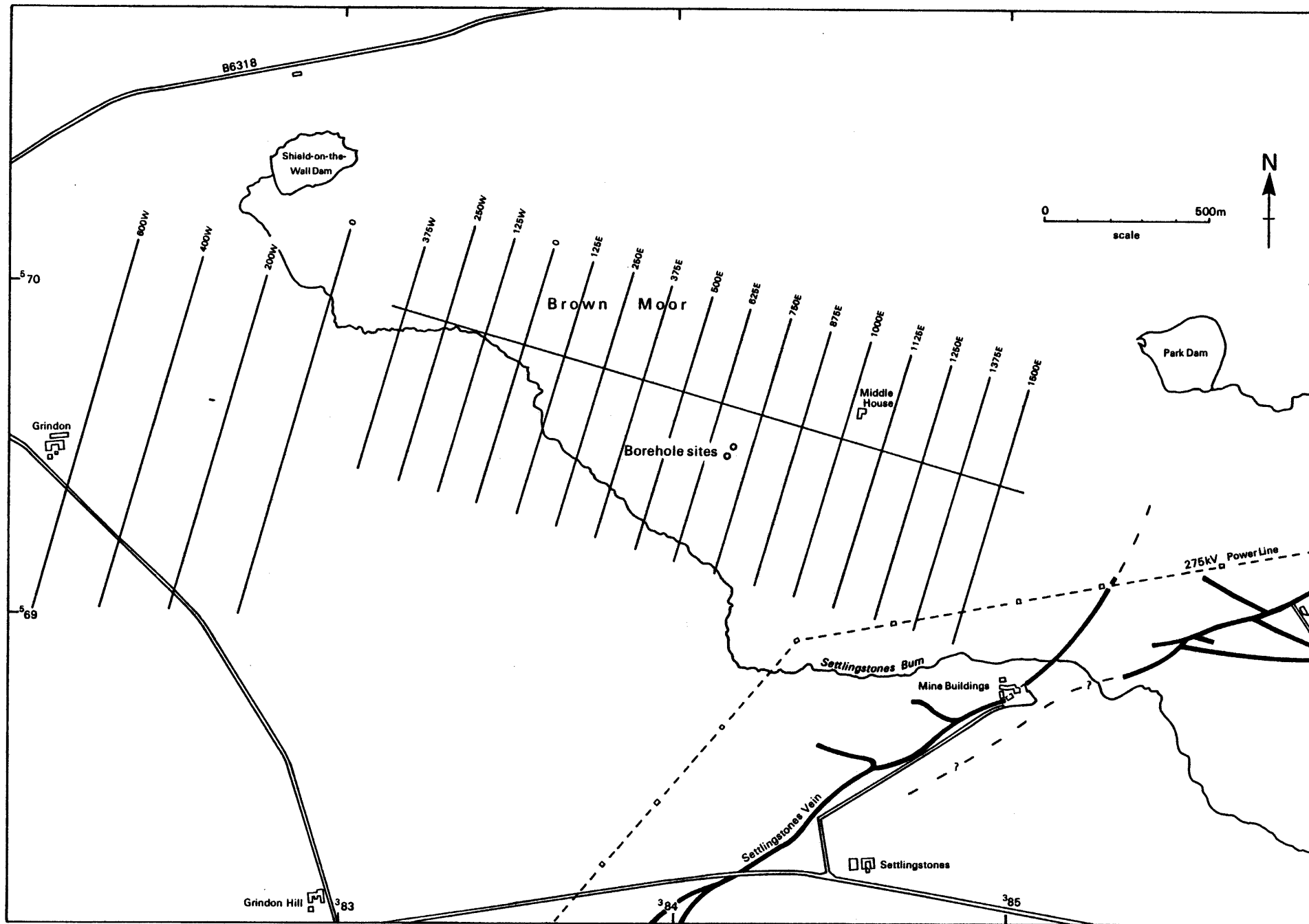


Fig. 27 Location map for geophysical traverses at Brown Moor

ERRATUM

pp 38-39

Caption for Figs 28 & 29 have been reversed

Fig 28 Calculated profiles

Fig 29 Total magnetic fields



such as change of rock body colour and grain size. In holes 1, 2 and 4 values for Ba, Pb and Zn show marked peaks which although not precisely coincident do occur in the areas of greatest shattering and alteration as indicated by low magnetic susceptibility values. In hole 3, the most southerly of the four, there is less evidence of shattering and alteration (apart from one section at 35-40 m), the magnetic susceptibility values are higher and values for Ba, Pb and Zn are low.

During the drilling of hole 1 the surficial glacial till material was also cored and samples collected for analysis from the 5 m of material immediately above bedrock. The data for Ba, Pb, Rb, Sr and Zn are recorded graphically in Figure 24

In general the 15.5 m of glacial material are characterised by boulders of Whin dolerite and some limestone set in a matrix that varies from fine sand to dark clay. Boulders and lithic fragments vary in size and do not show any sorting; one boulder of limestone measuring at least 25 cm in diameter was cored.

The relationship of these four elements, in both till and soil, to the values obtained from the dolerite in drillhole 1, have also been investigated and the different values in each presented (Figure 25) in the form of a percentage gain/loss histogram. These data indicate that there is a considerable depletion in Ba/Pb and Sr in soils but an increase of 50% in the corresponding values for Zn in soil. The till data show that Ba and Pb are both reduced but that Sr and Zn show considerable concentrations in this medium.

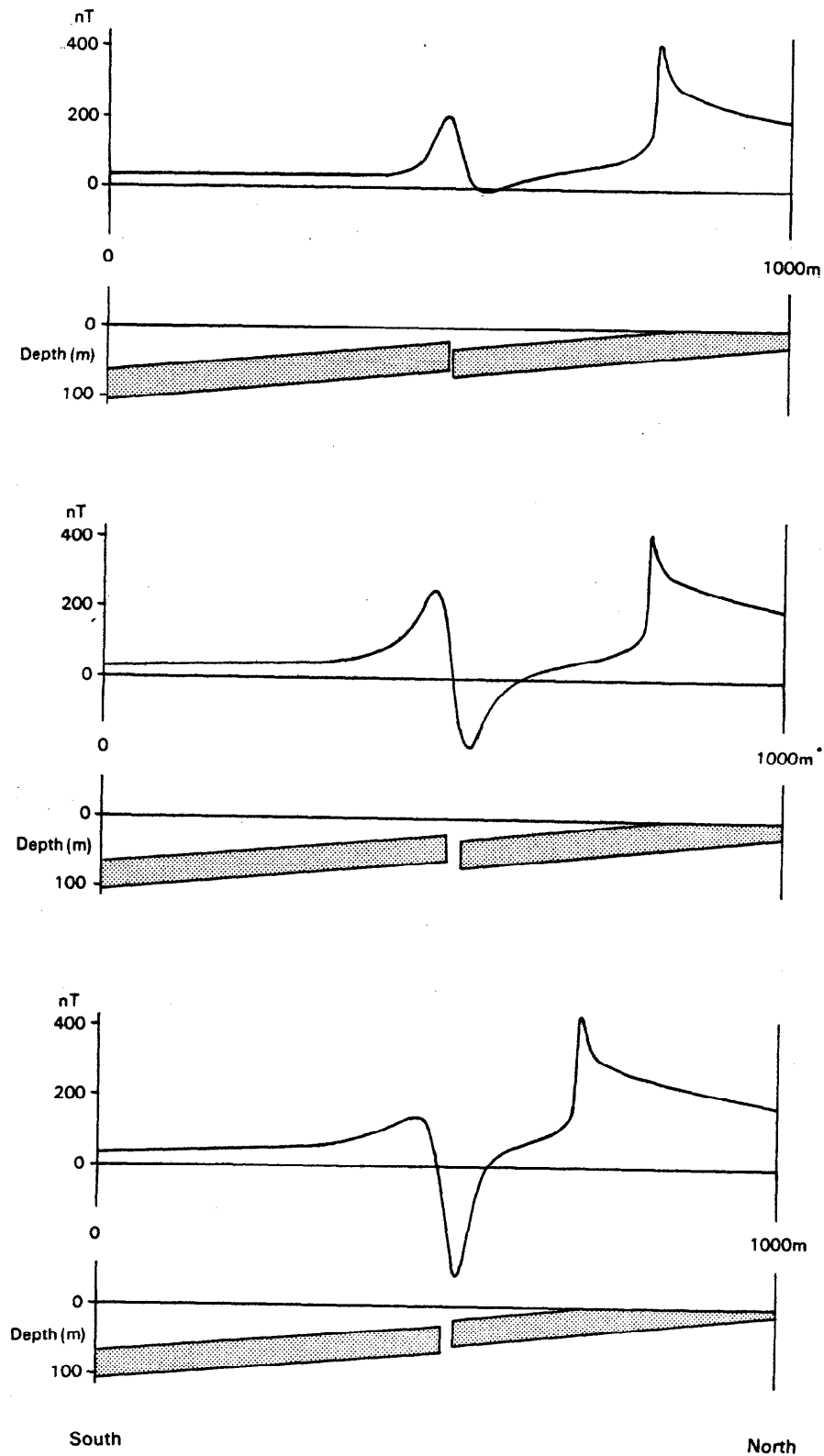
Discussion of geophysical data

The Brown Moor airborne magnetic anomaly is a linear negative feature, trending WNW, with a length of c 2 km. The anomaly is almost continuous with the anomaly over the Stonecroft Sun Vein; a distance of about 500 m separates the extremities of the two (Figure 26).

The anomaly was investigated with a series of sixteen ground magnetic traverses (Figure 27) from [8320 6990] to [8495 6935]; east of the latter point the proximity of a 275 kV power line prevents satisfactory observation of data over the area of interest. The traverses were spaced 125 m apart, and were generally about 800 m in length, with observations at intervals of 10 m. VLF-EM measurements were made along alternate traverses 250W.....1000E, and on each of the four easternmost traverses. The VLF-EM data show a number of features related to topography, but no anomalies indicative of bedrock conductors. These data are therefore not discussed further.

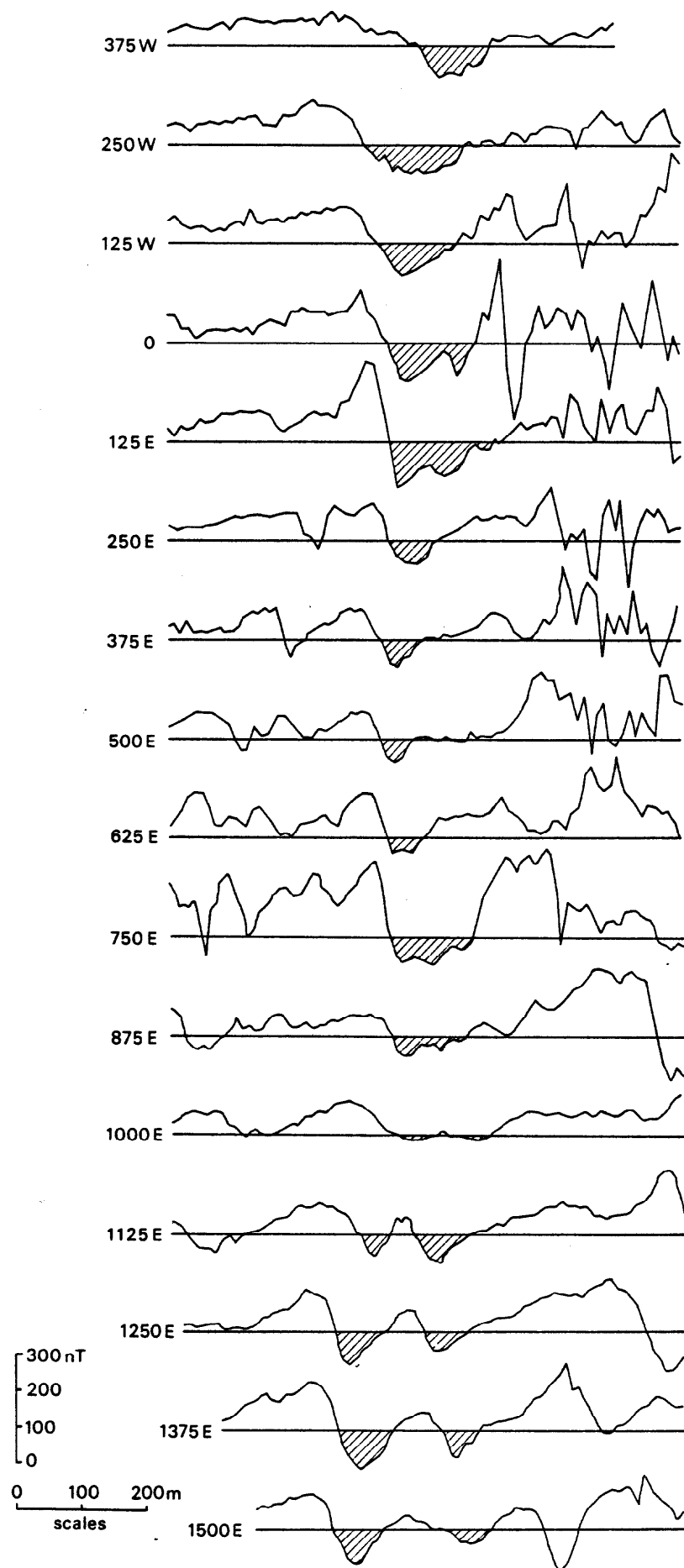
Magnetic results

Irregular fluctuations seen on many of the ground magnetic profiles (Figure 28), reflect the proximity of the survey area to the outcrop of the Whin Sill; traverses from 0 to 750E extend onto outcropping dolerite. Over the remainder of the area, where dolerite is not exposed, the irregularly weathered top of the dolerite probably forms a dip slope beneath the drift before the succeeding sediments appear to the south. It is also likely that dolerite boulders occur throughout the drift of the area. Although these factors contribute to the irregularity of the magnetic profiles, there is a clear indication that the magnetic anomaly observed on the airborne data is reflected in the ground profiles. This is seen in Figure



Total magnetisation of sill (J_T) = 350×10^{-5} emu
 Declination of J_T = 190°
 Dip below horizontal of J_T = 15°

Fig. 28 Total magnetic field profiles at Brown Moor



Hatching denotes principal negative anomaly with observations below 48800nT

Fig. 29 Calculated profiles of magnetic anomaly for various configurations of faulting, and demagnetised zones, in Whin Sill

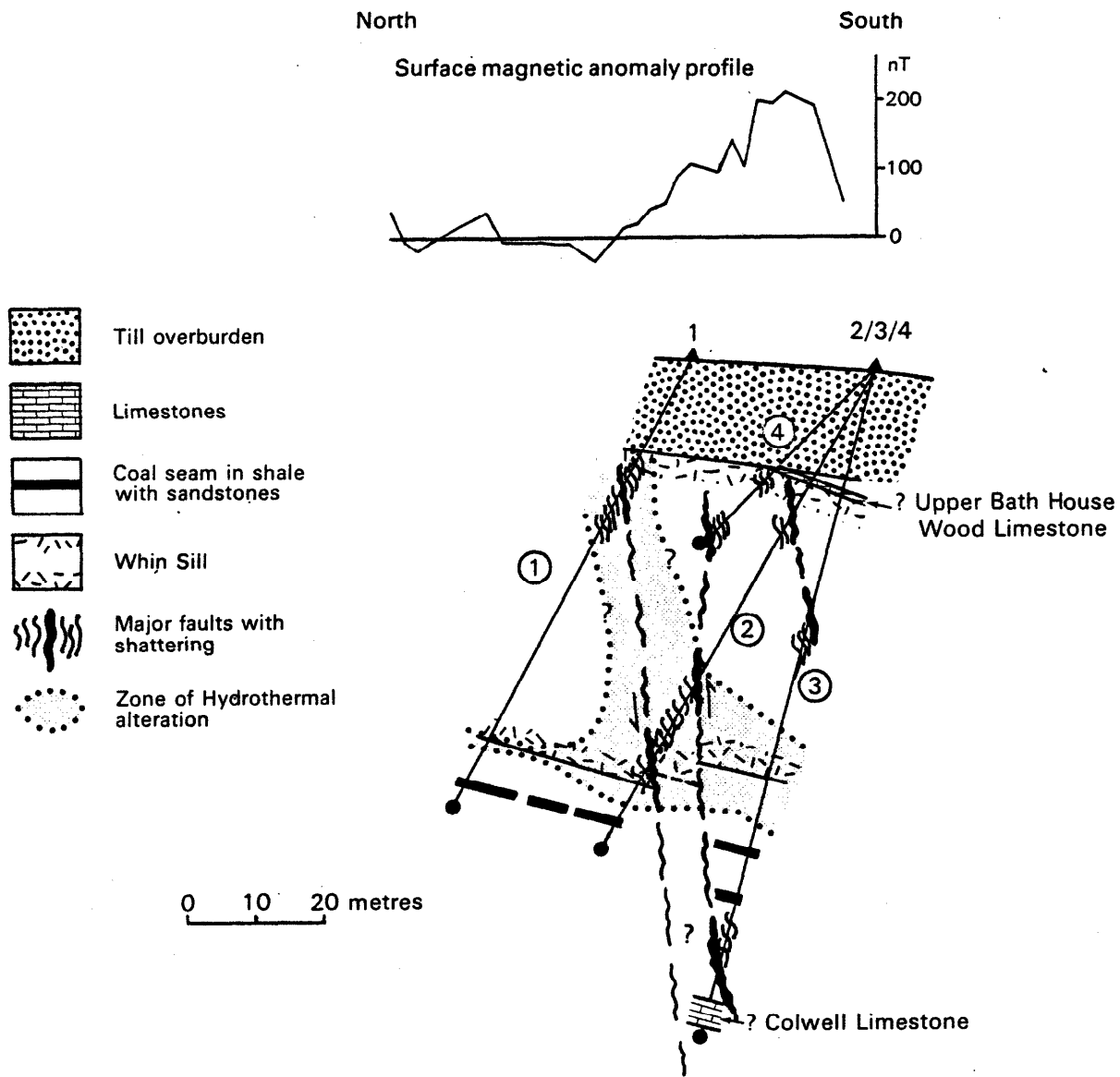


Fig. 30 Interpretation of the borehole data, Brown Moor

28, which shows that a 48800 nT contour would outline a negative anomaly extending over the length of the survey area.

The Brown Moor anomaly makes an interesting comparison with the eastward extension of the magnetic low over the Stonecroft Sun Vein (Figure 26), which has been investigated by ground surveys and drilling at Newbrough (Bateson and others, 1984; Bateson and Johnson, 1984). The airborne magnetic map indicates that these two linear anomalies are part of a suite of such features related to the faults/veins of the Settlingstones/Stonecroft mining area. The Newbrough anomaly was shown to be due to faulting in the Whin Sill, with downthrow to the south, along which alteration had occurred. The Brown Moor anomaly, being very variable in characteristics along its length, is difficult to interpret, but at the site chosen for drilling is considered as being due to a fault with downthrow to the north, again with probable accompanying alteration of the Whin. The necessity for this difference in interpretation is readily apparent by reference to Figure 29. The Newbrough anomaly is a simple, approximately symmetrical, negative anomaly; to the north and south the background magnetic field is clearly established before other anomalies appear. The Brown Moor anomaly is not a simple negative; it is invariably accompanied by a significant positive anomaly immediately to the south, this being more evident from the ground profiles than from the airborne data. At the site selected for drilling, this positive anomaly is more evident than the negative. The model in Figure 29 shows that this anomaly can be explained as being due to a fault in the Whin Sill with downthrow to the north of approximately 10 m. The results of drilling have shown the sub-surface configuration of the Whin Sill to reflect closely this model.

As at Newbrough, magnetic susceptibility determinations were made on the borehole cores at intervals of approximately 0.3-0.5 m, though over some short sections of core the degree of fracturing was too great to permit satisfactory measurement. The resulting susceptibility 'logs' are shown in Figures 21-22. The two sections of the sill most clearly demagnetised are at the top of borehole 1 (c. 8 m) and at the base of the sill in borehole 2 (11 m). Considered in conjunction with the top and base-of-sill intersections in each hole and the position of shattered zones, there is strong evidence for the presence of a fault zone, having steeply to the south, with a downthrow to the north of 5-10 m, within which extensive hydrothermal alteration of the Whin Sill has occurred; boreholes 1 and 2 have intersected the upper and lower limits of this zone respectively. Elsewhere, the susceptibility values are very variable, though some narrow zones of partial demagnetisation do correlate with veining and shattering in the core. Sections of more uniformly magnetised sill occur in borehole 2 (36 m-46 m) and borehole 3 (41 m-51 m) with the peak value (reaching 40×10^{-3} SI) comparing closely with the results from the Newbrough cores.

Interpretation of drilling data

The interpretation of the various data gathered - drill core geochemistry, soil data and geophysical observations on the ground and from the core - is presented in Figure 30.

Evidence from boreholes 1 and 4 suggests that the topmost part of the Sill here has been exposed by erosion prior to the deposition of the glacial till; thin sediments above the Sill are only encountered in boreholes 2 and 3.

The data from the holes suggest that the main fault zones can be identified and projected between the boreholes in a manner that produces steep to near vertical fault zones, an interpretation that is compatible with an interpretation of the physical evidence from the core which shows the shears and fractures at angles of 45-50° to the axis of the core (the inclinations of the boreholes varied within a range of about 45-70°).

The base of the Whin Sill was intersected in holes 1, 2 and 3; in 2 the bottom 20 m (core length) of the sill shows intense shattering as the result of the convergence of two faults in this part of the sill (see Figure 30).

The depth below datum (datum for this purpose taken as ground level at site 2) at which the base of the sill was encountered was 59 m in borehole 3, 60 m in 2 and 52 m in 1. Evidence from holes 2 and 3 indicates that the chilled top margin of the sill is overlain by a thin limestone passing upwards into mudstones, silts and thin sandstones (all of which show some degree of alteration due to the intrusion of the sill into the sediments). A regional dip of approximately 10° south is indicated.

The evidence from the drilling indicates that in this small area the fault pattern as proposed has the effect of displacing the Whin downwards to the north (the faults here are, therefore, slightly reversed) - by approximately 6 m. (But note that the variations in the magnetic profiles indicate significant changes in the amplitude and directions of throw along strike). It is of interest to note that the structure at Newbrough also shows some reversed faulting with displacements of the order of 5 m. There are insufficient data available to clarify the stratigraphy of the area - from the published map (Bellingham Sheet 13) the most likely limestone to lie immediately above the Whin Sill is the Upper Bath House Wood (UBHW). On the basis of this correlation the 3 m limestone encountered towards the base of borehole 3 may be the Colwell Limestone (CL) although if this correlation proved to be correct the thickness of the sediments (predominantly sandstones and shales) between the UBHW and CL has decreased from 65 m at Settlingstones Frederick Shaft (Frost and Holliday, 1980, p. 35, Figure 19) to approximately 30 m at Brown Moor. The presence of three thin coals in the 20 m or so of the succession above the lower limestone (?Colwell) is similar to that at Settlingstones and in this part of the trough in general. It is of interest to note that the distance between the base of the Sill and the highest coal seam varies between 12 m in borehole 3 to 8 m in 1, which may be taken to indicate that the base of the Sill here is transgressive, in a manner similar to that observed at Newbrough.

Conclusions

The data obtained from the drilling project at Brown Moor, taken in conjunction with that obtained at Newbrough, lead to the conclusion that the elongate magnetic feature is the result of faulting and accompanying alteration of the Whin Sill. It may further be concluded, by analogy with the proven mineralisation in the area and the evidence from Newbrough and Brown Moor, that such structures may be considered as potential sites of mineralisation and as such they should feature high as exploration target areas.

ACKNOWLEDGEMENTS

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