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Mineral reconnaissance surveys in the Craven Basin

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Mineral reconnaissance surveys in the Craven Basin

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SUMMARY

A geochemical drainage survey covering about 900 km^2 showed the presence of anomalously high levels of Cu, Pb and Zn in stream sediments and panned concentrates from water courses in various parts of the Craven Basin, although the values are generally lower than those reported in Irish areas of similar geology with economic mineralisation. An airborne geophysical survey (magnetic, electromagnetic and radiometric) over the Craven Faults, at the northern margin of the basin, identified localities which gave an anomalous EM response; ground EM surveys showed that five of these merited more detailed examination. High radiometric readings were obtained over several limestone reefs. Seismic traverses over the South Craven Fault provided information about the stratigraphy on each side of this fault, and regional gravity data provided information about the major structures.

Detailed geophysical, geochemical and geological investigations were carried out in sixteen areas where the geological environment or the results of earlier reconnaissance work suggested that mineralisation might be present. Sulphide mineralisation associated with limestones of reef facies was proved, in particular at How Hill and Cow Ark, and evidence was found of a continuation of the mined Bycliffe Vein, but on present evidence none of the areas appears to contain deposits of ore grade. It is not possible at this stage to be certain of the mechanism and control of the mineralisation, but many of the minerals appear to have been emplaced by the concentration of brines in structural or stratigraphical traps, in which limestones have acted as host rocks. Comparisons with the important sulphide deposits in the Lower Carboniferous of Eire suggest that the most promising area for mineralisation is near the northern boundary of the Craven Basin, possibly at depths of 300–400 m.

INTRODUCTION

This report describes mineral reconnaissance surveys carried out over about 900 km^2 of the Craven Basin and adjoining areas. The basin is a geological concept as discussed below, but geographically the area coincides broadly with the Craven Lowlands of West Yorkshire and Lancashire, together with parts of the Bowland Fells to the west, the moors north of Settle and Grassington and, on the south, the ridge of moorland culminating in Pendle Hill (Figure 1). The area is traversed by the middle reaches of the River Ribble and this valley, together with the tributary valleys of the Hodder and Calder, contain rich farming land largely devoted to pasture. In the north-east, the drainage flows eastwards down the Aire and Wharfe valleys. There are substantial market towns at Clitheroe, Skipton and Settle and many small villages. There is some industry at Barnoldswick but the district is predominantly agricultural. Limestone is worked for aggregate and for lime in major quarries at Clitheroe, Lothersdale, Skipton, Swinden near Grassington, and Settle. The moorlands have much rough grazing, a limited amount of afforestation and extensive grouse moors. This high ground, in places up to 550 m, is the only part of the area not easily accessible from minor roads. The southern boundary of the Yorkshire Dales National Park runs along the northern edge of the basin and in the west the Bowland Fells have been designated an Area of Outstanding Natural Beauty, so in both areas planning restrictions tend to be tighter than elsewhere.

An integrated geological–geochemical–geophysical investigation of base-metal mineralisation in the area of the Craven Basin was commenced by the Institute of Geological Sciences in 1973 as part of the Mineral Reconnaissance Programme on behalf of the Department of Industry. The objective of the work was to investigate the potential for the occurrence of 'Irish-type' base-metal sulphide deposits in the Carboniferous succession of the Craven Basin.

The presence of reefal limestones within the lower part of the Carboniferous was well known from the geological mapping of the earliest workers in the area. Similarly, there is a history, dating back to the 16th century, of small-scale mining operations within the area, usually working metalliferous occurrences in limestone lithologies.

Investigations in the area commenced with a reconnaissance geochemical drainage survey covering the whole of the Craven Basin. An airborne geophysical survey was carried out over the northern margin of the basin and over a limited area around Lothersdale, and three seismic reflection traverses were made over part of the South Craven Fault. Upgrading of the regional gravity coverage was also undertaken.

Sixteen areas were chosen for detailed investigation, on the basis of their geological setting or the presence of former mining activity, or because the geochemical drainage survey or the geophysical airborne survey yielded interesting anomalous values. The techniques used in these investigations included detailed geological mapping, ground geophysical methods (normally IP and EM), geochemical soil sampling, deep overburden sampling and diamond drilling.

GEOLOGY

The Craven Basin is an area of thick Lower Carboniferous sedimentation, in contrast to the thin block sequence of the Askrigg Block to the north. The basin has a recognisable northern margin, particularly east of Settle where it broadly coincides with the Mid-Craven Fault; near Grassington the margin lies just south of the North Craven Fault but farther in this direction it is not clear

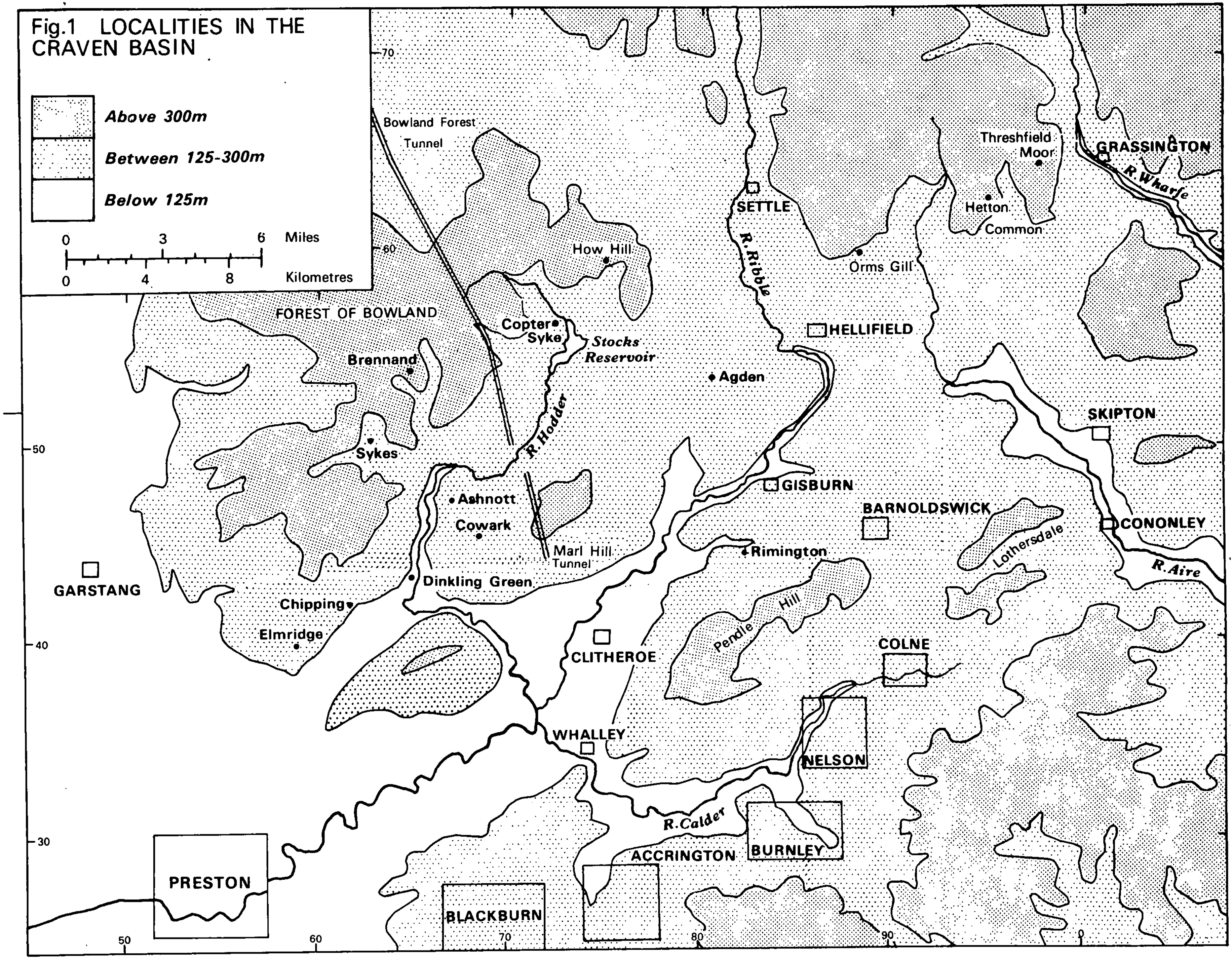


Fig.1 LOCALITIES IN THE CRAVEN BASIN

whether it follows the course of this fracture towards Pateley Bridge or runs farther south beneath the younger rocks of Simon Seat. To the west of Settle, the basin margin does not trend to the north-west with the Craven Faults but appears to take a more westerly course, via the Nether Kellet reefs near Carnforth and the southern part of the Furness peninsula. The limits of the basin in other directions are much less well defined since they are entirely covered by younger rocks, but their approximate positions can be estimated from indirect evidence. For example, the basin is characterised by periclinal, NE-trending open folds which are exposed south-westwards as far as the Chipping Anticline and persist beneath the Permo-Triassic beds of the Irish Sea, so there is no sign of a limit in the west. Indeed, the Craven basin may have been coninuous during sedimentation with the area north of Dublin. On the east of the basin, the characteristic folding persists via the Skipton Anticline as far east as Harrogate, but farther south the folds end against the north-trending Pennine Anticline whose western limb may mark the approximate edge of the basin; it also coincides with the eastern limit of minor Pb, Zn and Ba vein mineralisation characteristic of the basin. The southern limit of the basin may lie along the northern limb of the Rossendale Anticline as far west as Anglezarke Moor, again using the edge of the folding and the minor mineralisation as indicators. Within the Craven Basin the amount of local geological data is variable. Parts of the area lack modern geological studies, particularly where the bedrock is largely concealed by superficial deposits.

Figure 2 shows the main geological features of the basin. Lower Palaeozoic strata are exposed adjacent to the Craven Faults along the northern boundary. These rocks form part of the rigid Askrigg Block, underlain by Lower Palaeozoic basement intruded by plutonic granite. At surface, the sedimentary rocks of the Ingletonian Group of (?)Cambrian–Ordovician age are overlain unconformably by Upper Ordovician and Silurian beds.

No Devonian rocks are exposed in the Craven Basin or adjacent areas but they were proved in the Boulsworth Borehole sunk on the eastern edge of the basin. This borehole penetrated Old Red Sandstone facies strata, below a thick sequence of Lower Carboniferous rocks, indicating that the edge of the Craven Basin lies farther to the east.

Boreholes adjacent to the Craven Faults between Settle and Malham proved up to 50 m of banded dolomites and evaporites low in the Carboniferous succession; these probably represent shallow, shelf deposits abutting onto the Askrigg Block.

The base of the Carboniferous succession is not proved and the oldest exposed rocks belong to the Upper Courceyan Stage (C_1 Zone). These are present in the core of the Clitheroe Anticline, as the Chatburn Limestone Group. The exposed Chatburn Limestone Group in the type area is at least 820 m thick though it varies greatly in other areas. It is composed of dark, well-bedded bituminous limestones and calcareous shales basinal in facies.

The base of the Worston Shale Group is taken where the predominant lithology becomes shaly. The top of the Group is equated with the prominent Pendleside Limestone in the central and western part of the basin, but elsewhere this horizon is not developed and here the boundary is taken at a horizon of grey-brown shales and limestones lying immediately below black pyritous shales of the Bowland Shale Group. The Worston Shale Group contains contrasting facies, comprising deep-water argillaceous deposits, reefs, and shallow-water shelf deposits. The lower part of the group reaches a thickness of 950 m in the central part of the basin east of Clitheroe. This thickness varies greatly in other parts of the basin. The rocks are calcareous mudstones, interbedded with argillaceous limestones or cementstones. In places they are strongly bituminous, show graded bedding and are turbiditic. A series of reefs is developed near Clitheroe, of Chadian age, which form knolls of poorly-bedded calcite mudstones, showing some evidence of radial dips. Associated with the reefs are flank and interbank facies (Miller and Grayson, 1972). The Worston Shale Group is separated into Upper and Lower divisions by the thin but distinctive *Bollandoceras hodderense* beds. The Pendleside Limestone is generally crinoidal, and in some areas passes into largely argillaceous sediments. It appears to thin and fail against the highs within the basin. Along the southern edge of the Askrigg Block an extensive reef belt was initiated in Holkerian times and became fully developed in Brigantian times. It is exposed between Settle and Appletreewick and probably extends beneath Namurian cover to the Carnforth area where Hudson (1937) described similar reefs. The reefs are composed of calcisiltites and calcilutites with varying amounts of organic material and are generally unbedded to poorly bedded. They show all the characteristics of being deposited in shallow water. At some localities the reefs are seen to pass into bedded limestones, while on their flanks are a series of talus breccias.

Above the Worston Shale Group in the Craven Basin lies the Bowland Shale Group, whilst on the block the correlatives are of Yoredale facies. The Bowland Shales are mostly mudstones with subordinate sandstones and limestones and can be divided into a lower sequence of dark grey to black, calcareous rocks with bands of argillaceous limestones and an upper sequence characterised by dark grey to black, thinly-bedded, papery and often pyritous shales containing minor beds of argillaceous limestones. The sandstones are medium-grained, feldspathic and flaggy and are interbedded with varying amounts of argillaceous material. The sandstones are prominent towards the basin edge and show considerable variation both vertically and laterally, many being turbiditic in origin.

North of the Craven Faults, the equivalent strata form a group of cyclothems of Yoredale facies, composed of alternations of limestone, mudstone, sandstone and thin coals. A reduced thickness along the southern edge of the Askrigg Block is due to contemporaneous faulting on the Mid-Craven Fault (Hudson, 1933).

In Namurian times blocks and basins still affected sedimentation giving the continuing deposition of the Yoredales on the block and the Millstone Grit facies in the basin. The latter comprises mudstones, siltstones, sandstones and grits. The boundary between these two facies was situated along the Craven Faults in lower Namurian times, but later migrated northwards. Westphalian strata are found in the south of the Craven Basin around Burnley and along the Craven Fault near Ingleton. In the west, Permo-Trias deposits lie unconformably on the Carboniferous, and outliers are found as far east as Clitheroe.

The ENE-trending folds crossing the basin were produced by the main Hercynian movements at the end of Carboniferous times. Fold axes can be traced for up to 15 km and amplitudes are generally about 500 m, although some folds are periclinal and others are arranged en-echelon in plan. Fold styles vary from open and

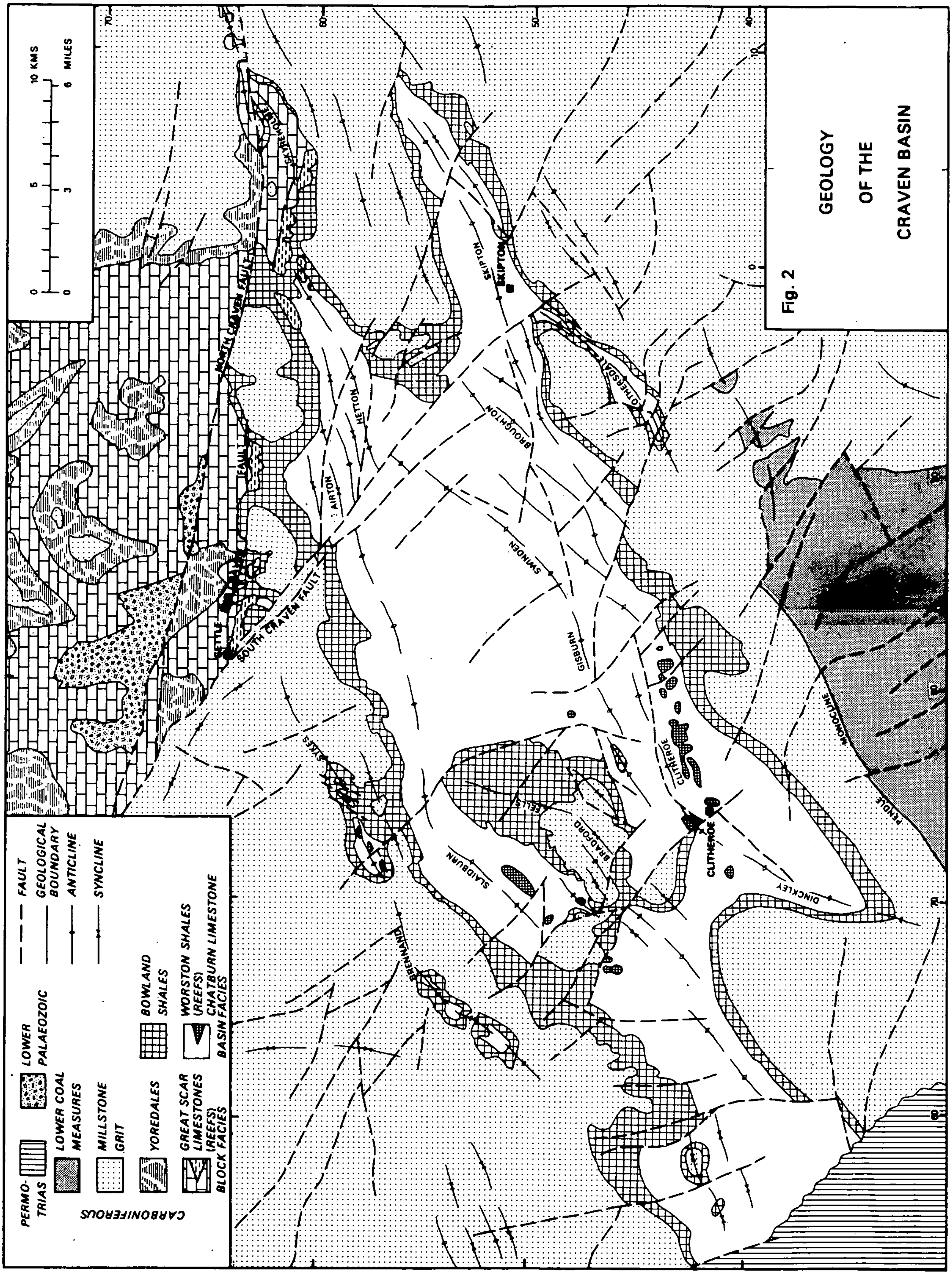


Fig. 2

GEOLOGY OF THE CRAVEN BASIN

sinusoidal to tight and narrow-crested; the style tends to intensify downwards in each fold, becoming much tighter in the Dinantian rocks than in the Namurian cover. At the deepest structural levels exposed, the folds are either close to isoclinal or their limbs are overturned, and reverse faulting or thrusting is developed. For example, the Horrocksford Hall Thrust in the Clitheroe Anticline has a horizontal displacement of 300 to 700 m. It seems likely that there has been brittle fracturing and thrusting of the Lower Palaeozoic rocks beneath each major fold in the basin.

The significance of intra-Carboniferous earth movements in the development of the basin is still controversial. The intensity of folding undoubtedly varies in different parts of the Lower Carboniferous succession. This has been interpreted as the result of local periodic pulses of tectonic activity throughout most of Carboniferous times. Alternatively, the variation in folding style may have resulted from the relative competence or incompetence of the different rocks under Hercynian stresses. A third view has recently gained ground, that the major folds began to flex during Dinantian times and locally affected sedimentation as they grew, producing many local breaks in the succession and rapidly varying sedimentary facies across the folds.

The Craven district has been subject to several glaciations but it was last covered by ice during the late-Devensian and most of the drift deposits date from that time, but glacial sands and gravels, and laminated clays are also common. Postglacial deposits form extensive alluvial terraces, while solifluction deposits are present at numerous sites. Constructional features such as moraines and drumlins cover large areas. The area is known for its widespread drumlin fields in the Craven Lowlands, especially between Skipton, Settle and Chatburn. The axes of the drumlins generally show that the ice movement was from the north or north-west.

MINING

The former mines of the Craven Basin were never as productive as those of the North Pennine orefield. The southern margin of the latter extends to the edge of the Askrigg block and the orefield includes the Grassington Moor and Greenhow areas. A detailed account of the mines in the southern part of the North Pennine orefield is shortly to be published (Dunham, in preparation). The Craven mines are limited in both size and number but their history was similar to that of the other Pennine mines. The earliest operations started in the 16th century and the period of greatest activity was from the late-17th to the mid-18th century (Raistrick, 1973). The mid-19th century saw another burst of activity, but very few mines survived the decline in metal prices later in the century and none have persisted up to the present. In the accounts of the detailed investigations given later in this Report, reference is made to the mines at Raygill and Cononley (Lothersdale), Skeleron (Rimington), Brennand, Whitendale and Ashnott, as well as trials at High South Bank (Settle), How Hill, Sykes, and Dinkling Green. The following notes deal with the other mineral occurrences worked in Craven, in order from north to south.

The Pikedaw mines north-west of Malham include several small workings for Pb, Cu and Ba [8831 6364 and 8800 6324] along thin veins, which have been tried periodically since the 16th century (Raistrick, 1954). In 1788 miners in a small Cu mine at [8746 6383] broke through into a series of natural caverns about 1000 m long in total. The passages of this phreatic system were mainly enlarged joints aligned north-east or north-west and their floors were covered by a fine silt rich in smithsonite (Dunham, in preparation). A shaft from the surface was sunk in 1806 [8757 6400] and production continued until exhaustion in 1830. A short distance to the west, several NNE–trending veins carrying Cu, Pb, Zn and Ba were tried, for example at [8693 6377], but with little success. The veins, which occupy both major joints and small faults, are sufficiently dolomitised and silicified to stand out as small ridges.

To the west of Settle the only mineralisation recorded is from a small Pb vein [7274 6377], worked just east of the Keasden road near Dovenanter End. The vein cuts flaggy sandstone along a 280° trend and was worked from a shaft now flooded. Some galena is present on the tips but the extent of the dumps is so small that there can have been little working underground.

About 2 km south of Lothersdale, small adits [962 438 and 965 437] were driven on a mineralised section of the Cowling Fault carrying Pb and Ba. The country rock is Namurian sandstone near the base of the Sabden Shales. The trials were not successful. Farther south, between Sabden and Clitheroe, a vein of Pb and Ba was tried near the Nick of Pendle [767 384]. At least nine shallow pits were dug along the WNW-trending fault where it cuts the Pendle Grit, but little mineralised ground was found. On the slopes of the Newton Fells to the west, the Victoria mine [761 504] worked galena in veins cutting calcareous mudstones just below the Pendleside Sandstone. The SE-trending veins are associated with a major fault throwing down to the north-east (Earp and others, 1961). The ore was lean but the veins do not seem to have been tested in the more promising host-rocks of the Pendleside Limestone a short distance below. Near Harrop Fold, the St Hubert mine [749 493] worked an easterly-trending vein in the uppermost Bowland Shales. Although there were pockets rich in galena on the vein, overall production was low. Nearby there are other minor trials on veins cutting the Worston Shales near Rodhill [763 473] and above Springs Wood [767 487] but no economic mineralisation has been proved here.

In the disused workings throughout Craven, the commonest minerals are galena and baryte, with subordinate Zn and Cu minerals generally. Gangue minerals are calcite and pyrite, with fluorite in the mines in the Askrigg block. Apart from the remarkable Pikedaw calamine deposit, the worked minerals generally occur in thin veins, limited in lateral extent and situated along joints or minor faults. There is little evidence to suggest an association between mineralisation and major faults within the basin. Massive limestones and sandstones tend to be favoured host-rocks but veins do continue into adjacent mudstone sequences.

GEOCHEMICAL SURVEYS

DRAINAGE SURVEY

A reconnaissance survey of the whole drainage system of the Craven Basin was carried out to delineate anomalous areas and establish a background against which anomalies could be assessed. During the reconnaissance survey 970 stream sediments were collected from an area of about 900 km^2. Panned concentrates were collected from many of the localities, and a limited number of water samples were also taken. During the survey the flow regime of the rivers and streams varied considerably with rainfall, but it is unlikely that this altered analytical values sufficiently to obscure geochemical anomalies. Man-made geochemical anomalies were recognised, resulting from industrial activity or the mining of metallic ores in the past. The extent of contamination from old mines and dumps is often difficult to recognise, in some places mineral debris being transported for long distances by small streams. Another limitation on the value of the survey as a guide to bedrock mineralisation is the presence of extensive drift deposits over large areas of the basin. This is particularly acute in the drumlinised areas where the drift is commonly thick and impermeable, and even large streams have failed to cut down to bedrock. The material sampled here may have suffered secondary, or even tertiary, transport and so may bear little relation to the solid geology.

The density of sampling varied with the number of water courses. Relatively few samples were collected in the north-east where the topography is karstic, and near the internal watersheds within the basin. Samples were collected from the active portion of the stream alluvium in all the main water courses.

Copper, lead and zinc values in the minus 100 mesh stream sediment material and zinc values in the surface waters were obtained by AAS techniques, and XRF analyses provided data on copper, lead, zinc, barium and tin contents of the panned concentrates.

Simple statistical calculations performed on the entire population indicate the following values for the mean plus one standard deviation:

	Stream sediments	*Pan concentrates*
Copper	30 ppm	50 ppm
Lead	70 ppm	100 ppm
Zinc	240 ppm	500 ppm
Barium	—	2000 ppm

Values of these elements appear to be low compared with similar areas where sulphide mineralisation has been proved. Only 3–4% of the samples show anomalous values well above background. Figure 3 shows all the sample sites and the locations of anomalies for Cu, Zn, Pb in sediment, Cu, Zn, Pb, Ba and Sn in pan concentrates, and Zn in water.

Pan concentrates from the sites of anomalous sediment samples were examined to identify discrete mineral phases and were also analysed for Sn as a guide to industrial contamination. A threshold value of 20 ppm Sn was taken as background and several localities showed consistently high values due to pollution. For example, Savick Beck [590 383] below Longridge shows a dispersion train at least 3 km long of anomalous Sn with Pb, Cu and Zn. On the other hand, Westfield Brook and Sparting Brook just to the north show only slightly anomalous Sn values which probably mark very local contamination. Further east, anomalous Sn values up to 650 ppm are found along Chipping Brook and several of its tributaries, both above and below Chipping village. In the following summary, the data are described across the basin from south-west to north-east.

Lead in stream sediments Across the drift-covered ground north of Preston a few scattered samples have values some tens of ppm above background. Anomalies in Savick Beck [590 360] below Longridge probably arise from industrial pollution, but the cause of high values in the tributaries of Westfield Brook at Goosnargh [559 369] and at Brook Farm [571 383] is unknown. Farther along the Chipping valley, five anomalous values up to twice background are scattered along Chipping Brook (e.g. [612 443], [624 427] and similar values are present along the River Hodder near Whitewell. The mineralisation in the core of the Sykes Anticline gives local anomalies in Langden Brook [627 518] and the more extensive mining at Brennand is marked by values up to 870 ppm in a dispersion train at least 3 km long in the River Dunsop. Crag Beck draining the Ashnott area shows a group of anomalies reaching a maximum of 430 ppm. These probably mark float from the disused mines at Ashnott, but the lower anomalous values near the head of Birkett Brook [681 473], close to the south-west, cannot be related to previously-known mineralisation.

Copper in stream sediments Several scattered anomalous values between 30 and 90 ppm are present in the streams flowing towards Preston, while around Chipping values reach 220 ppm. At Ashnott the maximum value reaches 60 ppm. At Sykes there are low-anomalous samples with values of 35–50 ppm. Values of 30–40 ppm are seen in streams east of Settle. South of Malham Tarn are anomalous values of between 30–180 ppm in several streams. In the eastern area there are scattered anomalous values (65–150 ppm) upstream from Skipton on the River Aire. A few anomalous values just above background are present in streams south and south-west of Grassington.

Zinc in stream sediments West of [600] only a single low-anomalous value is present, while at Chipping a few low-anomalous samples were found.

Around Dinkling there are scattered values of up to 1200 ppm, but no dispersion trains are present. At Ashnott are found numerous anomalous samples, which reach a maximum 1540 ppm and form short dispersion trains. At Sykes scattered values reach 470 ppm. At St Hubert a group of anomalous values was found, with a maximum value reaching 2850 ppm. North of this, scattered values of 400–600 ppm are present adjacent to the reservoir. To the east of Settle the southward flowing streams show numerous anomalous values of between 240 and 700 ppm with isolated values reaching a maximum of 1020 ppm. The streams adjacent to Skeleron–Todber have numerous anomalous values, with a maximum of 3550 ppm near the old mines. To the east of here the sampling produced a few scattered anomalous values just above background. North and west of Skipton scattered values of between 240 and 390 ppm are present, with a single value reaching 1580 ppm. Low-anomalous values are seen west of Grassington, with numerous values of between 250 and 960 ppm in the streams flowing towards Grassington.

Lead in pan concentrates In the west of the area there are a few scattered low-value anomalies. A group of anomalies just above background occurs near Dinkling, while at Ashnott a large group of anomalies occurs with values between 200 and 5300 ppm forming a dispersion train. There are groups of anomalies at Sykes and Brennand with values up to 1460–2050 ppm. Anomalies with values of 1500–2650 ppm occur near St Hubert. North of this are scattered anomalous values between 100 and 1100 ppm, with scattered anomalous values in adjacent areas. To the east of Settle there is an isolated value of 25125 ppm. Anomalous values between 140 and 3025 ppm are seen north and east of Skipton, and south-west of Grassington are anomalous values between 180 and 500 ppm, while the River Wharfe above Grassington has a number of scattered values between 790 and 12250 ppm.

Copper in pan concentrates In the west of the area are a few anomalous values between 75 and 650 ppm. In the Chipping–Dinkling area there are a few anomalous samples just above background, while at Ashnott a small group of samples gives 60–140 ppm. In the Sykes–Brennand area are groups of samples with 60–770 ppm. In the area north of Clitheroe only six samples gave values in the range 87–172 ppm. Around the Skeleron area are a series of weak dispersion trains (50–137 ppm), with some other scattered points above background, but north-west of this, in the area extending to Settle, Grassington and Skipton, only nine samples gave anomalous values (50–220 ppm).

Zinc in pan concentrates Scattered values of 650–720 ppm occur in the south-west, with a dispersion train west of Chipping which shows a maximum value of 2200 ppm. Scattered anomalous samples with low values between 500 and 900 ppm occur in the area around Chipping and Dinkling with values of up to 2570 ppm in a stream north of Chipping. At Ashnott a group of anomalous samples with a maximum of 10650 ppm was recorded. At [370 445] a group of samples gave values of 500–900 ppm, and at St Hubert the values ranged between 1300 and 28000 ppm. In the streams north of Victoria are scattered anomalous values of between 500 and 2200 ppm. In the same general area are scattered anomalous values, together with dispersion trains reaching a maximum value of 7200 ppm. Around Skeleron numerous values are seen between 600 and 4675 ppm. One stream north of Settle and another to the east have values of 500–4800 ppm. There are few low value anomalous samples in the east of the area.

In seven areas (outlined and numbered 3–9 on Figure 3) the anomalous values obtained from the drainage reconnaissance were considered to be of sufficient interest to justify follow-up investigations. These investigations, together with studies in other areas, are described below in the section on 'Detailed investigations'.

SOIL SAMPLING

Soil samples were collected as part of the detailed investigations described below. The areas in which this method was used are: Ashnott (centred on [SD 6984] Rimington [8144], Elmridge [5941], Dinkling Green [6446], Cow Ark [6846], Lothersdale [9645], Copter Syke [7157], How Hill [7459], Agden [7953], Settle–Malham [8563], Orms Gill Green [8759] and Hetton Common [9362].

At each site the initial sampling was done using a hand auger, the material being obtained generally from depths of 60–80 cm, below the humic layer. In areas where the drift was known to be thicker, and also for further 'follow-up' sampling, mechanical augers were used to obtain samples from greater depths. If the superficial deposits were of less than about 5–7 m the basal till could be sampled. The density of the soil sampling varied (partially dependent upon the overall size of the area to be examined) between grids of 200 × 50 m and 350 × 150 m, representing sample densities between approximately 125 and 30 per km^2. Re-sampling at closer intervals was undertaken in the more interesting areas as necessary. Sampling of the auger profiles was also undertaken at some sites in order to investigate in more detail the distribution of the metals in depth. The chemical data for Cu, Pb and Zn obtained from the soils at each site were subjected to a simple statistical treatment involving the determination of the arithmetic mean ($\bar{x}$) and the standard deviation (s). Values in excess of $\bar{x}$ + 2s were regarded as anomalous. Some populations are highly positively skewed, and in these the highest values (not normally amounting to more than 3–4% of the total population) were not used in the statistical calculations, since they would have an excessive effect upon the calculations which defined the $\bar{x}$ + 2s values.

DRILLING

The exploratory drilling programme included both rotary percussion boreholes and cored boreholes. The rotary percussion holes were drilled by contractors and enabled ground to be tested with a large number of shallow holes. The method is cheap and rapid, the air-flush equipment producing a stream of rock dust and chippings representative of the lithologies penetrated which allows a simplified stratigraphy to be established. The rock debris is suitable for geochemical analysis and samples, each representing 1 m of rock penetrated, were systematically collected. Grab samples were then analysed, after grinding, by atomic absorption spectrophotometry.

The cored boreholes were drilled by an IGS drilling team using a JKS 300 rig, producing good recovery of core with diameters of either 26.9 mm or 36.3 mm. The core was analysed on site with a portable X-ray fluorescence analyser. In addition, sludge samples were taken under optimum drilling conditions, with a good return of drilling fluid and therefore little contamination between sampling intervals. It was found most convenient to collect samples over a 10 ft (3.05 m) interval, this being the length of the core-barrel. The sample was freeze-dried and analysed by the portable XRF instrument. Samples of core for more detailed analysis were then selected and split lengthwise, one half being stored for reference and mineralogical study. The other half was cut into 1 m lengths and crushed, and the powders analysed by AAS methods.

GEOPHYSICAL SURVEYS

An examination of the existing regional gravity and aeromagnetic data was made in an attempt to clarify the nature of the deeper parts of the basin and the basement rocks. Three short seismic traverses were measured at the northern margin of the basin to try to establish locally the form of the bounding structures and the depths to basement. A low-level airborne survey was flown over the Craven Faults, and some of the anomalies detected were investigated on the ground. The results of this broad-scale work are described in this section. Detailed surveys were also carried out, using principally IP and EM methods. Some 15 km^2 were covered with these surveys, which are described later in the Report.

REGIONAL AEROMAGNETIC DATA

The aeromagnetic map (Geological Survey of Great Britain, 1965) shows low magnetic values and gradients over most of the Craven Basin, suggesting that magnetic

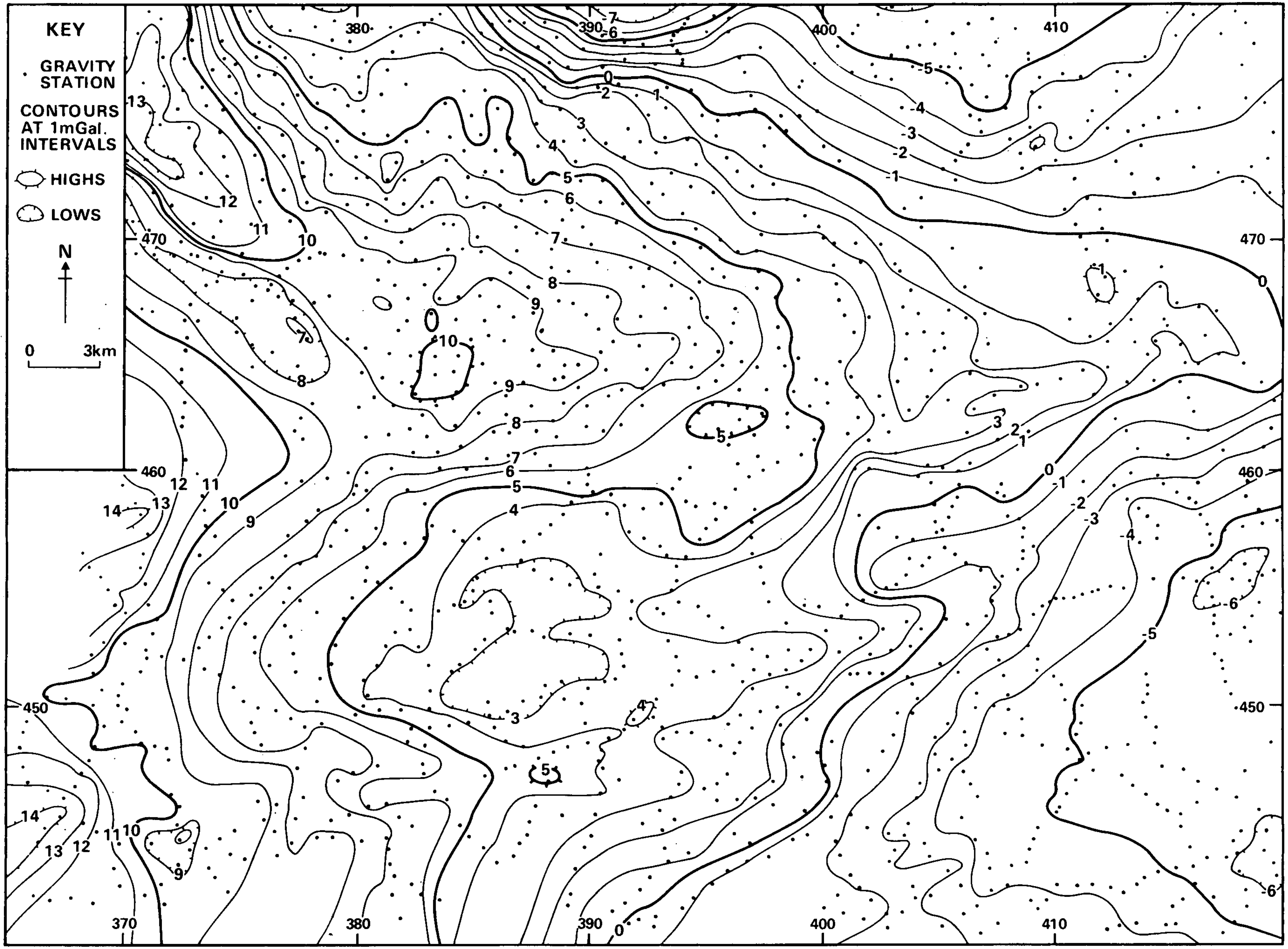


Fig.4 Bouguer anomaly map of the Craven district

basement rocks are at a considerable depth or absent altogether. The magnetic low is flanked by anomalies of deep and unknown origin on the south and east sides whilst farther north, over the southern part of the Askrigg Block, a group of ESE-trending anomalies is due, in part at least, to magnetite-bearing sediments within the pre-Carboniferous basement (Wilson and Cornwell, 1982). The central axis of the magnetic low is aligned roughly north-eastwards parallel with the main folds in the basin (Figure 6).

REGIONAL GRAVITY DATA

The Bouguer anomaly map (Figure 4) is based on the 1:250 000 Bouguer anomaly map of Liverpool Bay (Institute of Geological Sciences, 1978) combined with data from about 650 new gravity stations established during the course of the investigations described in this report. Elevation control was usually provided by Ordnance Survey bench marks and spot heights, but levelling data were also supplied by construction firms and the Yorkshire Water Authority. On some moorland areas barometric levelling was used but proved unreliable unless very short control loops were used, when an accuracy of ± 1 m could be expected. Where this was not possible, traverses were repeated using tacheometric surveying techniques. Gravity values were calculated either with reference to the NGRN73 value at the Skipton FBM or to a local base established at Hellifield [3855 4564] and tied to the Skipton FBM. A density value of 2.58 g/cm^3 was used for the Bouguer correction near the Craven Faults; this value is a reasonable approximation for the overall density of the Lower Carboniferous sediments in both the cyclothemic sequences of the Askrigg Block and the predominantly argillaceous sequences of the Craven Basin. Detailed density information is not available for the whole area but the values in Table 1 have been assembled from IGS data and from published sources, including Whetton and others (1956) and Myers and Wardell (1967).

Table 1 Densities of main rock types in the Craven area.

		Density g/cm^3
Carboniferous	Millstone Grit	2.40
	Yoredales	2.60
	Shales (Lower Bowland)	2.54
	Sandstones	2.42
	Limestone (Chatburn)	2.70
Silurian	Various sediments	2.73
Ordovician	Limestone and volcanic ashes	2.70
Ingletonian	Various sediments	2.7–2.8

From these data it would appear that the main density contrast north of the Craven Faults occurs between the Yoredale rocks and the underlying Lower Palaeozoic basement rocks. South of the faults, the main density change probably occurs at the base of the Bowland Shales. The Chatburn Limestone and the sediments beneath probably have a density similar to that of the Lower Palaeozoic rocks but the latter have not been proved in the basin. An inspection of the Bouguer anomaly data for northern England suggests that there is a large-scale regional increase of values westwards towards the Irish Sea. Within the area shown in Figure 4, this regional field appears to consist of an approximate linear increase of Bouguer anomaly values by about 11 mGal (about 0.2 mGal/km) from east to west. On this regional gradient are superimposed the more restricted anomalies due to density changes occurring near the surface and of interest to the present investigation. A residual Bouguer anomaly map was therefore prepared (Figure 5) by removing the regional field from the observed data.

The Bouguer anomaly map of the area may be divided into four zones (Figure 6). The low values appearing in zone 1 lie on the flanks of the pronounced Bouguer anomaly low over the Wensleydale Granite (Dunham, 1974). There does not appear to be any coincidence of the Askrigg Block mineralisation with the buried granite (Bott, 1961, 1967) as is the case for the Alston Block. The Grassington Moor–Greenhow mineral field occurs over an area where the contours trend regularly north-westwards, and are sufficiently close to suggest that there may be a fault in the basement (Figure 5). The same trend continues north of the area shown and passes along the southern flank of the concealed Wensleydale Granite. Whether this proposed fracture is related to the Grassington Moor mineralisation is unknown.

In zone 2 a north-westerly trending high has particularly steep gradients on the south-west side along the line of the Craven Fault. The anomaly is most pronounced over the Ingletonian sediments of Chapel-le-Dale but does not continue over the Upper Ordovician and Silurian sediments of Ribblesdale. The Ingletonian sediments may be responsible for the high if the density data in Table 1 are representative, but an insufficient number of sites was sampled to make this certain. The small feature at [384 464], which could be a continuation of the main high, coincides with the block of Carboniferous sediments between the North and South Craven faults and suggests that in this area Ingletonian rocks may form the basement. In zone 3 along the western edge of the map (Figure 6) high values occur over the thick Namurian sequence of the Bowland Fells. The presence of high Bouguer anomaly values over thick sequences of low density sediments is unexpected; after removing the regional gradient, these high values still remain (Figure 5). The basement rocks here probably lie closer to the surface than elsewhere in Craven or they may have a particularly high density. It is also possible that the Dinantian succession contains particularly thick limestones, although even a marked thickening seems inadequate to account for the whole effect. The south-eastern margin of zone 3 is marked by a pronounced zone of NE-trending contours. The well-defined nature of this gravity feature suggests that the density boundary it represents is a major basement structure, perhaps a fault which runs into the eastern part of the North Craven Fault (Figure 6). The seismic reflection profiles described elsewhere in the report cross this gravity feature. The high values of zone 3 decrease northwards to form a low along the south-western side of the Craven Fault, which is probably due to the presence of low-density Upper Carboniferous sediments. These are exposed around Ingleton [370 472] and may extend further to the south-east beneath an extensive cover of drift.

Zone 4 is dominated by anomalies which are thought to be due to folds in the Dinantian rocks. The main density contrasts (Table 1) are likely to be between, on the one hand, the shales and sandstones of the Namurian and Dinantian successions and, on the other, the thick Dinantian limestones and the basement rocks. This contrast, however, is not likely to be large or even persistent, as lateral changes in the lithologies of both the Carboniferous sequence and the basement rocks occur. The Bouguer anomaly values in Figures 4 and 5 are also likely to have been distorted in places due to the selection of a

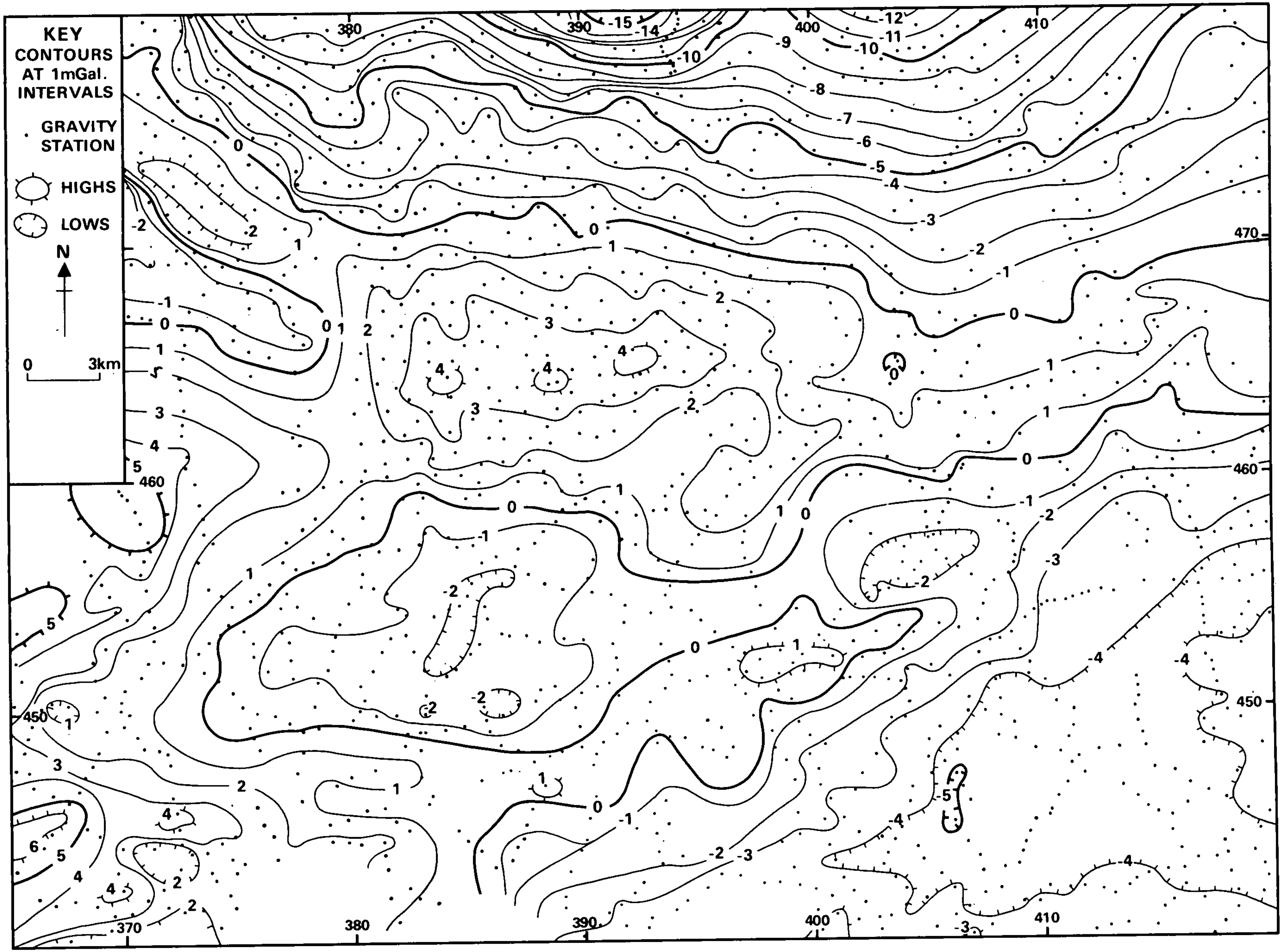


Fig.5 Residual Bouguer anomaly Map of the Craven district

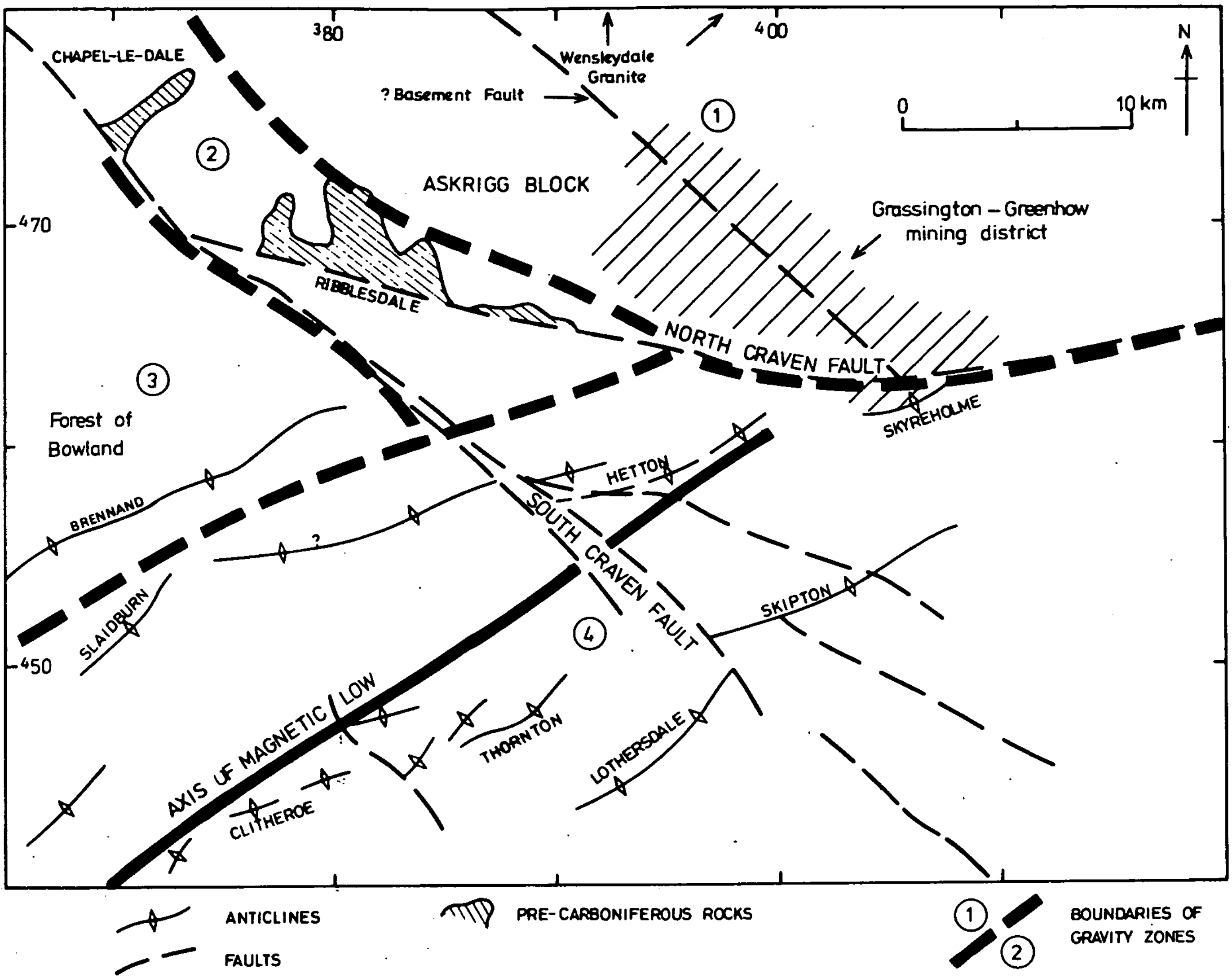


Fig.6 MAP OF GRAVITY ZONES AND STRUCTURES

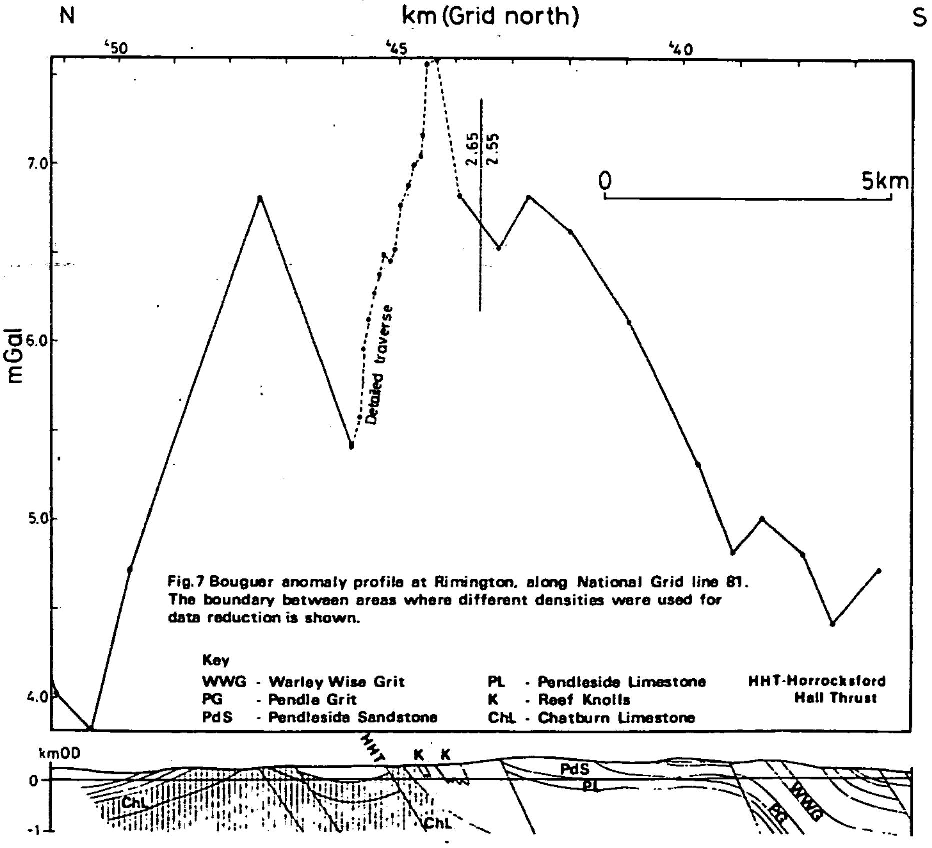


Fig.7 Bouguer anomaly profile at Rimington, along National Grid line 81. The boundary between areas where different densities were used for data reduction is shown.

Key

WWG	- Warley Wise Grit	PL	- Pendleside Limestone	HHT-Horrocksford Hall Thrust
PG	- Pendle Grit	K	- Reef Knolls	
PdS	- Pendleside Sandstone	ChL	- Chatburn Limestone	

standard density for the Bouguer reduction which locally may not be representative.

Most of the principal anticlines in the basin can be recognised on the Bouguer anomaly map. They are particulary clear where Dinantian limestones in the core of the folds are surrounded by less-dense Namurian sediments, as in the Skipton and Chipping anticlines. One continuous anomaly in the southern part of the area follows the line of the Clitheroe, Thornton and Skipton anticlines but there is no distinct feature associated with the Lothersdale Anticline. The Skyreholme and Hetton anticlines are also indicated by Bouguer anomaly highs but there is no westward continuation of the highs to connect this structure with the Slaidburn Anticline. There is no obvious explanation for the low Bouguer anomaly values in this area around [380 455]; possibly the Carboniferous sequence hereabouts is underlain by a low density basement.

A trial detailed gravity traverse was made near Rimington, with stations at 100 m intervals. The profile (Figure 7) agrees well with the surface geology, a broad high occurring over the Clitheroe anticline with lows over the Namurian rocks to the south and Worston Shales to the north. The detailed traverse shows a sharp high at 4445 N, to the south of the Horrocksford Hall Thrust which brings steeply dipping Chatburn Limestone to surface. To the north of the thrust a low of 1.4 mGal corresponds to a local syncline. Detailed surveys of this type might be useful in delimiting anticlinal cores beneath thick drift elsewhere in the basin.

The large area of consistently low values in the south-east corner of the map (Figure 5) occurs over a thick Namurian sequence of sandstones and shales. The low values are consistent with thick low-density sediments. The north-western margin of this low is marked by a pronounced gradient zone which coincides with the Pendle monocline. Inspection of the Bouguer anomaly map for the surrounding areas shows that this gradient zone is extensive and could reflect a large NE–trending basement discontinuity.

LOW-LEVEL AIRBORNE SURVEY AND GROUND FOLLOW UP

A combined magnetic, electromagnetic and radiometric airborne survey was flown by helicopter over the area of the Craven Faults and the adjacent part of the Askrigg Block, including the old mining areas of Grassington Moor and Greenhow Hill (Figure 8). The depth penetration of the electromagnetic equipment is not great, but, as the superficial deposits across these moors are not generally thick, this was not a major drawback. The extensive outcrop of the Great Scar Limestone gives a karstic topography within which stream sediment sampling is less effective than usual, so the airborne work across this particular area was the major method of reconnaissance. There were few difficulties in maintaining the prescribed flying height for the helicopter of 60 m above the ground since the topographical variations are generally gradual; the steepest slopes are along the limestone scarps of Stockdale and Malham Cove, and in the deep ravines of Gordale and Trollers Gill. Artificial conductors, such as water pipes and electrical cables, are common around the villages and farms and gave rise to many electromagnetic anomalies and a smaller number of magnetic anomalies. A trial airborne survey carried out at the same time over a much smaller area at Lothersdale is described in the appropriate section later in this report. The original flight records and copies of the 1:10 560 scale magnetic and electromagnetic maps for both the Craven Faults and Lothersdale areas are deposited with the Institute's Applied Geophysics Unit. The radiometric data have not been compiled or interpreted in detail but are available for inspection as flight profiles.

The survey was under the technical supervision of the contractors, Hunting Geology and Geophysics Ltd. The outline of the survey area is defined by the co-ordinates [3820 4680, 3850 4680, 3950 4650, 4000 4650, 4000 4690, 4120 4680, 4150 4650, 4150 4640, 4060 4600, 4040 4600, 3970 4610, 3970 4620, 3820 4620]. A total of 939 line km was flown along flight lines aligned north-south and spaced at 200 m. The EM measurements were made using a transmitter and receiver both housed in a 'bird' towed 30 m below the helicopter, the co-axial vertical loop system giving a transmitter–receiver separation of 10 m. A primary field frequency of 1600 Hz was used and both the in-phase and out-of-phase components of the received resultant field were recorded. The magnetometer was attached to the EM cable about 15 m below the helicopter. The position of the helicopter was recorded by taking vertical photographs at 1 second intervals, and where flight lines were seen to deviate excessively from the 200 m spacing they were re-flown. A radio altimeter assisted in maintaining nominal ground clearance. The maximum permitted noise levels were 10 ppm peak-to-peak for the EM records and 3 nT peak-to-peak for the magnetometer record. Further details of the technical aspects of the survey are given in Burley and others (1978).

Magnetic data

The magnetic data showed no significant anomalies, so a detailed account is not given here. The survey area lies on the southern flank of a major, positive, magnetic anomaly, extending from Ribblehead via Upper Wharfedale and Pateley Bridge to Harrogate, and caused in part, at least, by magnetite-bearing rocks in the Lower Palaeozoic basement of the Askrigg Block (Wilson and Cornwell, 1982). There is, therefore, a marked regional gradient with the magnetic contours aligned north-eastwards near Settle, eastwards around Malham and north-westwards beyond Grassington. Several small strong magnetic anomalies were recorded but these coincide with, and seem due to, industrial sites. Weaker anomalies, 5 to 10 nT above background, occur at several localities, but are not considered to be significant as they are generally restricted to single flight lines.

EM data

The EM data were interpreted from the flight records of both the in-phase and out-of-phase values. A simplified contoured map of the in-phase measurements is shown in Figure 8b. Anomalies which are too weak to give contour closures can only be located by inspecting the flight records. To preserve clarity, negative anomalies, which are generally caused by electrical transmission lines, have not been shown and closures confined to a single flight line are also omitted. Many EM anomalies were produced by artificial conductors. For example, National Grid transmission lines leading to Grassington and Malham, and others near Greenhow, Malham and Settle, all give strong negative EM anomalies although the numerous local transmission lines serving farms and villages do not produce such features. Metal pipes, on the other hand, produce anomalies varying in size from a few ppm to more than 100 ppm. When well defined, these anomalies have a characteristic symmetrical shape but when they are

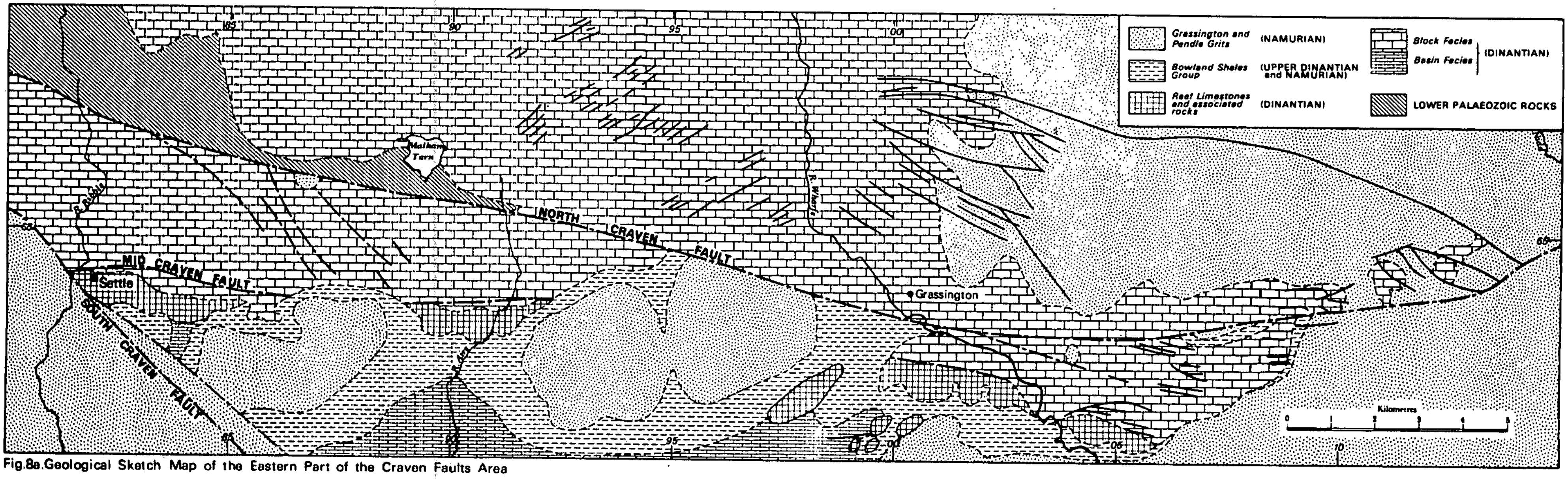


Fig.8a.Geological Sketch Map of the Eastern Part of the Craven Faults Area

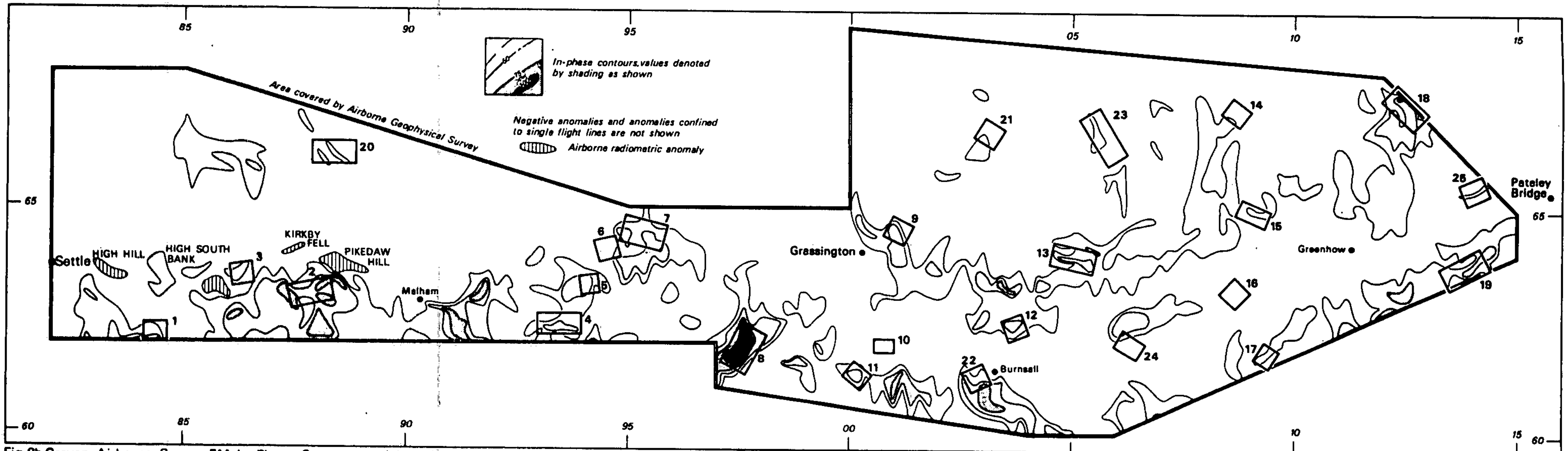


Fig.8b.Craven Airborne Survey:EM In-Phase Contours and Location of Ground Target Areas

Table 2 Target locations and airborne EM indications
(Anomaly amplitudes in ppm refer to the in-phase component, to the nearest 25 ppm)

Target	*Grid reference*	*Description of airborne EM anomaly*
1 Scaleber	842 621	Sharp anomaly on single flight line, 100 ppm.
2 Kirkby Fell	880 632	Arcuate anomaly, 75 ppm. Close to Mid-Craven Fault.
3 Ryeloaf Hill	862 634	Broad anomaly, up to 50 ppm. Close to Mid-Craven Fault.
4 Hetton Common	934 624	Well defined E–W anomaly, up to 75 ppm. Length 750 m.
5 Pot Gill	941 633	Broad anomaly up to 75 ppm. Close to Mid-Craven Fault.
6 Bordley	945 640	E–W anomaly, 25 ppm. Length 200 m.
7 Threshfield Moor	953 644	Broad anomaly, up to 50 ppm. Adjacent to North Craven Fault.
8 Linton Moor	976 620	Well defined NE–SW anomaly, up to 125 ppm. Length 1 km.
9 Grassington	010 646	Sharp anomaly on single flight line, 125 ppm.
10 Elbolton	009 619	Sharp anomaly on single flight line, 175 ppm, over mineralised reef knoll.
11 Stebden Hill	002 612	Broad anomaly, 75 ppm. Several mineral veins in immediate vicinity.
12 Rainlands	036 623	Broad anomaly, 75 ppm. Close to branch of North Craven Fault.
13 Hartlington Pasture	050 638	Sharp, well defined E–W anomaly, up to 75 ppm. Length 600 m.
14 Ashfold Side	087 672	Sharp, negative NW–SE anomaly. Parallel to adjacent mineral vein.
15 Jack Hole Moss	090 650	Unusual anomaly pattern. Values up to 50 ppm.
16 Stump Cross	086 632	Sharp, negative NW–SE anomalies. Close to mineral veins and Craven Fault.
17 Tarn Moss	094 618	NE–SW anomaly, 25 ppm. Length 400 m. Broadens rapidly to east.
18 Heathfield Moor	126 673	Anomalies up to 100 ppm on boundary of survey area.
19 Gillbeck	140 637	Broad SW–NE anomaly up to 75 ppm. Length 900 m.
20 Malham Smelt Mill	884 661	Pair of NW–SE anomalies, 25 ppm. Parallel to nearby mineral veins.
21 Coalgrove Beck	032 667	Weak anomalies in mining area. Possible correlation with veins.
22 Joy Beck	028 613	Weak anomalies above disturbed background. Close to Mid-Craven Fault.
23 Red Scar Mine	057 665	Anomaly 25 ppm, coincident with vein. Length 1200 m. Large in/out phase ratio.
24 Appletreewick Pasture	063 620	Anomaly, 25 ppm. Position and orientation indicate vein extension.
25 Riggs House	140 654	E–W anomaly, 25 ppm. Length 500 m.

weaker they may resemble anomalies from mineral veins, so all anomalies of this type have been checked on the ground.

A programme of ground surveys was carried out to locate more accurately the features responsible for each of the selected airborne anomalies so that those which might reasonably be attributed to mineralisation could be identified. The areas covered by the ground surveys are shown in Figure 8b, superimposed on the corresponding airborne anomalies where these are of sufficient amplitude to be shown. Anomalies were selected for follow-up on the basis of the absolute and relative amplitudes of their in-phase and out-of-phase responses, and their extent and location relative to geological features. Brief details for each target are given in Table 2. As explained above, it was necessary to follow up some anomalies even though these appeared to be due to man-made features. Similarly, it was considered advisable to follow up, for orientation purposes, some anomalies which appeared to be related to particular stratigraphical formations. Brief geological inspections of certain areas were also made at this time.

Few difficulties were experienced in obtaining access to land as most of the area is used only for rough grazing. The district is well served with roads and tracks, and vehicle access to within a few hundred metres of the survey areas was generally possible, though the moorland area north of the Grassington–Pateley Bridge road is an exception with the nearest permitted vehicle access being up to 3 km distant. Access on foot to this latter area is also restricted as the greater part of this area is used as a grouse-moor.

The ground EM surveys were carried out using the Slingram, Turam and VLF (Very Low Frequency) methods. Generally it was sufficient to use only one method over each anomaly but in particularly promising cases, two or more methods were used. The Slingram equipment was operated at a frequency of 2640 Hz, with a transmitter-receiver separation of 60 m and stations generally 30 m apart. The Turam equipment was operated at a frequency of 660 Hz with additional measurements at 220 Hz over particular anomalies. The receiving coil separation and station spacing was usually 40 m. The VLF equipment was tuned to an appropriate transmitting station chosen from Rugby (GBR, 16.0 kHz), Moscow (UMS, 17.1 kHz) or Maine (NAA, 17.8 kHz). Stations were spaced at either 15 m or 25 m. Earth resistivity equipment was used in the Wenner configuration on Threshfield Moor to fix the position of the North Craven Fault. The profiles were measured with electrode and station spacings of 20 m. Table 3 gives details, for each of the target areas, of the number of traverses measured, their total length and spacing between them. In five areas – Hetton Common, Threshfield Moor, Stump Cross, Ashfold Side, Red Scar – the results are sufficiently encouraging to deserve the fuller description given in the detailed investigations section. In ten of the target areas, man-made conductors proved to be the cause of the airborne anomalies. The conductors were metal pipes of various kinds. In eight of these areas it was sufficient only to carry out a visual inspection or to measure trial geophysical traverses.

Surveys in certain of the areas showed broad anomalies indicative of shallow-dipping conductors. The subsequent

Table 3 Ground geophysical surveys and results

Target	*Ground survey*	*Results*
1	Slingram. 3 traverses. Spacing 150 m. Total length 1200 m.	No anomaly located. Airborne anomaly probably caused by iron culvert pipe located between ground traverses.
2	Turam. 6 traverses. Spacing 160 m. Total length 2000 m.	Broad anomaly indicative of shallow-dipping stratigraphical conductor. Geological evidence supports this.
3	Slingram. 2 trial traverses.	Airborne anomaly coincides with water pipe.
4	Turam. 5 traverses. Spacing 100/200 m. Total length 1800 m.	Ground geophysical anomaly unexplained. Coincident geochemical anomaly.
5	Slingram. 4 traverses. Spacing 100 m. Total length 1200 m.	Several weak anomalies, possibly due to shales and landslipping, and not considered significant.
6	Slingram. 4 traverses. Spacing 100 m. Total length 1200 m.	Airborne anomaly coincides with water pipe.
7	Turam. 6 traverses. Spacing 160 m. Total length 3300 m.	Ground geophysical anomalies unexplained. Detailed Slingram, VLF and resistivity follow-up.
8	Slingram. 4 traverses.	Survey not completed. Airborne anomaly re-interpreted as due to stratigraphical conductor.
9	Inspection of area.	Airborne anomaly coincides with industrial pipeline.
10	Slingram. 2 traverses. Total length 700 m.	No ground anomaly comparable with airborne, which is therefore considered spurious.
11	Slingram. 6 traverses. Spacing 100 m. Total length 1800 m.	Pair of linear anomalies, though only weak. Parallel to local mineral vein trends.
12	Slingram. 1 trial traverse.	Airborne anomaly coincides with water pipe.
13	Turam. 6 traverses. Spacing 160 m.	Airborne anomaly coincides with reservoir pipeline.
14	Slingram. 4 traverses. Spacing 100 m. Total length 1400 m.	Favourable anomalies led to extensive VLF surveys in the area.
15	Slingram. 4 traverses. Spacing 200 m. Total length 1700 m.	Several weak anomalies. No correlation between these, and they are therefore not considered significant.
16	Slingram. 3 traverses. Spacing 100 m. Total length 1200 m.	Area subsequently covered by VLF and IP surveys.
17	Slingram. 4 traverses. Total length 1700 m.	No significant anomalies recorded.
18	Turam. 8 traverses. Spacing 80/160 m. Total length 3600 m.	Broad anomaly indicative of shallow-dipping stratigraphical conductor.
19	VLF. 2 traverses.	Survey not completed; airborne anomaly re-interpreted as due to stratigraphical conductor.
20	Shallow-penetration EM.	Airborne anomaly coincides with iron pipe.
21	Slingram. 1 trial traverse.	Airborne anomaly coicides with industrial pipeline.
22	Inspection of area.	Airborne anomaly coincides with water pipe.
23	Turam. 10 traverses. Spacing 100 m. Total length 3000 m.	Favourable anomalies led to extensive VLF surveys in the area.
24	Slingram. Trial traverses.	Airborne anomaly coincides with iron pipe.
25	Inspection of area.	Airborne anomaly coincides with water pipe.

Notes

1 Target numbers are those assigned to localities in Table 2

2 At five localities (4, 7, 14, 16, 23) preliminary results reported here justified further work described later in this report

geological assessment of these areas suggested that particularly conductive horizons within the Bowland Shales were the cause of these anomalies and of the corresponding airborne anomalies. However, it appears from a comparison of the airborne EM results with the geology that this relationship is not consistent throughout Craven and that other factors, possibly folding, lateral lithological variations or the amount of groundwater, also influence the pattern of the airborne EM anomalies.

Radiometric data

The radiometric data from the Craven airborne survey were not processed or compiled into map form. However, the flight records were inspected for prominent anomalies, the flight line control points being used to obtain their locations. Four such anomalies were seen on the flight records, all occurring in the country between Settle and Malham. These anomalies occur over local outcrops of massive limestone between High Hill and Pikedaw.

The anomalies were followed up by ground surveys and the results are briefly described in the Settle–Malham detailed investigation. No other comparable anomalies are evident, though weak anomalies occurring throughout the area, not readily distinguishable from changes in background levels, may be related to lithological changes in the Bowland Shales.

SEISMIC TRAVERSES

Current views on mineral genesis point to the margin of the Dinantian basin between Settle and Malham as an area of particular exploration interest. It was decided, therefore, to try to establish locally the position and nature of the faults bounding the sedimentary basin and

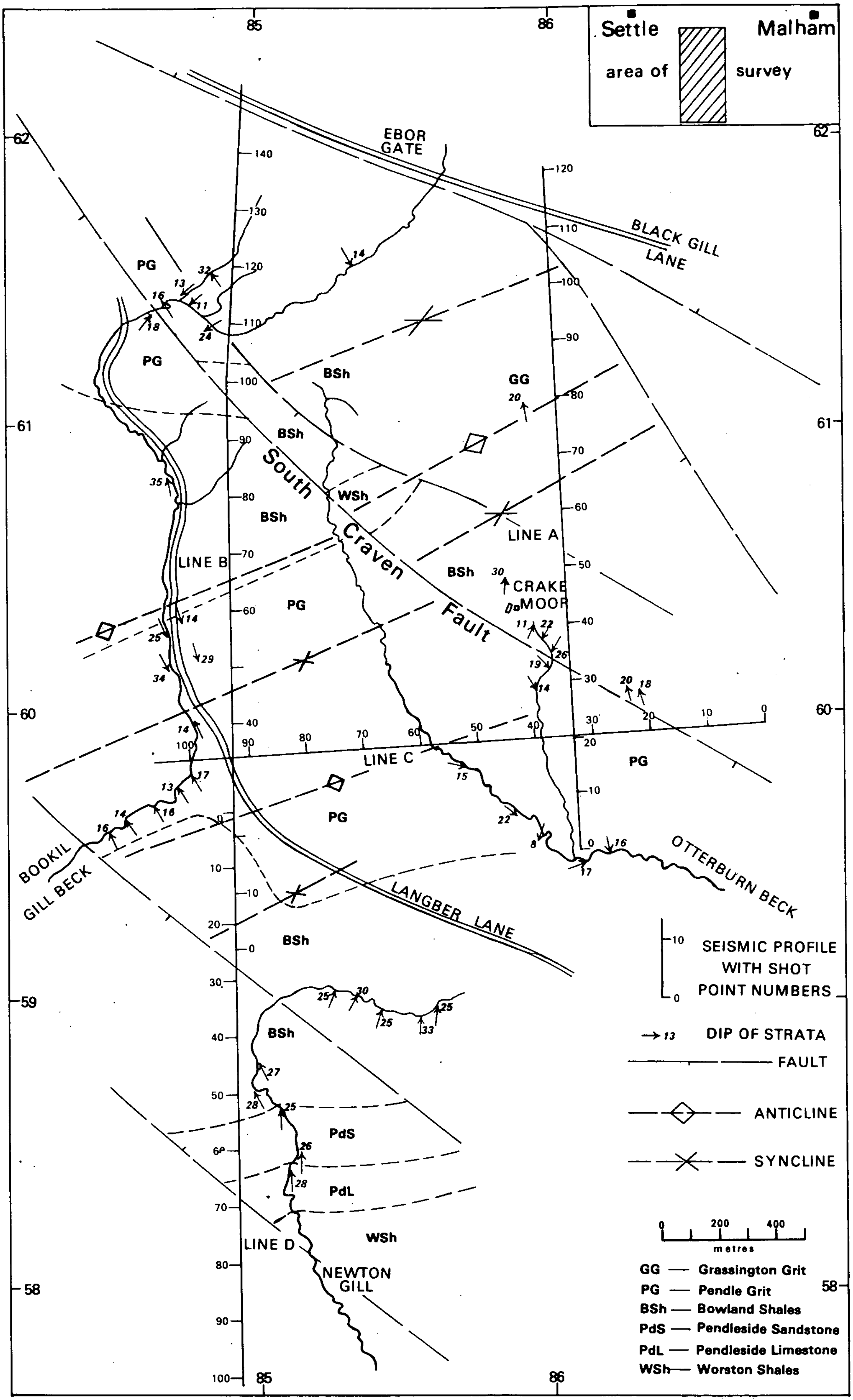


FIG 9 SEISMIC PROFILES, GEOLOGY AND LOCALITIES

the depths to basement rocks in this area. Two short seismic reflection profiles, aligned north-south, were recorded across the presumed line of the South Craven Fault, approximately along grid lines 850E and 860E (lines A and B, Figure 9). The profiles were extended northwards as close to the line of the Mid-Craven Fault as practicable but the steepness of the topography above Stockdale Beck limited the traverses in this direction. Subsequently, an east-west tie-line, approximately along grid line 600N (line C), and a southerly extension of line B (line D) were measured.

Preliminary measurements on line A were used to determine the field parameters for the reflection survey. The optimum shot point offset was determined at 240 m. The other spread geometry parameters were dictated by equipment availability and specifications: the station interval was 20 m with six geophones connected in series at each station with a 4-m separation. The optimum depth of the shot was 9 m and the charge size was ½ lb. As soon as a sufficient length of line A had been measured the results were sent for processing at both 12- and 6-fold stack. For 12-fold stacking with 24 channels, information from every shot point is used and the signals from 12 different geophone stations, receiving energy from a common depth point, are added together to enhance the signal-to-noise ratio. For 6-fold stacking, it is only necessary to use information from every other shot point and since the pace of the survey was dependent on the rate of drilling shot holes, an obvious advantage would have been obtained had the 6-fold stack been adequate. Unfortunately, as can be seen from those time sections which have been stacked 12-fold, over most of the lines recognisable reflections are weak or absent. The reflection profiles were, therefore, completed as for 12-fold stacking and had to be shortened, due to the time taken to drill shot-holes every 20 m, to the extent that neither traverse crosses the Mid-Craven Fault.

During the course of the field work it became evident that poor quality reflections were being recorded, due either to poor velocity contrasts or to a multiplicity of thin beds. In particular, some concern was felt about delimiting the positions of the faults. Two single-ended refraction profiles were therefore measured using spare or recoverable shot-holes. These profiles were designed to straddle the points where the South Craven Fault was anticipated to cross lines A and B. On line A the shot point was at station 78, and 24 detectors at 20-m intervals were at stations 66–43 and a further 24 detectors at 30-m intervals at stations 38.5–4. On line B the shot-point was station 149 and the detectors were at stations 137–114 (at 20-m intervals) and 122.5–88 (at 30-m intervals). Reverse shots, which would have given a more definitive result, were not possible because of limitations on drilling time.

During the shooting of lines C and D the shot point was placed at the centre of the spread to enhance the shallower reflections, reducing the maximum offset from 700 m to 230 m. Other field parameters remained the same. In total, 8.62 km of reflection profile were measured, using 369 shot holes and covering 7.86 km sub-surface.

Seismic reflection profiles

The seismic time sections were produced from the field recordings by Seismograph Service (England) Ltd on a Phoenix computer using their standard processing package (Figures 10a, 11a and 12a). The results are shown as standard processed sections (Figures 10b, 11b, 12a, 12b and 13a) and for lines A, B and D as migrated time sections (Figures 10c, 11c, 12c and 13b) in which the reflecting horizons have been restored geometrically to their true dip and positions. Figures 14a to 14c show the interpreted depth sections for selected events on the time sections of all but line C. Because no measure of vertical velocities below the surface layers exists the depths have been calculated using the root-mean-square velocities derived from the moveout during the processing and listed for each line, together with the rest of the processing data, in Figures 10a, 11a and 12a. Inspection of the listed values shows that whilst the velocities may have been appropriate for stacking purposes they have yielded interval velocities greater than 5.0 km/s, which seem abnormally high for a mainly argillaceous sequence and hence the depths shown are probably too great.

At the southern end of line A a series of poor-quality reflections, with two-way times between 0.3 and 0.6 seconds, probably marks the Pendleside Limestone and overlying Bowland Shales. These events extend to about shot-point 35 where they terminate against the South Craven Fault (Figure 9). Between shot-points 35 and 53 surface exposures show the Bowland Shales to be faulted with variable dips but overall they are inclined northwards. Farther in this direction the Bowland Shales are seen to be folded (Figures 9 and 14a) on the seismic section but this part of the seismic section carries many diffractions and structure cannot be interpreted with much confidence. Surface exposures are restricted to an outcrop of coarse-grained sandstone at High Barn [859 611], probably referable to the Grassington Grit which lies unconformably upon the Bowland Shales (R. S. Arthurton, *personal communication*). In the depth section (Figure 14a) it is suggested on stratigraphical evidence that the Pendleside Limestone is thrown down about 200 m by the South Craven Fault. The limestone does not appear to extend as a reflector farther north than shot-point 50. The base of the Carboniferous succession cannot be identified with certainty and the deepest reflector to the north of the South Craven Fault, at about 700–800 m, may be the local correlative of the Chatburn Limestone, but this is uncertain.

Lines B and D can be considered together (Figures 14b and 14c). At the southern end of line D there is no difficulty in tracing the Pendleside Limestone from its outcrop in Newton Gill at about shot point 70, northwards into a syncline near shot point 20. The succeeding anticline crosses line B at shot point 23, where the fold is clearly indicated on the seismic sections (Figures 11b and 11c), and the next syncline crosses near shot point 45. The dips in the Pendle Grit outcrops in Bookil Gill Beck accurately mark these folds at the surface (Figure 9). Another anticline crosses line B at shot point 67 and is confirmed by opposing dips in the Bowland Shales seen in the beck nearby, but is not clearly recognisable on the seismic section. This is partly due to the disappearance of the Pendleside Limestone as a good reflector at about shot point 43; it is not detectable further north. This truncation is perhaps due to faulting, but alternatively it might result from the dying out of the proximal facies of the Pendleside Limestone northwards. This latter explanation is preferred for reasons given below.

As well as the Pendleside Limestone, the interpretation (Figure 14c) shows a reflector at about 1000 m down near the southern end of line D, which descends to nearly 1300 m beneath the syncline and continues, at about 1000 m depth, northwards to the South Craven Fault. This horizon appears to lie beneath the Worston Shales and may be the local equivalent of the Chatburn

Limestone, but is not exposed hereabouts.

The South Craven Fault crosses the section (Figure 14b) as a belt of faulted ground between shot points 95 and 106. Further north the Bowland Shales and Worston Shales appear to be upthrown but the lower reflectors cannot be identified and the magnitude of the throw on the fault cannot be assessed.

The time-section on line C (Figure 12a) shows only poor reflections. It is possible to pick out the poorly-defined Pendleside Limestone folded into a gentle anticline about shot point 55. Where line C intersects lines A and B, this poor reflector corresponds to the suggested positions of the Pendleside Limestone on these lines. No doubt the poor quality of the limestone as a reflector on the line C record is due in part to its position near the northern limit of this lithology. Because of the poor quality of the data on line C no migrated section has been produced and no depth conversion attempted.

Seismic refraction profiles

Before interpretation, the travel times for the two profiles on lines A and B were corrected for the effects of variable topography and reduced to a datum having a slope of 1:20 to the south. The datum elevation on line A is 238 m at station 4 and on line B is 319 m at station 88. The time-distance curves are shown in Figures 15a and 15b and the interpretation assumes that the refractors are parallel to the datum. For strata dipping at ± 10°, say, the errors in velocities and depths will not exceed 20%.

Two simple models derived from the data on line A are shown in Figure 15c. Without the reverse profile it is not possible to choose between them. Both models show a change of dip in the refractor beneath shot point 35. The step feature of model (a) may be intrepreted as the South Craven Fault and, in view of the geological and reflection evidence, is the more likely. However, the hade has not been determined and it is not possible to deduce the nature of the refractor from the velocity because, without a reversed profile, the velocity is not uniquely determined, and the value of 4.25 km/s could be related to sandstone, shale or limestone. However, is it unlikely to be basement.

The model for line B shown in Figure 15d, which comprises plane-parallel layers of contrasting velocities, is compatible with the corrected data but is subject to the provision made previously for dipping strata. There is no evidence for any faults having significant throw between shot points 93 and 120, which is where the South Craven Fault crosses line B. The seismic velocity of 5.1 km/s is compatible with either limestone or Lower Palaeozoic basement but is too high (unless the layer has fairly steep undetected dip to the north) for shales or sandstone.

Gravity profiles

A total of 217 gravity stations was measured using seismic stations along lines A to D, to establish whether the South Craven Fault has gravimetric expression. The Bouguer anomaly is relative to sea level, assuming an average rock density of 2580 kg/m^3. Corrections allowing for local terrain have been applied. The elevations of the gravity stations were determined tacheometrically and the stations were tied to the National Gravity Reference Net at the Fundamental Bench Mark in Skipton via a local base station at the field gate [8534 6195] just west of Ebor Gate cattle grid. The anomaly profiles are illustrated in Figures 16a, b and c. The high frequency noise on these profiles is thought to be largely due to sub-drift topography, although levelling errors arising from the use of inexperienced staff for these measurements may have contributed. Particular examples suggesting the presence of errors in levelling are the anomaly changes on line C between stations 13 and 15 and stations 57 and 59. Some of the small changes in Bouguer anomaly values may reflect near-surface variations in the density of the bedrock. On line A, for example, the step in the anomaly profile between stations 30 and 40 marks the position of the South Craven Fault and the vertical displacement of the 4.25 km/s refractor (Figure 5c). Between stations 70 and 80, another step may indicate faulting but this was undetected on the ground. The profile along lines B and D shows breaks at stations 95 to 105 where the South Craven Fault crosses the line, and near station 20 where only minor faulting seems likely from the reflection data. These small anomalies on lines A, B and D are superimposed on a longer wavelength anomaly indicated by the gradual increase of values to the north. This anomaly is part of the gradient zone between gravity zones 3 and 4 (Figure 6) considered to represent the boundary between areas with differing basement rock types or depths. The boundary, however, trends to the ENE; oblique to the trend of the South Craven Fault but parallel to the fold axes in the Carboniferous sediments at the surface (Figure 9). There is no evidence for this boundary on the seismic reflection profiles, perhaps because its depth is too great. None of the gravity profiles can be interpreted in reliable quantitative terms.

Conclusions

The results of the reflection measurements are disappointing in that, over most of the profile length, at best only short disjointed segments of 'events' can be seen. The most useful length of profile occurs at the southern end of line B and the northern half of line D, but even here the quality and continuity deteriorate below about 0.3 seconds. It is possible that the segmentation of events is an expression of multiple faulting but it is thought more likely that poor velocity contrasts, lateral variations in velocity and possibly a multiplicity of intercalated beds make the area one of poor response to the seismic reflection method.

Nevertheless, it is generally possible to delimit the broad structure along parts of the reflection profiles when they are interpreted in the light of the surface outcrops. The Pendleside Limestone is the best reflector on both line A and line B–D, but it is absent to the north of the South Craven Fault on both lines. Certainly the surface exposures show that the limestone is not present at School Share [845 623] and Scaleber Bridge [840 625], about 2 km to the north-west. It seems likely, therefore, that the South Craven Fault had topographical expression during Asbian times and may have been a growth fault during much of Dinantian sedimentation. This latter conclusion is difficult to sustain however from this work, since both the beds below the Worston Shales and the Lower Palaeozoic basement rocks are largely undetected on the profiles.

DETAILED INVESTIGATIONS

SETTLE-MALHAM AREA

The area between Settle and Malham (Figure 17) is traversed by the Mid-Craven Fault and is one of the most promising areas for mineral exploration in Craven, since the line of the Fault approximated to the northern margin of the basin during much of Dinantian time. The stream-

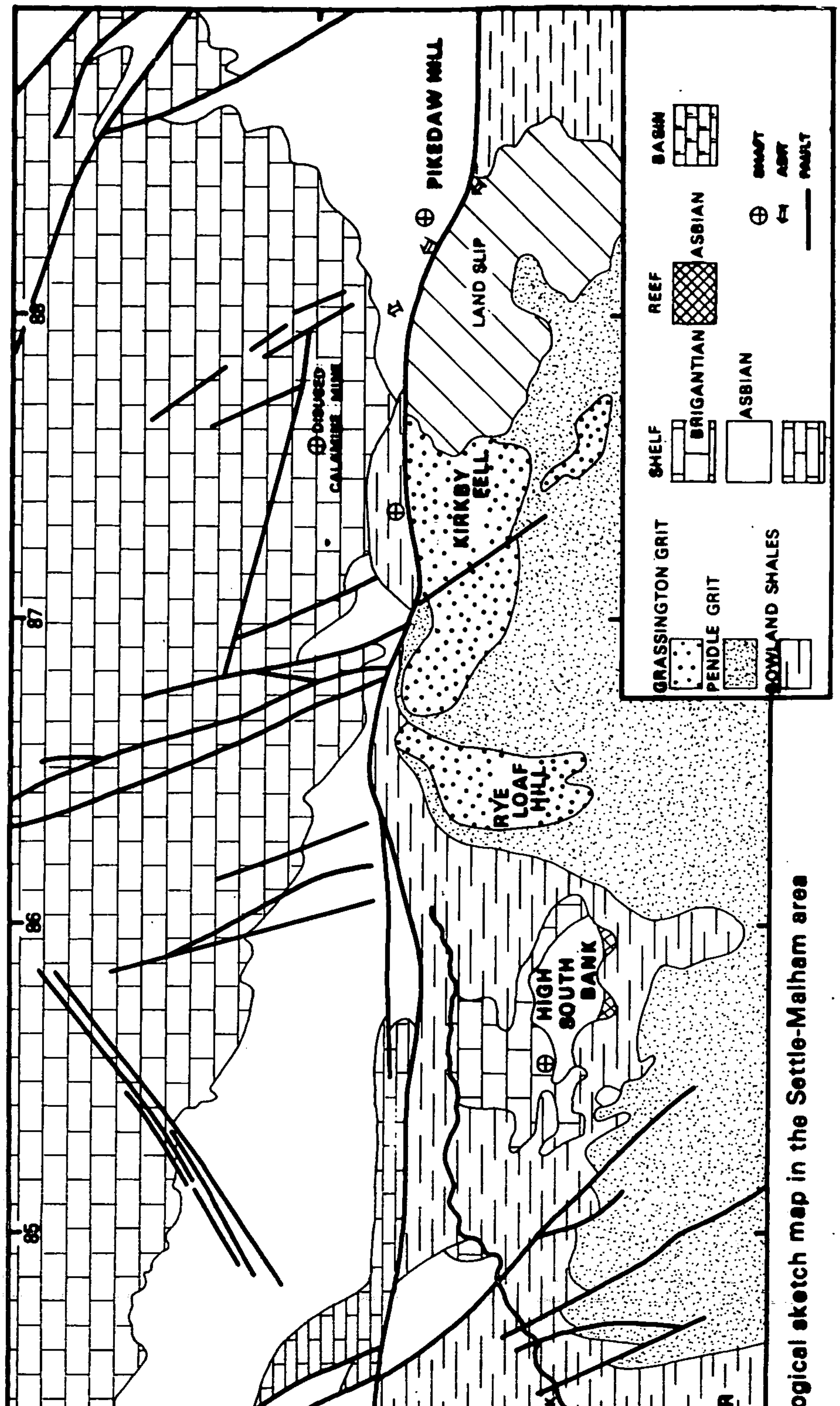


Fig.17 Geological sketch map in the Settle-Malham area

sediment survey found anomalous concentrations of Pb, Zn and Ba in Stockdale Beck (Figure 3) and the airborne geophysical survey recorded radiometric anomalies, with total gamma counts up to three times background, between High Hill [8363] and Pikedaw Hill [8863]. Limited follow-up investigations were subsequently carried out. The following summary describes these surveys but takes no account of the detailed work done by mining companies in the area.

There is considerable topographical relief, elevations varying between 275 and 550 m. North of the Mid-Craven Fault, the topography is karstic with impressive limestone scarps and pavements, whilst farther south the higher ground is moorland with rough pasture on the lower slopes. Access is by minor roads and rough tracks.

The geological map of the area has recently been revised by R. S. Arthurton and D. J. C. Mundy (Figure 17). The oldest rocks, cropping out in Stockdale on the upthrow side of the Mid-Craven Fault, are dark grey, fine to medium-grained calcarenites. They are classified here as sub-Asbian since the stage boundaries in this part of the succession have not been finalised. The overlying Asbian rocks vary laterally in facies. In the north the block facies comprises pale grey to white calcarenites, commonly cross-bedded and pseudobrecciated. The reef facies to the south is a complex mixture of poorly-bedded carbonate lithologies accompanied by breccias, and boulder beds. Passing into the basin, the Asbian rocks are dark-grey, thinly-bedded, fine-grained calcarenites with muddy partings and some chert. The overlying Brigantian rocks are interbedded dark-grey or crinoidal calcarenites and calcirudites, with calcisiltites and cherts towards the top. An unconformity underlies the succeeding Bowland Shales and marks a period of considerable erosion, the pyritic and calcareous mudstones of the Bowland Shales overlapping onto markedly different horizons in the Dinantian rocks. The sandstones and siltstones of the Pendle Grit come on above and are succeeded by the coarse, pebbly Grassington Grit.

A mineral analyser survey carried out over exposures above Scaleber Bridge [841 627] indicated a high Zn content in dolomitised and silicified limestones, along zones varying between a few cm and 15 m wide, generally following major joints trending between 280° and 320°. Partial silicification, with smithsonite concentrated in cavities, is common hereabout [8414 6262] especially in the Asbian boulder beds. In totally silicified rocks exposed in crags east of Stockdale Beck [8415 6270] sphalerite and smithsonite are abundant in disseminated patches where Zn reaches 8-10%. Dolomitised limestone with traces of smithsonite is found in a 280°-trending zone west of Stockdale Beck [8413 6297]. A limited number of soil samples, collected around Stockdale Beck as an orientation study for the area, showed a rapid decline in metal values in passing from mineralised limestone onto the surrounding Bowland Shales. Further soil sampling on High South Bank showed a scattered distribution of highly anomalous Pb and Zn values. Traces of galena and baryte are present around small trials on northern slopes of the hill [8555 6327], and dolomitic, silicified limestones with traces of smithsonite and quartz-spalerite veinlets crop out at several localities nearby. This area is, therefore, probably the source of the anomalous stream sediments and concentrates in the upper part of Stockdale Beck.

A few soil and rock samples were collected on High Hill and anomalous Zn values were again common near outcrops of dolomitic silicified limestone. 1000-2000 ppm Zn were recorded on joint surfaces in grey calcarenites. Most of the Zn seems to be in the form of smithsonite. A comparison of cold-extractable and hot-extractable Zn in soils from High Hill (T. J. Shepherd, pers. comm.) indicated that most of the Zn could be extracted by cold acid, thereby confirming that most of it occurs in a secondary phase rather than as a primary sulphide.

The radiometric anomalies observed from the airborne survey are indicated, with locality names, on Figures 8b and 17. They are sharply-defined, isolated anomalies, and no comparable anomalies were recorded elsewhere in the survey area. Ground follow-up using a 1597A ratemeter confirmed the anomalies and indicated background values of 10 μR/hr with peak values of 160 μR/hr over soils and 100 μR/hr over rock exposures. Most of the high values were of limited areal extent, with peak gamma counts dropping rapidly over less than a metre.

Much of the mineralisation in this area is similar to that at How Hill and other Craven localities, in that it appears to be local enrichment along joints and bedding planes in limestones below the cap rocks of the Bowland Shales. The possibility of large disseminations of sulphides along the Mid-Craven Fault, trapped in the lowest basinal carbonates against the Lower Palaeozoic basement of the Askrigg block, remains as yet untested.

STUMP CROSS

The Stump Cross area (Anderson, 1928) lies about 5 km WSW of Pateley Bridge just south of the Grassington-Pateley Bridge road and just beyond the eastern boundary of Figure 1. The ground lies between 300 and 400 m OD and is used for rough grazing. In parts the land is much affected by forming mining, and many of the larger spoil heaps have been re-worked for fluorite in recent years. Several old mine tracks allow access from the road. Apart from an 11 kv overhead power line close to the road, artificial conductors affecting geophysical measurements are absent.

The mineral potential of the district derives from its position on the northern margin of the Craven Basin. The North Craven Fault appears to separate the Dinantian sequence of the Askrigg Block to the north from the basinal succession to the south, although this is difficult to demonstrate with certainty. The fault also approximately marks the structural change from the flat-lying beds of the block to the broad folding of the basin, so it seems to be the best line for the margin of the Dinantian basin. It is uncertain whether there is a growth component on the fracture since Dinantian exposures are locally limited to small inliers.

The area was most recently mapped by Dunham and Stubblefield (1945) and the present work (Figure 18) is mainly based upon their field maps. These authors incorporate in their account information from the Bradford Corporation Waterworks tunnel driven through the high ground about 1 km east of the present area. The local succession is summarised in Figure 18. North of the North Craven Fault, the oldest rocks are dark grey, well-bedded limestones of the Timpony Limestone; about 125 m are exposed but the base of the formation is not seen. It has been customary to regard these rocks as Holkerian and Arundian in age but recent revision of the stratigraphical palaeontology in the Settle district suggests that they may be Asbian. The overlying Stump Cross Limestone consists of 84 m of pale grey, poorly-bedded, bioclastic dolomites. The Greenhow Limestone is the first formation to be seen on both sides of the North Craven Fault,

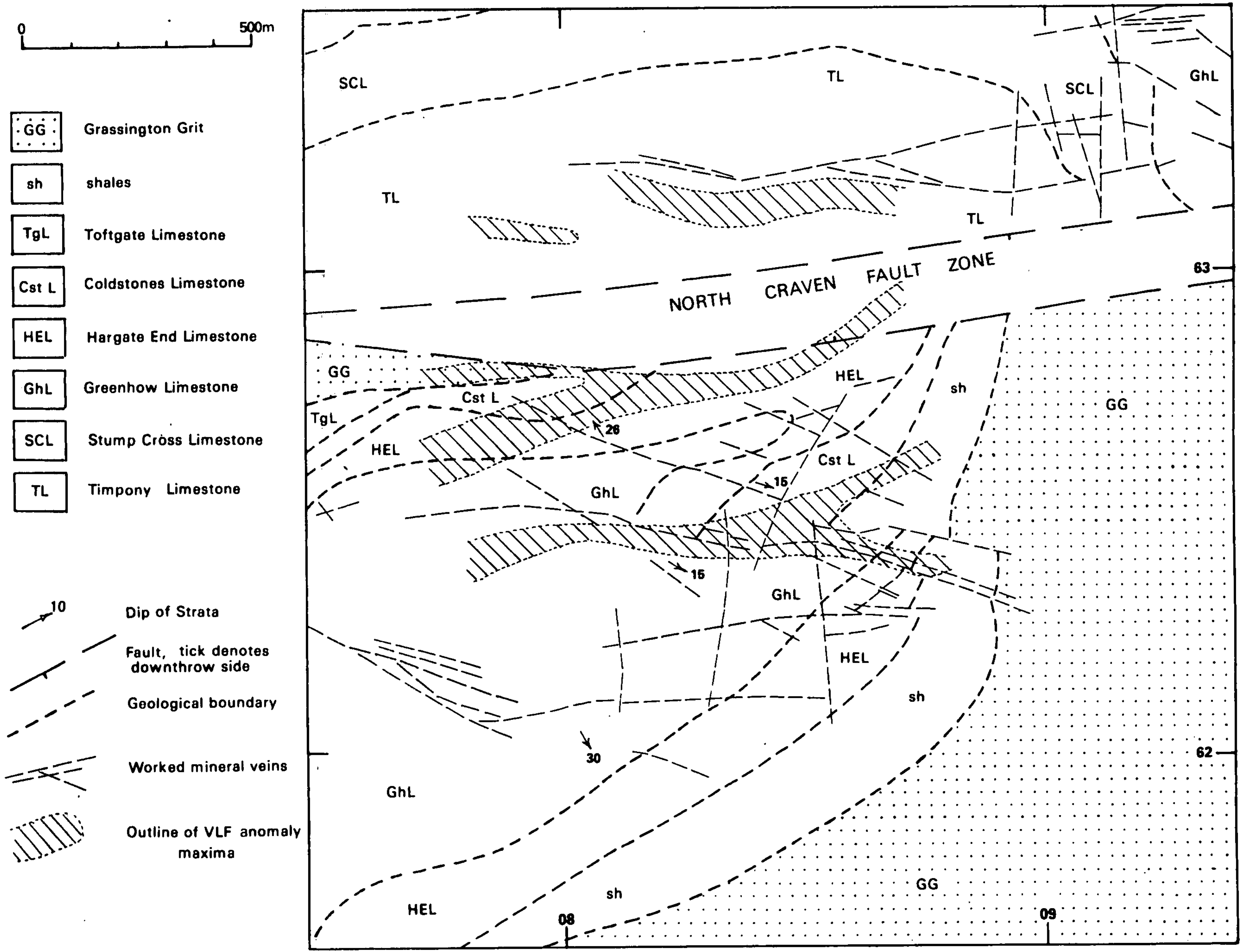


Fig. 18 Geology and geophysical anomalies at Stump Cross

and in the north comprises 120 m of white, fine-grained limestone in thick posts (massive beds) with marl partings. The Hargate End Limestone is dark grey, crinoidal and well-bedded, with chert bands throughout its total thickness of 45 m. The Coldstones Limestone, although only 12 m thick, is a distinctive sequence of fossiliferous calcilutites which passes up into the coarsely crinoidal Toft Gate Limestone, massively bedded and 63 m thick. Namurian rocks rest unconformably upon the carbonates and consist of a thin Bowland Shales succession capped by at least 50 m of Grassington Grit. Head is the main superficial deposit and is locally thick along the outcrop of the North Craven Fault.

The North Craven Fault forms a zone of very broken ground about 200 m wide. In the Waterworks tunnel the zone was synclinal (Dunham and Stubblefield, 1945) but elsewhere its detailed structure in unknown. The overall throw of the fault down to the south is variable but reaches a maximum hereabouts of 245 m. On the upthrow side, the Greenhow anticline trends roughly eastwards and has 30–60° dips on its northern limb, whilst on the downthrow side, the ENE-trending Skyreholme anticline has gentler dips of 10–30° on its limbs.

The limestones in the core of the Skyreholme anticline carry narrow Pb–Zn–F veins which have been intermittently worked for many years. The mines were especially active in the 1850s and by 1868 were producing annually about 150 tons of Pb concentrates. The Greenhaugh Mining Company carried out the last major phase of mining during the 1920s, extracting the fluorite which had been left as gangue in the old workings, and this has continued on a diminished scale up to the present. The veins occur along major joints and small faults, and were worked generally within 35 m of the surface although the deepest workings penetrate to about 85 m. The mining records indicate that some of the veins were especially rich in the lowest levels and sumps, but it seems most likely that the mineralisation is the result of the trapping of metal-rich brines in open fissures beneath the cap rocks of the Bowland Shales.

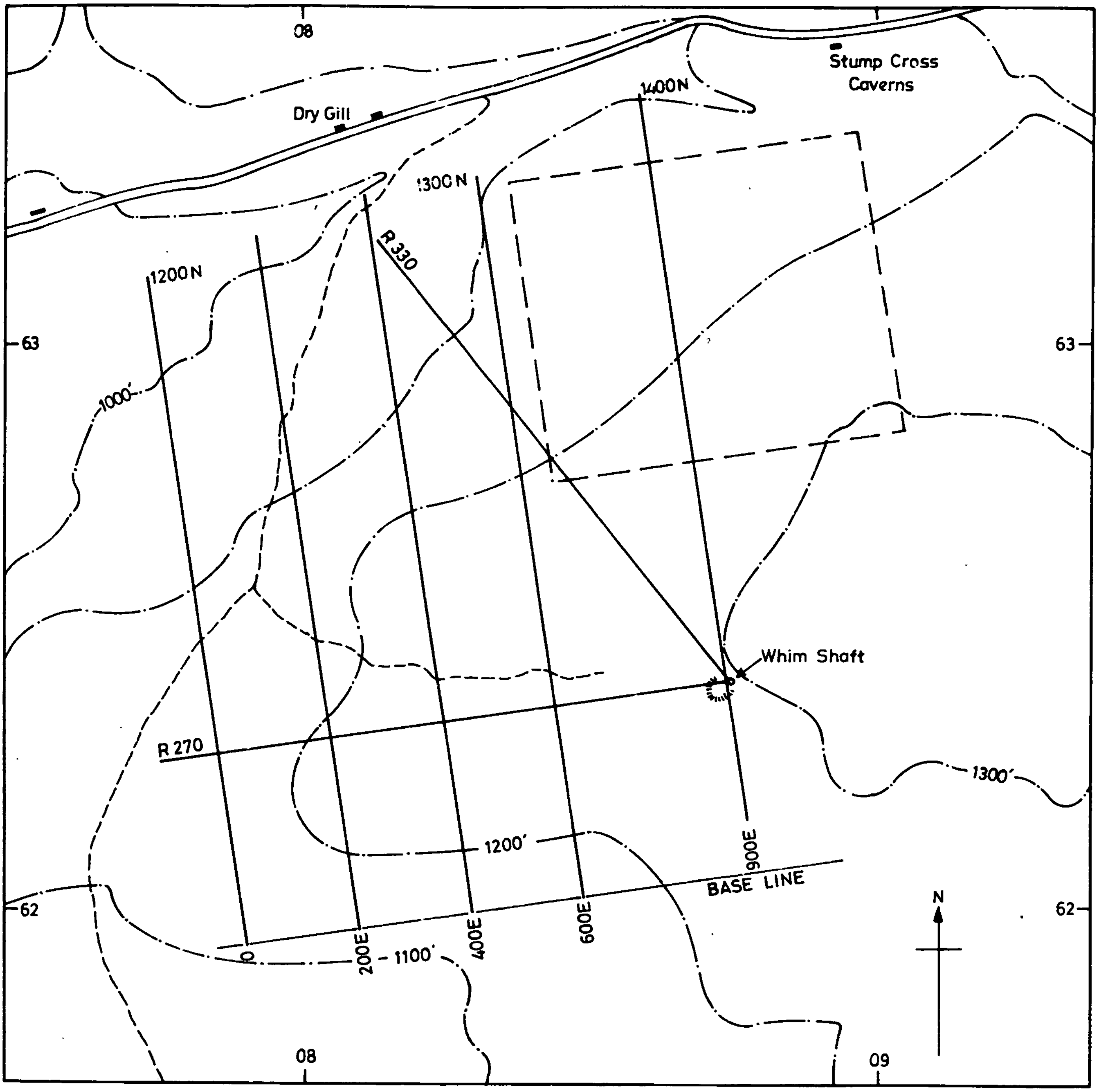
Of more interest is the possibility that disseminated sulphides were trapped against tight Lower Palaeozoic rocks on the downthrow side of the North Craven Fault. To assess this potential target, it is necessary to estimate the depth to Lower Palaeozoic basement in this part of the Askrigg Block. In addition, since such mineralisation probably lies in the basal carbonates of the basinal sequence, the likely depth of these beds must also be assessed. There is no definite evidence of Lower Palaeozoic rocks having been encountered in any of the local mines and none of the mine-dumps contains cleaved rocks. It has been claimed, however, that a local but unspecified driveage penetrated such rocks (Fearnsides, *in discussion* to Dunham and Stubblefield, 1945) but no further details have been published. Comparison with the succession in the Malham area suggests that, if the local sequence is comparable, basement rocks should lie within 200 m of the surface on the upthrow side of the fault, and they are perhaps present at much shallower depths. Depths to the basal carbonates on the downthrow side of the fault can only be tentatively estimated. If there is no growth element across the fracture, then about 250–350 m might be present in full sequence in the core of the Skyreholme anticline. Indications of sulphide disseminations might be present at depths shallower than this, and might be detectable using the IP method, with large arrays to give maximum depths of penetration. To test this possibililty, three IP traverses (Figure 19), 3.8 km long in total, were therefore laid out across the Skyreholme anticline, and VLF–EM traverses totalling 6.35 km were also measured to define more accurately the positions of faults and veins and assist in the interpretation of the IP data.

Geophysical work in the area commenced, however, with Slingram and VLF–EM surveys to follow up an airborne EM indication close to the Stump Cross caverns (Figure 19) and this preliminary work will be described first. The airborne EM anomalies, though negative, were strong and sharply defined. The Slingram survey consisted of three parallel traverses 420 m in length and 100 m apart aligned NE–SW across the area of the airborne anomalies, readings being taken at intervals of 30 m. A weak conductive feature was defined, trending just north of west, parallel to, and about 50 m south of the southern branch of the Black Hill Vein. VLF–EM measurements were then made along north–south traverses, normal to the anomaly direction. Several features are evident on the VLF profiles, the most prominent coinciding with the Slingram anomaly. There is overlap between these VLF traverses and those measured to cover the much larger area of the IP survey, and more detailed discussion of the VLF results is given below. There is no evidence from either of the EM surveys of any feature to produce the observed airborne EM anomaly and the latter is therefore considered to be spurious.

The IP survey commenced on traverse 400E (Figure 19) using the dipole-dipole array with 50 m dipoles. For reasons discussed below the dipoles were increased to 100 m on traverses 0 and 900E. In addition, the central portion of traverse 400E was repeated using the two-pole array. Finally, one current electrode was grounded 80 m below surface at the base of the Whim Shaft (at 250N on traverse 900E) while measurements were made using a three-electrode array on traverse 900E and on radial traverses R270 and R330.

The resistivity data for traverse 400E are presented in pseudo-section form in Figure 20, together with the VLF profile for the traverse. The prominent diagonal trend of the contouring is due to two pronounced resistivity features located at approximately 450N and 775N. As can be seen, these two features are coincident with strong anomalies on the in-phase VLF–EM profile, the feature at 450N also being coincident with a previously worked vein and the feature at 775N being very close to the southern boundary of the North Craven Fault zone.

IP measurements commenced at the southern end of traverse 400E. In this area massive limestone is covered only by thin drift and apparent resistivity values of over 10 000 ohm-m were recorded in a number of instances. Because of the high apparent resistivity, the voltage drop across the receiver dipole was large and a good signal-to-noise ratio was obtained. However, north of 750N on traverse 400E much lower apparent resistivities were encountered, less than 50 ohm-m in some instances. With the battery-powered equipment used, it is not possible to increase the transmitter current sufficiently to maintain a satisfactory signal at the receiver, and the signal-to-noise ratio is correspondingly reduced. This results in a reduction in the quality of the chargeability data to the extent that over the lower resistivity ground the poor repeatability of many of the chargeability values renders the data unusable. Thus satisfactory chargeability data could be obtained at a dipole separation of n = 5 over the massive limestone, but only at the n = 2 dipole separation over the lower resistivity ground to the north. In an attempt to overcome this problem, the transmitter and receiver dipoles were increased to 100 m on traverses 0 and 900E,



STUMP CROSS : LOCATION OF GEOPHYSICAL TRAVERSES.

ORDNANCE SURVEY 1:10560 MAP SHEET SE 06SE.

I.P. TRAVERSES : 0,400E, 900E, R 270, R 330.

V.L.F. TRAVERSES : 0, 200E, 400E, 600E, 900E.

KEY:

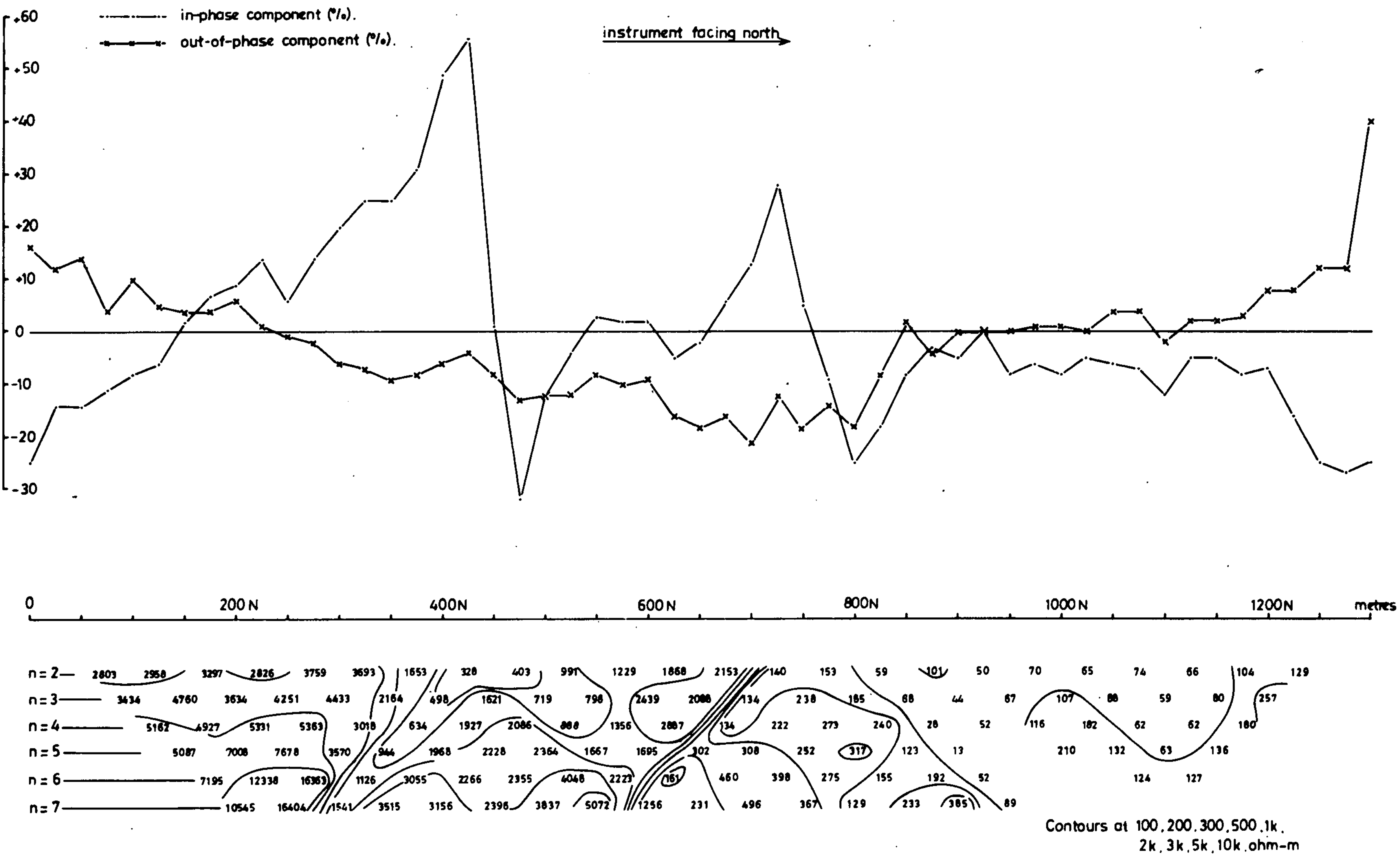
TOPOGRAPHIC CONTOURS AT 200' INTERVALS.

ROAD, TRACK.

AREA OF AIRBORNE EM ANOMALY COVERED BY INITIAL SLINGRAM & VLF TRAVERSES.

0 scale 500m

Fig. 19



Contours at 100, 200, 300, 500, 1k,
2k, 3k, 5k, 10k, ohm-m

Fig.20 STUMP CROSS : TRAVERSE 400E : VLF PROFILE AND APPARENT RESISTIVITY PSEUDO-SECTION.

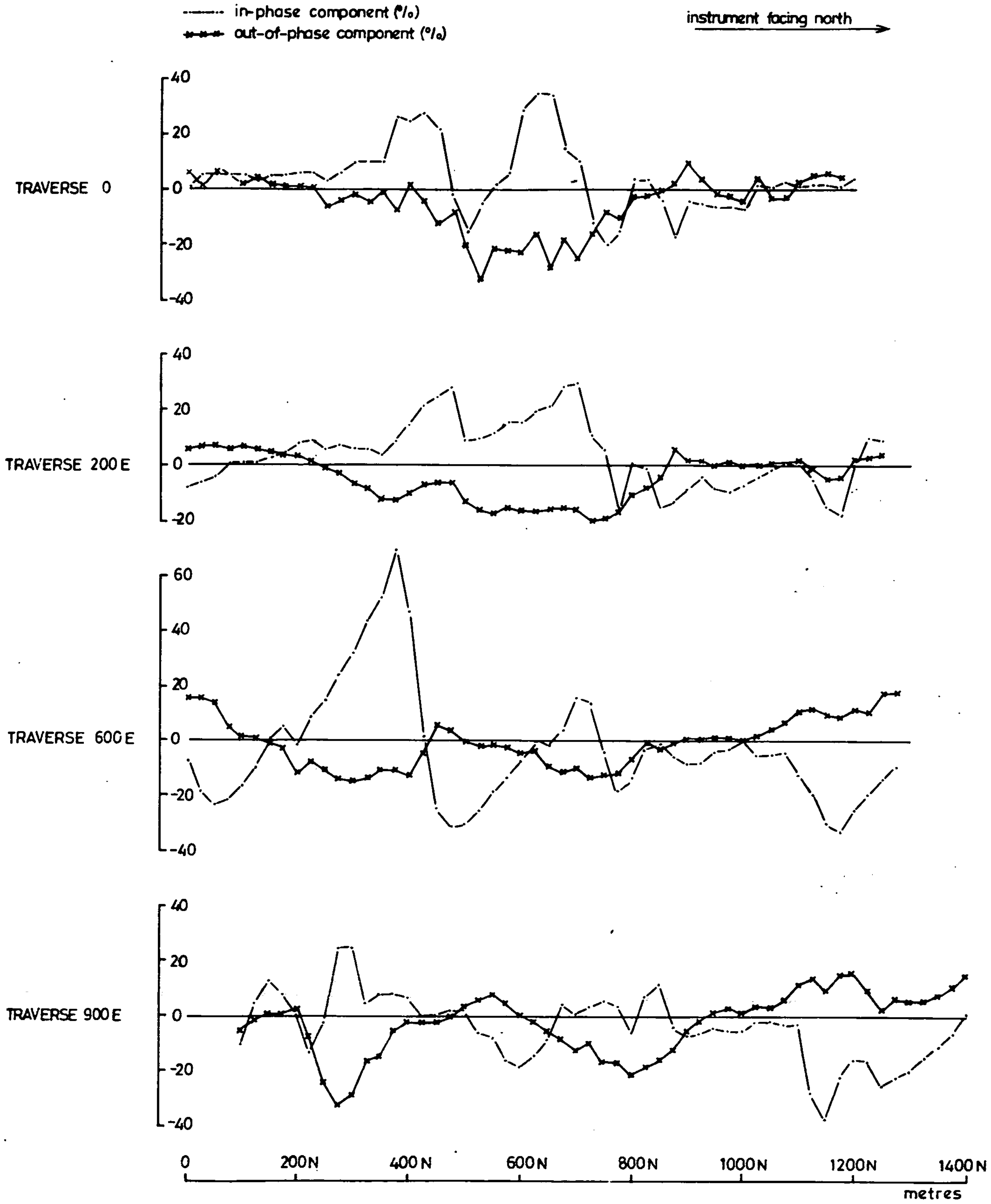


Fig. 21 STUMP CROSS: VLF-EM PROFILES

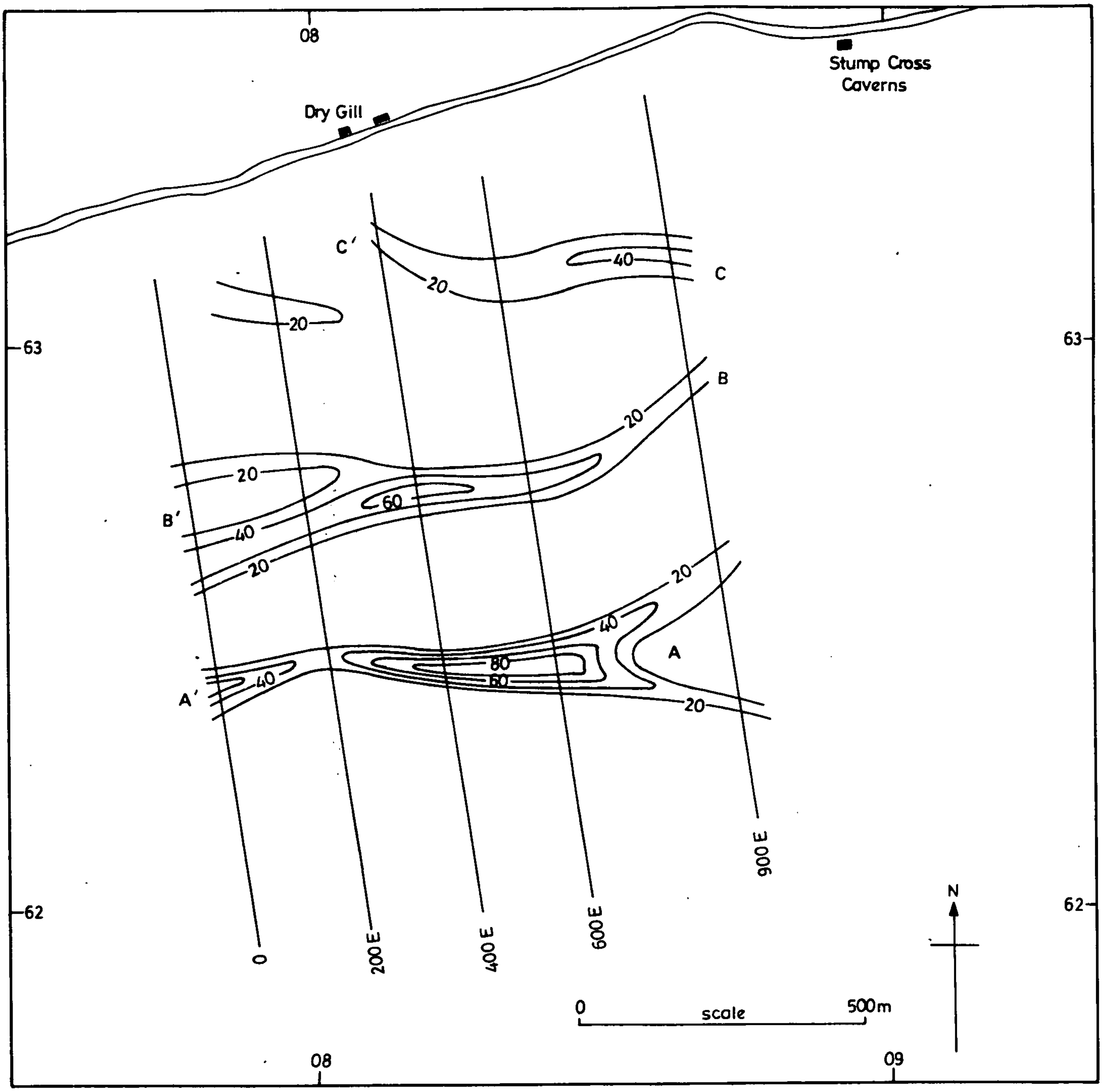


Fig.22 STUMP CROSS VLF SURVEY : CONTOURS OF FILTERED IN-PHASE VALUES

CONTOUR INTERVAL 20 UNITS. NEGATIVE VALUES NOT CONTOURED.

thus increasing the signal at the receiver for a given distance between the dipole centres. This provided satisfactory chargeability data at a separation nominally equivalent to using 50 m dipoles at n = 4.

The rapid and pronounced changes in near-surface apparent resistivities affect the validity of the standard pseudo-section approach to data interpretation, and the depths of which the chargeabilities at given 'n' values can be considered to be representative must vary along each traverse. However, over the southern half of each traverse, the thinness of the drift and the homogeneity of the limestone inferred from the apparent resistivity values suggest that chargeability values measured at the larger dipole separations are representative of depths below the limit of the old mine-workings. Chargeability values, though, are notably low, this being true of the whole area, and the few values obtained over 5 milliseconds are isolated. Because of the absence of chargeability anomalies and the problems associated with obtaining satisfactory data from the required depth, no further traverses were measured with the dipole-dipole array.

Following the initial dipole-dipole measurements, the central portion (between 250N and 1050N) of traverse 400E was repeated using a two-pole array. Remote current and potential electrodes were placed 250 m east and west of the traverse, the remaining current and potential electrodes being moved along a 400 m length of the traverse at a spacing of 25 m. This array gives a good signal-to-noise ratio, even over the lower resistivity ground, though the depth penetration is limited. The resistivity values recorded correspond closely with the values at the n = 2 spacing on the dipole-dipole pseudosection. No significant chargeability anomalies were recorded.

Trial measurements were then made using a subsurface current electrode in the only open shaft in the old mining area. This is the Whim Shaft, 80 m deep and located at 350N on traverse 900E. A standard current electrode was lowered to the bottom of the shaft where good electrical contact was made. Measurements were then made using three surface (one current, two potential) electrodes, along traverses radiating from the shaft — viz. 900E, R330 and R270 (Figure 19). The surface electrodes were spaced 100 m apart and readings were taken at 100 m intervals, working away from the shaft. The scale of the array relative to its distance from the sub-surface electrode was too great for the sub-surface electrode to be considered 'remote' and it was, therefore, necessary to calculate individually the geometric factors for each of the reading positions. Satisfactory repeatability of the chargeability values was obtained, but again no significant anomalies were located, values being generally below 5 milliseconds.

VLF measurements were made along all five north–south traverses shown in Figure 19, using the transmitting station NNA (Maine, USA, 17.8 kHz). All measurements were taken facing north, at 25 m intervals. The profiles of in-phase and out-of-phase values are shown in Figure 21, except for traverse 400E, the profile for which is given (at doubled horizontal and vertical scales) in Figure 20. The in-phase values were filtered using the method described by Fraser (1969) and the contoured filtered values are shown in Figure 22. The profiles show several prominent anomalies with good correlation between adjacent traverses. The anomalies represent a number of significant conductive features whose locations are evident from the contoured filtered in-phase data. The anomaly pattern shows a limited correlation with known geological features (Figure 18). The southernmost feature (AA') lies close to the course of the Old Vein on traverse 400E and east thereof, whilst west of traverse 400E it diverges significantly from the vein across unworked ground. The second major feature (BB') approximately follows the southern boundary of the North Craven Fault zone, though the southern branch of this feature on traverses 0 and 200E is apparently unrelated to the geology. The third feature (CC') had already been located with the initial Slingram and VLF surveys. This lies parallel to, but displaced 50 m to the south of, the previously-worked Black Hill Vein. Anomalies AA' and BB' correspond (on traverse 400E) to the two pronounced resistivity features located with the IP survey. These three prominent VLF anomalies can most easily be accounted for in geological terms as follows. The anomaly BB' is probably due to the southern margin of the North Craven Fault zone. The change in the form of the anomaly along its length, clearly seen on the profiles, is possibly due to changing lithology contrasts at the margin, since a series of beds strike into the fault here. The form of the anomaly CC' suggests that, rather than being related to the Black Hill Vein, it represents the northern margin of the North Craven Fault zone. The profiles also indicate that the anomaly at the north end of traverse 200E forms part of the same feature.

The anomaly AA' is of greater interest. The central portion and southern branch of the feature coincide with the course of the Old Vein, but to the west the feature turns south across unworked ground, while the Old Vein appears no longer to produce an anomaly. To the east, the northern branch of the feature is possibly due to an unrecorded branch of the Old Vein, though the anomaly on traverse 900E lies close to a shale/limestone contact.

The survey was only partially successful in achieving its objectives. The IP results show that it is possible only under ideal conditions to obtain satisfactory data using the large arrays necessary to achieve the required depth penetration. The influence of surface inhomogeneities, particularly faults and mineral veins, and the limited area of exposed limestone between the shales and grits to the south and east and the broad fault zone to the north, give too little opportunity for large arrays to provide uniform coverage of the area of interest. Where it has been possible to investigate the limestone at depth, the consistently low chargeability values over the area give no indication of the presence of sulphide mineralisation. The results of the VLF survey demonstrate the value of complementing IP surveys with VLF measurements, and in addition have located conductors which may merit further attention.

BYCLIFFE VEIN (ASHFOLD SIDE AND RED SCAR MINE)

The Bycliffe Vein is one of the main mineralised fractures of the Grassington Moor mining field (Dunham, 1952). It appears to extend eastwards via Groove Gill and across Gate Up Gill (Figure 23), and may possibly continue in this direction across the headwaters of Trunla Gill to join the mineralised Stony Grooves Vein at Ashfold Side, though much of this intervening ground is untried. The ground is moorland, generally lying above 400 m OD, partly covered by blanket peat and used for raising grouse or as rough grazing for sheep. Access is difficult, even for cross-country vehicles, and there is no habitation. Two rough tracks run northwards from Grimwith reservoir up Gate Up Gill and Trunla Gill respectively; otherwise access is on foot. The whole area lies within the catchment of the Yorkshire Water Authority Grimwith Reservoir.

The reconnaisance airborne geophysical survey indicated a number of anomalies, notably at Ashfold Side and near Red Scar mine, which were of interest because of their location on the largely untried ground between the Grassington and Greenhow mining fields. Favourable results from follow-up of these anomalies led to further work to see if the structure was continuous between the proved mining areas, and to test for sulphide mineralisation where the data from the reconnaissance work proved favourable.

Geology

The area is underlain by a Namurian deltaic sequence (Dunham and Stubblefield, 1945). Local revision mapping within the outlined area of interest was carried out by Mrs J. Tappin. The succession (Figure 24) is variable in thickness and consists of coarse feldspathic grits and sandstones interbedded with siltstones and mudstones. The argillaceous rocks are generally pyritic, but they are also calcareous in part and occasionally pass into thin limestones. The calcareous beds are sufficiently fossiliferous in parts of the sequence to form 'Shell Beds', which are stratigraphically distinctive and can be used for correlation. For example, the Cayton Gill Shell Beds crop out at the head of Trunla Gill [4070 4671] so the underlying sandstones can be confidently assigned to the Upper Follifoot Grit.

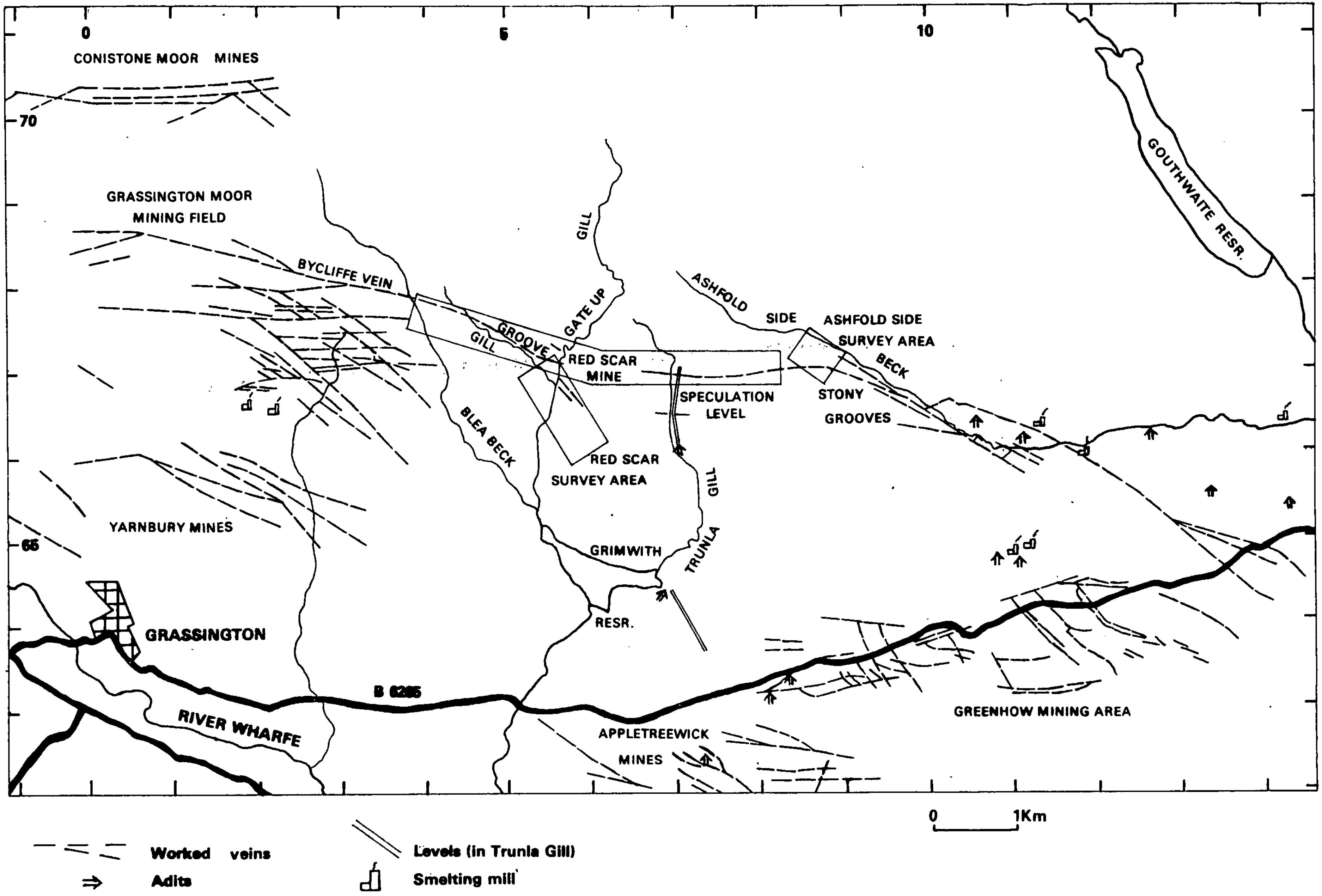


Fig.23 Location diagram, with the areas of former mining in the Grassington area

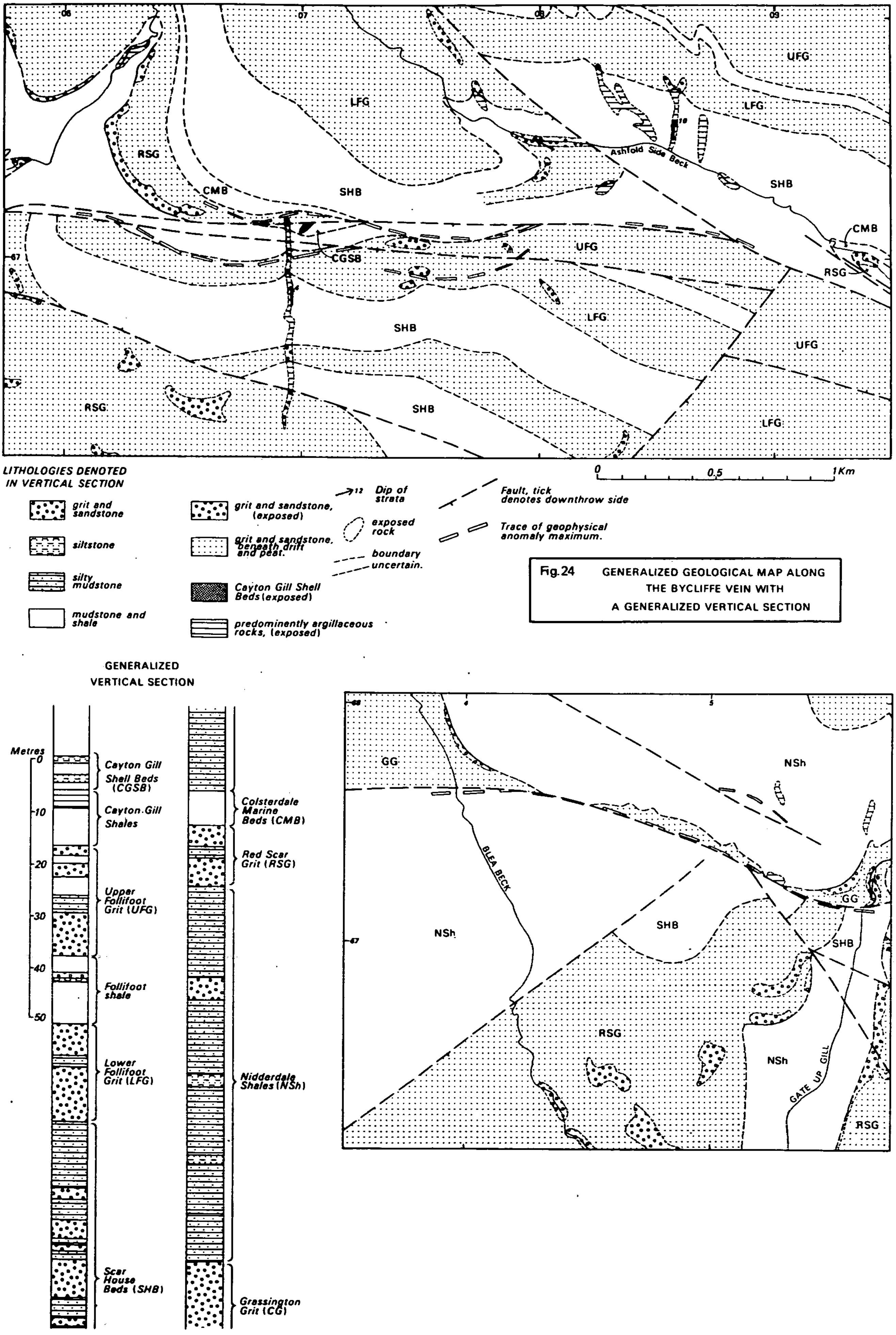


Fig. 24 GENERALIZED GEOLOGICAL MAP ALONG THE BYCLIFFE VEIN WITH A GENERALIZED VERTICAL SECTION

The regional dip of the rocks is to the north at 5° to 10° but close to faults the beds are more steeply inclined, commonly to the south. On Grassington Moor, and probably eastwards as far as Gate Up Gill, the Bycliffe Vein is generally a single fracture, but farther east the structure which possibly represents its extension seems in places to consist of several parallel faults, with an overall throw down to the south of 60 to 100 m.

The main superficial deposit is head, a jumbled mass of locally-derived sandstone boulders and pebbles in a matrix of weathered siltstone and mudstone debris. As it is a solifluction deposit produced under periglacial conditions, it is locally very variable in thickness. It is thickest in valleys and below prominent scarps, and is present on the main interfluves only as a thin layer. Upslope, the soliflucted material generally grades into the outcrops of the principal sandstones, which are extensively cambered and affected by frost-heaving. Blanket peat up to 4 m thick occurs generally on poorly-drained ground on shale outcrops or on thick head. In places it is being strongly gullied and eroded.

The Pb–Zn veins of the Grassington Moor and Greenhow mining fields were extensively worked in the 18th and 19th centuries. At Grassington, the most productive horizon was in the Grassington or 'Bearing' Grit near the base of the Namurian sequence. Where workings extended down into the Dinantian limestones, the mineralisation was more tenuous and failed below about 50 m. At Greenhow, on the other hand, it was the Dinantian limestones exposed in anticlinal cores which carried the veins. In the present area of interest there was much less activity. In the west a vein along Groove Gill was worked from five shallow shafts [0462 6758, 0499 6741, 0521 6730, 0527 6728 and 0543 6719] and the workings were drained by the Game Ing Level [0561 6712], driven in about 500 m from Gate Up Gill and vertically commanding up to 50 m of the vein. The position and trend of this vein suggest that it is an extension of the Bycliffe Vein, though there is a largely untried interval of about 1 km between the limits of the two veins. Much of this section has favourable host-rocks with Red Scar Grit in the hanging wall and Grassington Grit in the footwall. Baryte is the commonest gangue mineral in the dumps. The Vein is unmineralised at crop [0565 6716] where it crosses Gate Up Gill but downstream several SE–trending veins were formerly worked for Pb around Red Scar mine. The principal fracture at Red Scar splits off the Vein along Groove Gill and in the worked ground north-east of the mine was accompanied by several weak, parallel veins within the Grassington Grit. The mine was drained from the 14-fathom level driven from the side of the Gill [0551 6650] north-eastwards for about 350 m, and was worked from the main shaft [0558 6661] which is still open. About 250 m north of the shaft, Middle Vein trends ESE along Red Brow Sike. It has been tried at the surface but was not reached at depth by the workings from Red Scar mine. The trend of the Middle Vein suggests that it continues eastwards to cross Trunla Gill near Hard Hill, where several trial pits proved baryte and galena [0687 6644, 0696 6642] and steeply-dipping mudstones in the stream are veined with baryte. Even further east, baryte float marks the vein's position in Hush Dike [0724 6641]. The vein was proved in Speculation Level, driven northwards from Trunla Gill [0702 6603], but was not rich enough to work.

There is no clear evidence that the vein at Groove Gill extends east of Gate Up Gill, and it is untried for the next 1.4 km. Then two small pits in the headwaters of Trunla Gill [0698 6694 and 0695 6713] proved galena and baryte, and these minerals are common as float in the eastern tributary [0700 6711] despite the absence of trials on this stream. Two shallow trials were sunk south of the Wig Stones [0749 6701 and 0749 6691] without apparently reaching mineralised ground, but apart from these the vein is again untried for nearly 2 km, until the edge of the Stony Grooves workings is reached. This mine worked NW–trending veins from the Greenhow field to a maximum depth of 120 m. The mineralisation on these veins was rich but discontinuous, and a line of three trial shafts was sunk [0887 6723, 0882 6714 and 0877 6708] to test their extension to the north-west but there is no sign in the dumps that they were sucessful.

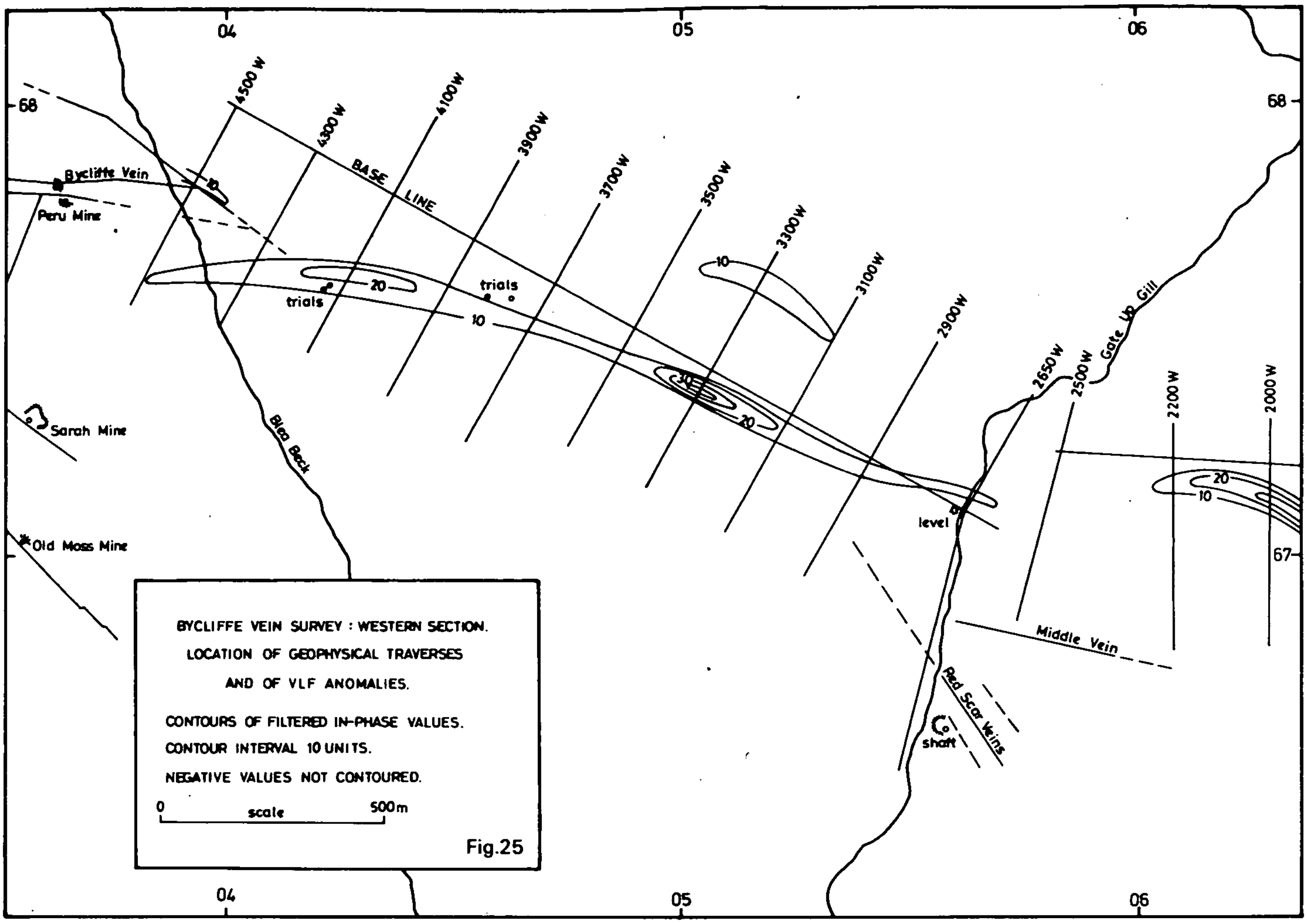
The pattern of testing and exploitation of the postulated extension to the Bycliffe Vein in the 19th century was so different on either side of Gate Up Gill that it seems likely that land and mineral rights ownership was an important factor in limiting activity on the eastern side. It is difficult otherwise to account for the lack of trials where mineralisation is visible and Pb–Ba float is widespread.

Geophyscial surveys

The suggested line of the extension of the Bycliffe Vein was covered by the airborne geophysical survey described above. Airborne EM anomalies were recorded near Red Scar mine and at Ashfold Side near Stony Grooves mine. Ground follow-up surveys were carried out in both of these areas (Figure 29). The Turam survey at Red Scar showed a strong anomaly over a short length of the vein worked at Groove Gill as well as over the Red Scar veins themselves. The VLF survey at Ashfold Side showed a weak anomaly, probably representing an extension of the Stony Grooves veins. This work is detailed later in the report. Thus in two separate areas, EM anomalies indicated that conductive features were present close to the suggested extension of the Bycliffe Vein, and it was decided to carry out a reconnaissance VLF ground survey between Red Scar and Ashfold Side to establish whether the anomalies were related to a single feature and to extend the survey westwards to link up with the proved veins of Grassington Moor.

A total of 25 traverses was measured, having a total length of over 12 km (Figures 25 and 26). In addition, traverse 1300W was extended to 2 km in length to obtain a sample profile of background variation in the area. The VLF instrument was tuned to the transmitting station NAA (Maine, USA, 17.8 kHz) throughout the survey (Burley and others, 1978). The traverses were laid out normal to the vein and their lengths adjusted to follow anomalies as they were recorded. The filtered and contoured data are shown in Figures 25 and 26, whilst three typical profiles are illustrated in Figure 27. The traverses are described from east to west.

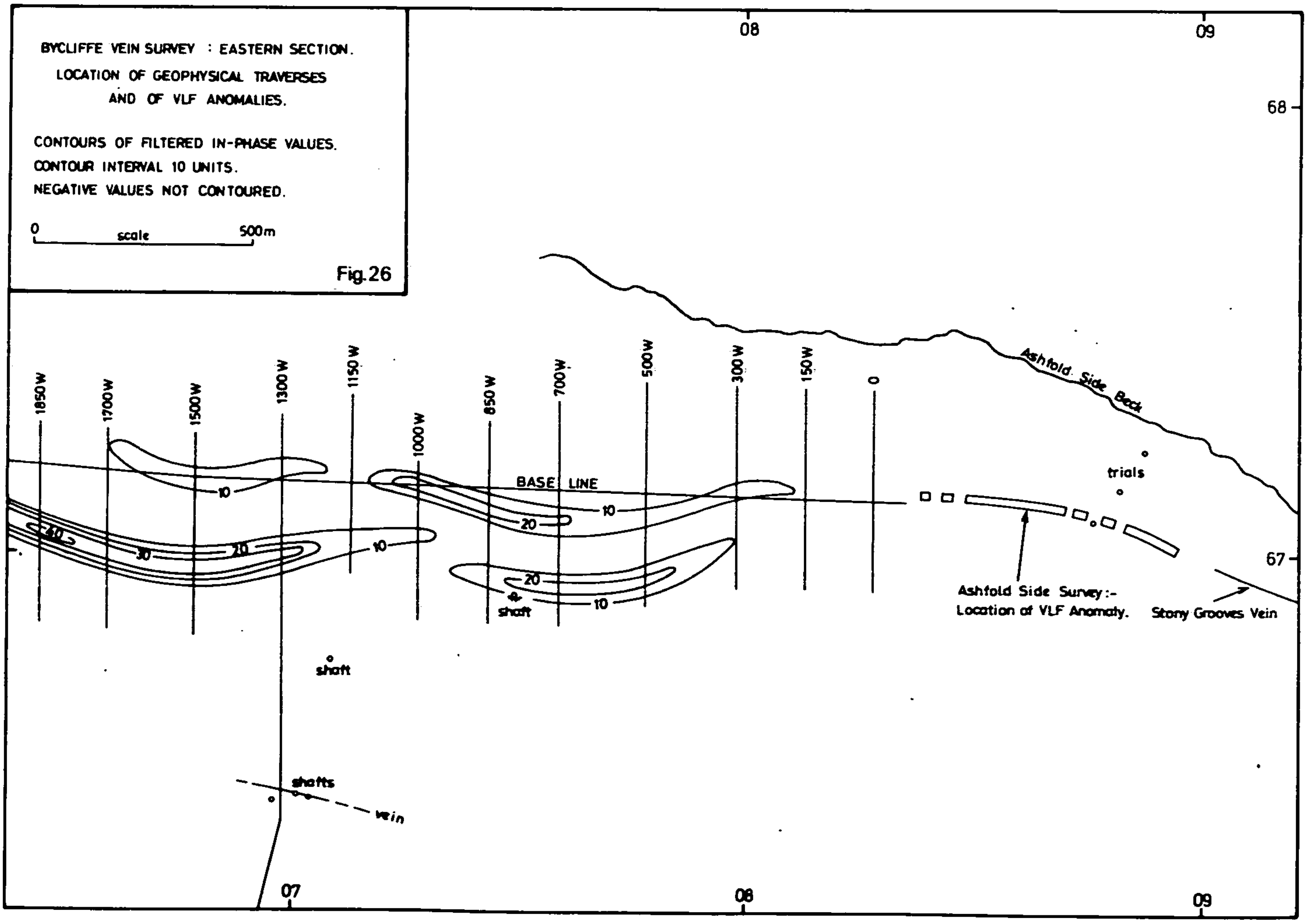
No significant anomalies were recorded on traverses 0W and 150W, the feature producing the anomaly in the Ashfold Side area presumably dying out quickly to the west. On traverses 300W to 1150W a well-defined pattern of anomalies is seen, these being of particular shape as shown in Figure 27 (a). These anomalies, although aligned with those at Ashfold Side, differ from them in profile and are therefore due to a different cause. Their profiles approximate to a mirror image of the type of profile normally associated with a steeply-dipping conductor. However, this 'reversed' anomaly is interpreted as resulting from two separate conductors, as illustrated by the filtered data. A pair of steeply-dipping conductors, however, would not give an anomaly of this type, and it



BYCLIFFE VEIN SURVEY : WESTERN SECTION.
LOCATION OF GEOPHYSICAL TRAVERSES
AND OF VLF ANOMALIES.

CONTOURS OF FILTERED IN-PHASE VALUES.
CONTOUR INTERVAL 10 UNITS.
NEGATIVE VALUES NOT CONTOURED.

Fig.25



BYCLIFFE VEIN SURVEY : EASTERN SECTION.
LOCATION OF GEOPHYSICAL TRAVERSES
AND OF VLF ANOMALIES.

CONTOURS OF FILTERED IN-PHASE VALUES.
CONTOUR INTERVAL 10 UNITS.
NEGATIVE VALUES NOT CONTOURED.

Fig.26

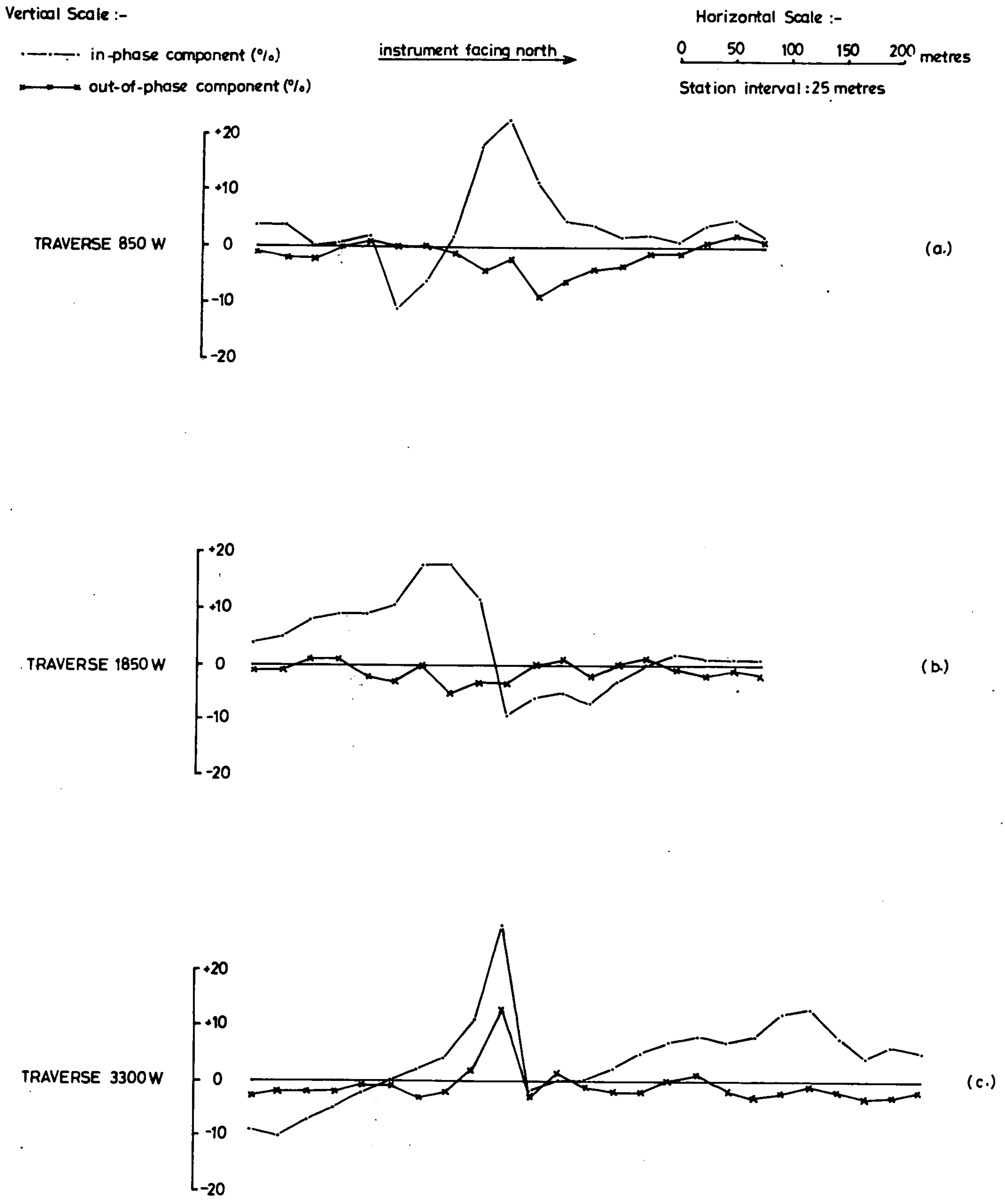


Fig. 27 BYCLIFFE VEIN SURVEY: VLF PROFILES

seems more likely that the anomaly is due to east-west faulting juxtaposing shales and grits, but with the fault planes not contributing significantly to the anomaly.

On traverse 1300W a further type of anomaly appears and is repeated on traverses 1500W, 1700W, 1850W and 2000W. The profile for traverses 1850W is typical and is shown in Figure 27 (b). It is thought to be due to the southern edge of a broad shale outcrop dipping gently north. The curved line of the anomaly (Figure 26), approximately following the topographical contours, supports this interpretation. The weaker anomaly at the northern ends of traverses 1300W, 1500W and 1700W probably represents the outcrop of a second overlying shale, separated from the first by a sandstone. Also of interest on traverse 1300W is a pair of anomalies between 600S and 800S, lying close to the three trial shafts near Trunla Gill. Short test traverses (not shown on Figure 26) to either side of traverse 1300W show similar anomalies trending slightly north of west, coinciding with the worked vein. No further geophysical work was done to test whether the vein is continuous with the Middle Vein of Gate Up Gill.

On traverses 2200W and 2500W there are only weak anomalies. There is no evident correlation between the traverses, though it is possible that the weak feature at 50S on traverse 2200W represents a westward extension of the strong anomalies to the east. There is no evidence on traverse 2500W of an anomaly corresponding to that recorded adjacent to the exposed fault on traverse 2650W. West of traverse 2650W similar anomalies are recorded on all the remaining traverses. The profile for traverse 3300W is typical and is shown in Figure 27 (c). The anomalies indicate a steeply-dipping conductor. The filtered data show two anomalies, though the northern one is weak and probably represents the outcrop of a northward-dipping bed of shale. The more prominent southern anomaly coincides with the exposed fault on traverse 2650W, and with the line of mine workings immediately to the west. At the western end of the area the anomaly divides. The weaker branch maintains the ENE trend and correlates with lines of trial pits as far as Blea Beck. The stronger southern branch of the anomaly turns to run west across apparently unworked ground towards New Peru mine [035 675]. The anomaly broadens west of traverse 3500W, indicating that the depth to the top of the conductive feature increases in that direction, which may account for the failure of trial pits to locate mineralisation west of the Groove Gill workings. It is also notable that the anomaly in the out-of-phase component, which is of the same polarity as the in-phase component between traverses 2900W and 3700W, changes gradually to the opposite polarity towards traverse 4500W, indicating a significant increase in the conductivity of the anomalous feature towards the west.

The airborne EM anomaly near Ashfold Side Beck [088 671] is strong but negative, and is therefore probably not geological in origin. The anomaly was nevertheless of interest because of its proximity to the Stony Grooves mine. Four Slingram traverses were measured and a weak ENE-trending anomaly was recorded, but this seems unrelated to the airborne anomaly. There are no visible artificial conductors in the area so the latter remains unexplained. The Slingram anomaly seemed to lie on an extension of the Stony Grooves veins, so VLF meaurements were also tried here (Figure 26), and these indicated two anomalies. The northern one is probably due to shales but the southern anomaly again seems to lie over an extension of the Stony Grooves vein.

Another airborne EM anomaly at Red Scar is weak but extends over 1200 m, and coincides with the main vein in the mine for about 800 m. The anomaly occurs on flight lines 118, 119 and 121 but not on 120, and the in-phase anomaly is much stronger than the out-of-phase one. The Turam method was used on the ground, since the steep terrain locally had too strong an effect on the VLF observations. A major NNW-trending anomaly coincides with the airborne anomaly and marks the principal vein worked at Red Scar mine (Figure 25). The results show that this vein does continue into the Bycliffe Vein in Groove Gill and is accompanied west of Gate Up Gill by a subparallel branch vein. A small baryte vein about 100 m north-east of the Red Scar Vein is also picked out.

The favourable VLF responses in the Groove Gill area were followed up with an IP survey. The gradient array method was used along traverses 2650W to 4100W. However, this proved unsatisfactory, because the apparent resistivity values measured indicated that the depth of measurement obtained varied according to the position of the receiver dipole. It seems likely that this is caused by a thin, very conductive surface layer, possibly thin shales overlying the higher resistivity grits. It appears that the greatest depth of measurement was obtained along a line approximately through the mid-points of the traverses — i.e. approximately along the line of the VLF anomaly. It is, therefore, considered signficant, but discouraging, that no chargeability values above 10 mS were recorded.

Traverses 2900W, 3100W and 3300W (Figure 25) were repeated using a dipole-dipole array, with 25 m dipoles at a distance of 100 m between their centres (n = 4). The apparent resistivity and chargeability profiles for these traverses are shown in Figure 28. The position of the vein is evident from the resistivity profiles, particularly on traverse 3300W, where a steady increase in values from the north, due to thinning drift and shale cover over the grits, is abruptly terminated between 12.5N and 12.5S. This feature is slightly displaced from a pronounced chargeability minimum on each traverse. None of the profiles shows a significant positive chargeability anomaly. It is, therefore, considered unlikely that there is significant sulphide mineralisation along the fault in this area, although galena can be found in the mine tips close by. The limited time available prevented extension of the dipole-dipole measurements along the full length of the VLF anomaly.

Conclusions

Such new geological mapping as is possible in this area of very limited exposure has failed to provide evidence that a single mineralised structure, or 'master lode' (the presumed extension of the Bycliffe Vein) links the Grassington and Greenhow mining fields, though the existence of approximately east-west faulting is apparent in the vicinity of Groove Gill and near the head of Trunla Gill. Geophysical surveys indicate that the fault at Groove Gill, there mineralised, originates in the Grassington mining field, and can reasonably be supposed to be an extension of the Bycliffe Vein. The geophysical surveys also suggest that this fault does not extend east of Gate Up Gill and that the mineralised fault at Stony Grooves extends little more than 600 m beyond the limit of mining. However, it is apparent in the vicinity of Trunla Gill that major east-west faulting does not of itself give rise to a VLF anomaly. It is, therefore, not possible to establish the relationship of this faulting to the mineral veins to the east and west, or the nature of the faulting, though the absence of an

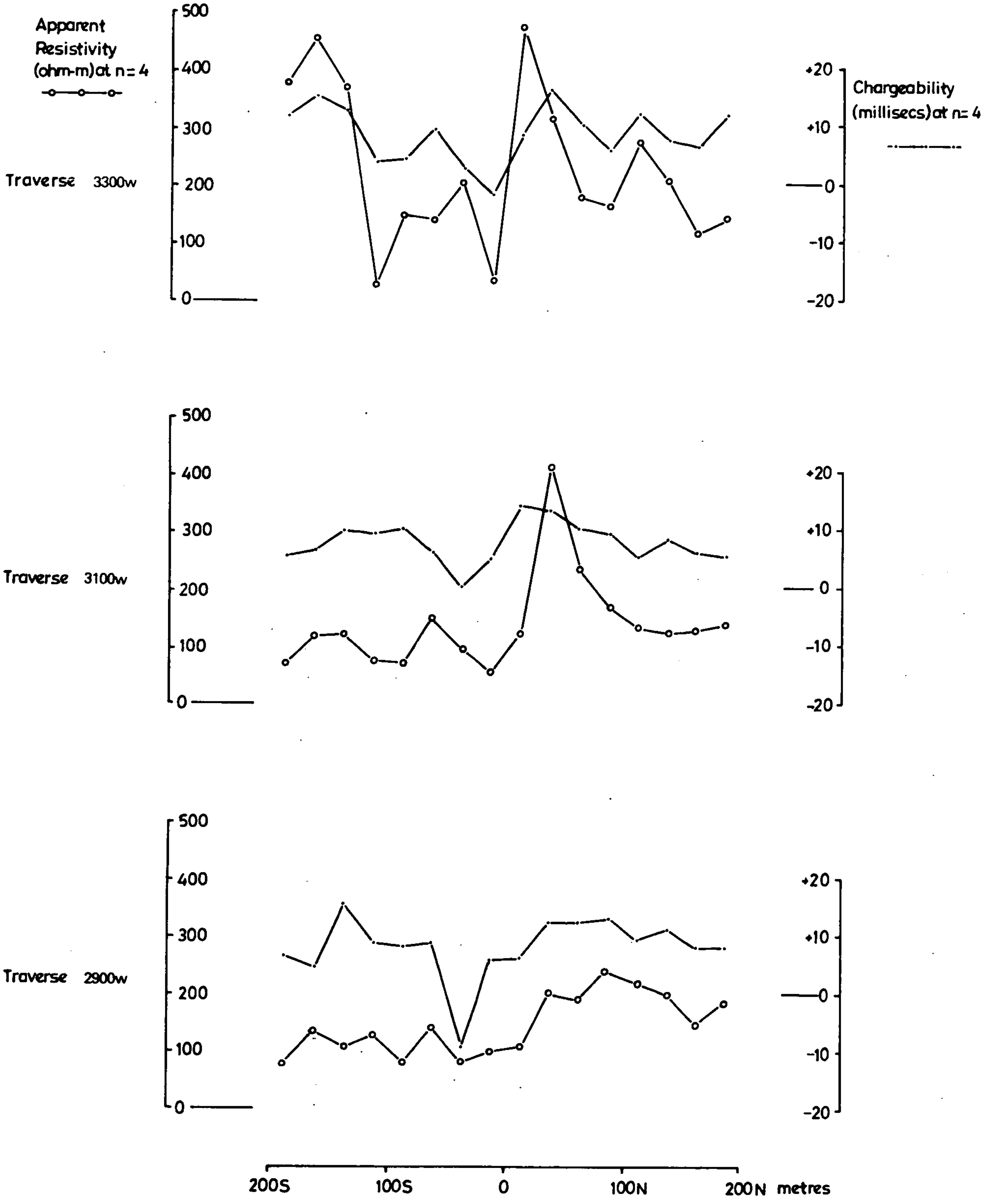
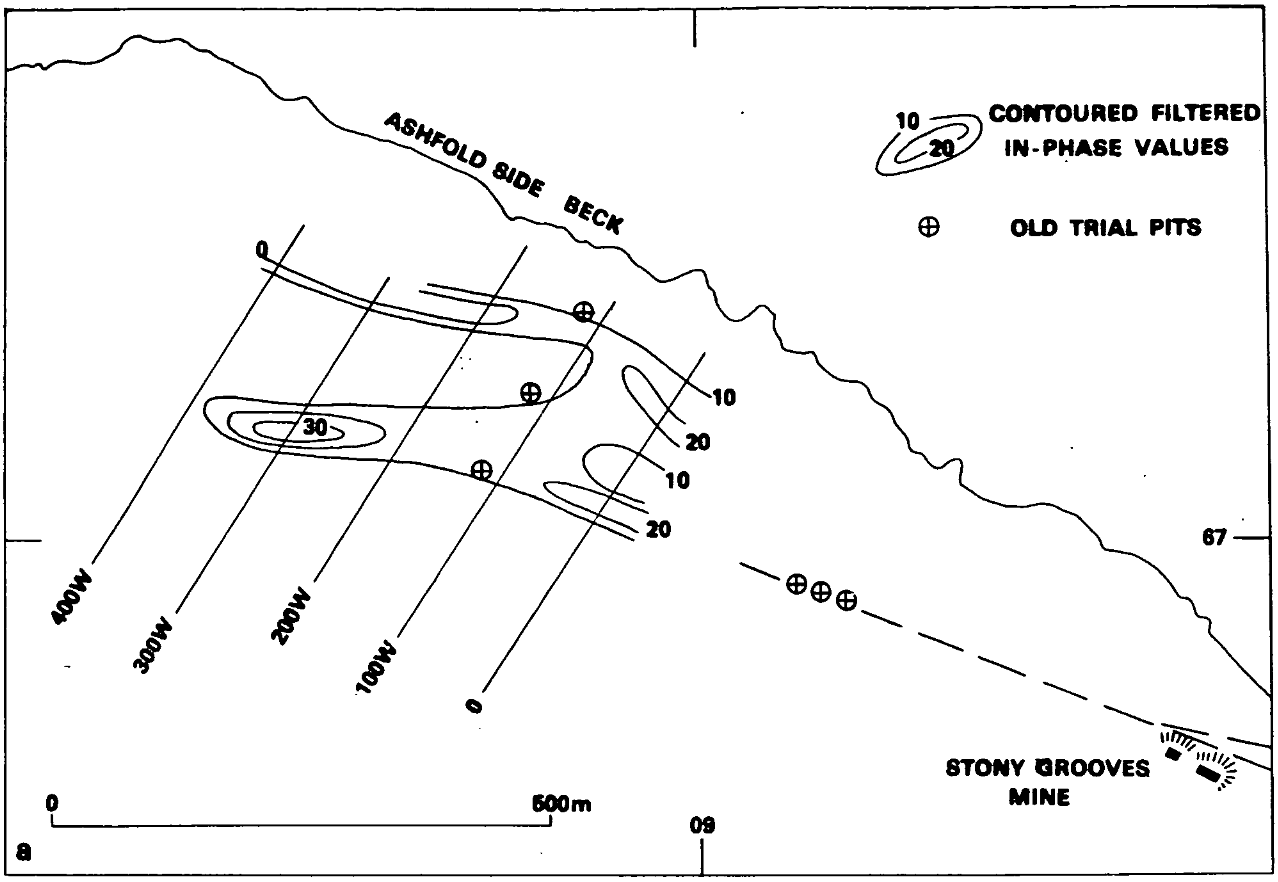


Fig. 28 BYCLIFFE VEIN SURVEY : PROFILES OF APPARENT RESISTIVITY & CHARGEABILITY.



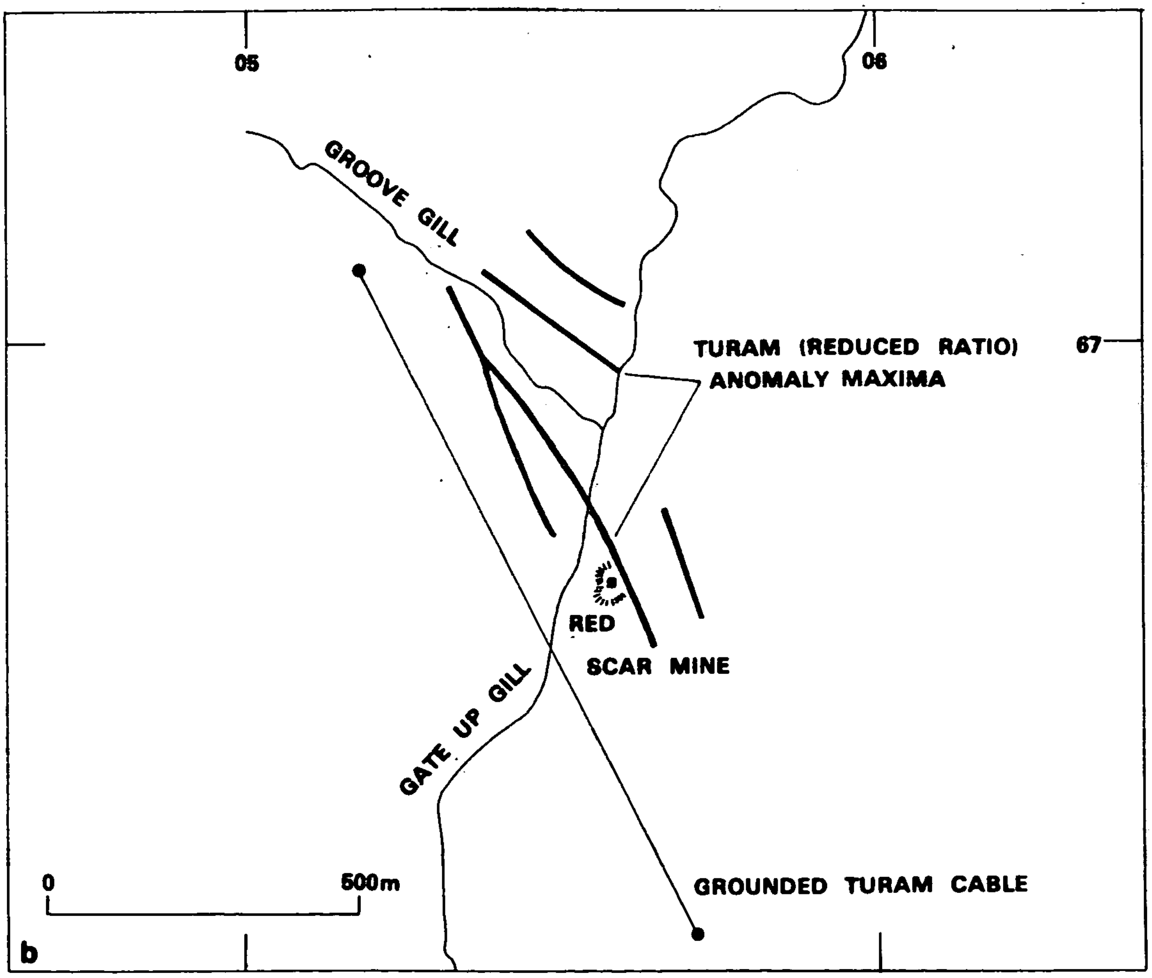


Fig 29 a VLF-EM traverses and geophysical anomalies at Ashfold Side.
b Geophysical anomalies at Red Scar Mine

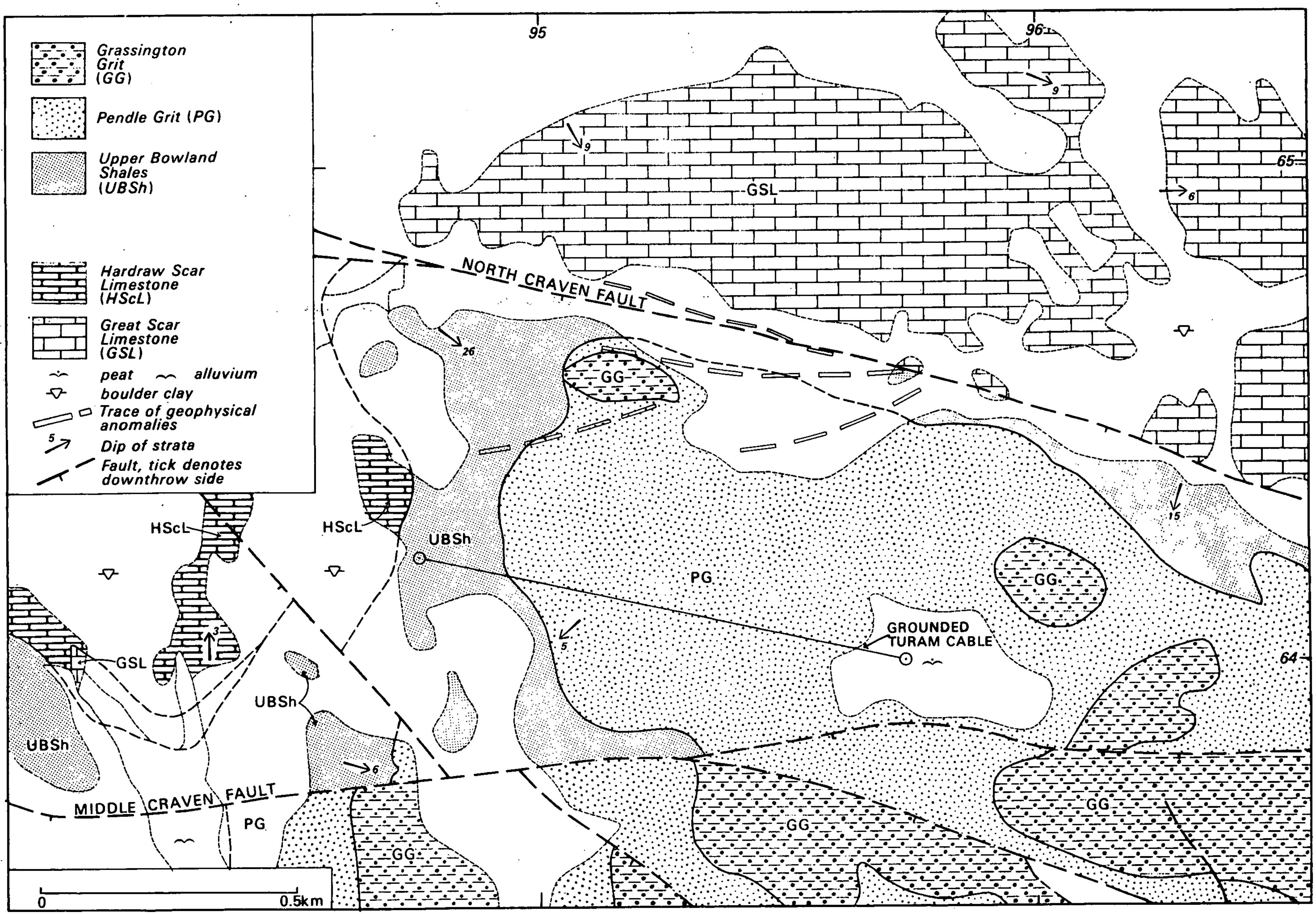


Fig.30 GEOLOGY ADJACENT TO THRESHFIELD MOOR AND LOCATION OF GEOPHYSICAL ANOMALIES

anomaly suggests that the structures are insufficiently 'open' for there to be significant mineralisation along them.

Further work in the area would be best directed to the ground immediately east of Blea Beck, where it appears that mineralisation on an extension of the Bycliffe Vein may have been missed by previous trials. The possibility of an extension of the Groove Gill vein south-east by way of the Red Scar veins, then east-south-east as the Middle Vein to Trunla Gill may also merit further investigation.

THRESHFIELD MOOR

This area lies 5.5 km north-east of Malham at about 350 m OD and is rough grazing land. Attention was initially drawn to the area by an EM anomaly on the airborne geophysical survey.

The geology of the area is shown in Figure 30, which is partly based upon recent re-mapping of the Settle district. Throughout much of Dinantian and Namurian times the thin block sequence to the north of the North Craven Fault passed southwards into thicker basinal successions. The exact position of the basin margin varied with time and is not always easy to define. At some horizons it appears to have coincided with the Mid-Craven Fault, whilst at other times the basinal sequences reach to the North Craven Fault. Nonetheless, it is clearly an area of mineral potential.

The Great Scar Limestone consists of about 200 m of well-bedded to massive, pale grey limestones. These are succeeded by grey, finer-grained, crinoidal, calcirudites which equate with the Hardraw Scar Limestone of the Askrigg Block sequence to the north. The overlying Bowland Shales are dark grey, silty, calcareous mudstones with thin, impersistent, limestone bands, and rest unconformably upon the older beds. Above, the succession of grits, sandstones and siltstones assigned to the Pendle Grit is unconformably overlain by coarse pebbly Grassington Grit. There is no folding hereabouts and the beds are only gently tilted, generally towards the south. The throw of the North Craven Fault with respect to the Namurian rocks is about 200 m down to the south. The solid rocks are partly obscured by a patchy till-sheet but the boulder clay is generally thin.

An initial ground geophysical survey using the Turam method was conducted along a series of lines running 15° east of north. Across the northern part of the area, two strong linear anomalies trending slightly south of east were located (Figure 30). The northerly one coincides with the North Craven Fault and is probably caused by it. Apparent resistivity measurements made along two of the Turam traverses confirmed the mapped location of the Fault. The southerly Turam anomaly closely follows the Bowland Shales–Pendle Grit contact over part of its length. From the anomaly characteristics, it is considered to be due to a local concentration of return current at that horizon, rather than being an induced effect, and therefore not significant.

Of greater interest are two further Turam anomalies lying 'en echelon' across the centre of the survey area, closely corresponding to the positions of the airborne anomaly maxima. The geological mapping shows no features which might account for them. They lie mainly within flat-lying sandstone outcrops and cross two geological contacts. Mineralisation, or a similar conductivity feature, at the top of the concealed limestone sequence may be the cause of the anomalies, but their characteristics suggest that their source is shallower than the anticipated top of the limestone. Slingram measurements along three of the Turam traverses failed to locate corresponding anomalies and VLF measurements along the same three traverses located only weak features of uncertain relationship to the Turam anomalies.

In conclusion, the cause of the two southernmost anomalies (Figure 30) is unexplained, though the northernmost one is related to the North Craven Fault. At present it is not known why some parts of this fault produce strong anomalies, which are absent from other parts where the geology is apparently similar. The anomalies to the south are probably caused either by changes in lithology or structural features not identified by geological mapping or possibly by some form of mineralisation.

HETTON COMMON

Hetton Common is an area of rough pasture lying 3.5 km east of Malham [935 625] at about 340 m OD. An EM anomaly indicated on the initial airborne geophysical survey, together with a stream sediment anomaly, concentrated attention on the locality.

The geology has been recently mapped by R. S. Arthurton during the re-survey of the Settle district and is summarised in Figure 31. Several coarse sandstones occur within a Namurian sequence of siltstones and mudstones comprising the Pendle Grit Group. The sandstones are variable in thickness and commonly discontinuous laterally, so they are regarded as channel infillings. The rocks are gently folded into an east-plunging syncline, bounded to the south-west by the Hetton Common Fault which throws down in this direction about 150 m. The till-sheet is patchy in distribution but is as much as 8 m thick locally.

The initial stream sediment survey yielded anomalous Ba, Zn and Cu values in three pan concentrates from Whetstone Gill. Two soil traverses with a sample interval of 50 m were carried out, but produced values only slightly above background level.

The airborne EM anomaly is a well-defined linear feature trending eastwards over nearly 1 km. The follow-up ground Turam survey located a similar anomaly (Figure 31) but displaced about 100 m to the south. The ground anomaly in the reduced ratio values is narrow, symmetrical and well-defined above a uniform, though high, background. There is no evidence of artificial conductors hereabouts and the anomaly crosses both solid and drift boundaries with deviation. The coincidence of the geophysical and geochemical anomalies points to the occurrence of Ba–Zn mineralisation, but there is no sign of it in Whetstone Gill. The sandstone is locally thick along the axis of the syncline but it remains an unusual geological setting for mineralisation. To this extent the anomalies remain unexplained.

ORMS GILL GREEN

This area of pasture and rough grazing lies 6 km south-east of Settle at 150–250 m OD. Recent work on the Settle sheet has resulted in the revised geology and stratigraphy shown in Figure 32. The oldest part of the sequence exposed is the Chatburn Limestone which consists of grey, finely crystalline limestones with bioclastic layers rich in crinoid debris or shelly faunas. The limestones are generally well-bedded with many thin mudstone partings, but in places they are more massive. The succession grades upwards into the more argillaceous Worston

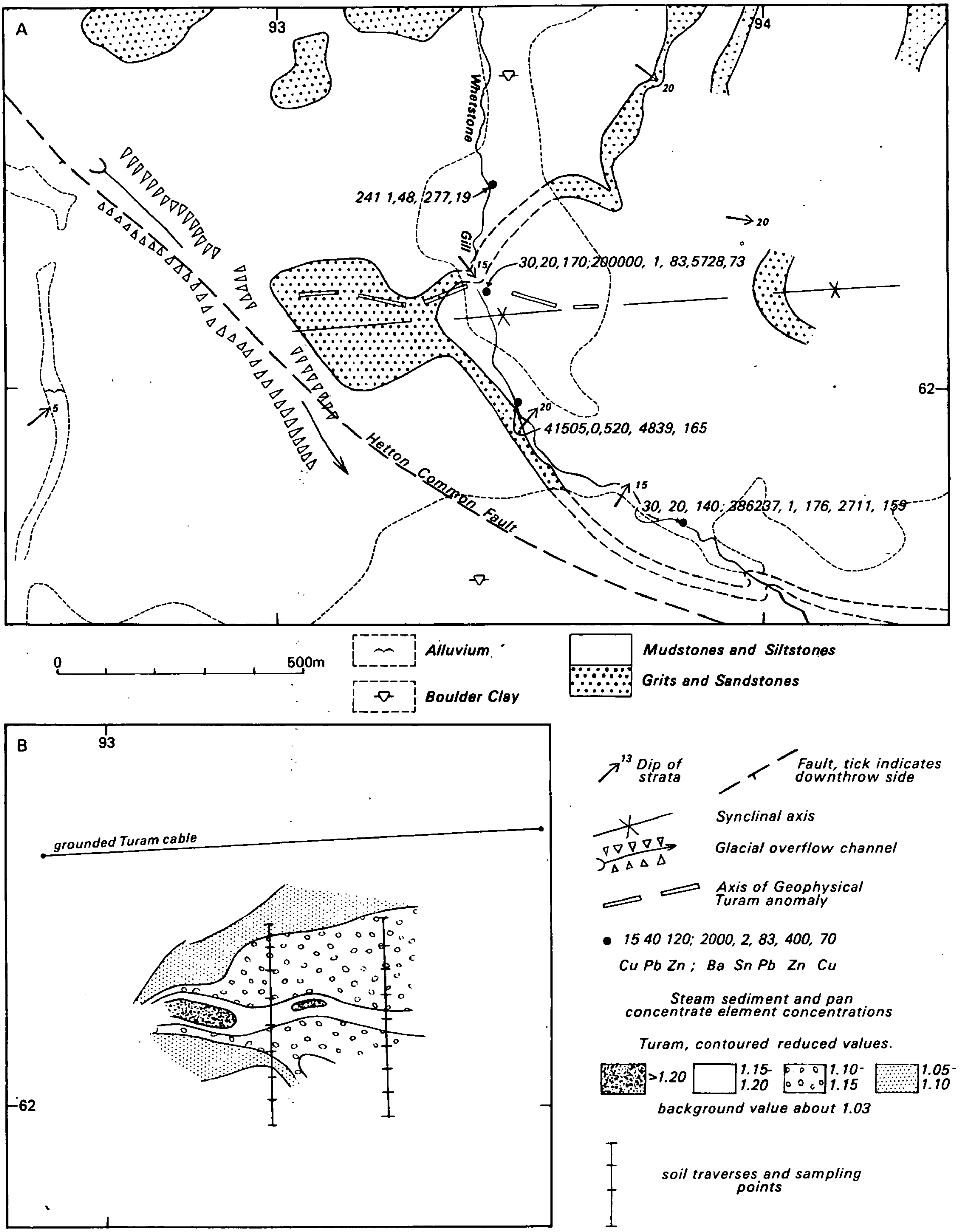


FIG.31 A. GEOLOGICAL SKETCH MAP WITH STREAM SAMPLING POINTS, VALUES OBTAINED AND TRACE OF GEOPHYSICAL ANOMALY MAXIMUM AT HETTON COMMON
B. TURAM SURVEY, CONTOURED REDUCED RATIOS AND SOIL TRAVERSES AT HETTON COMMON

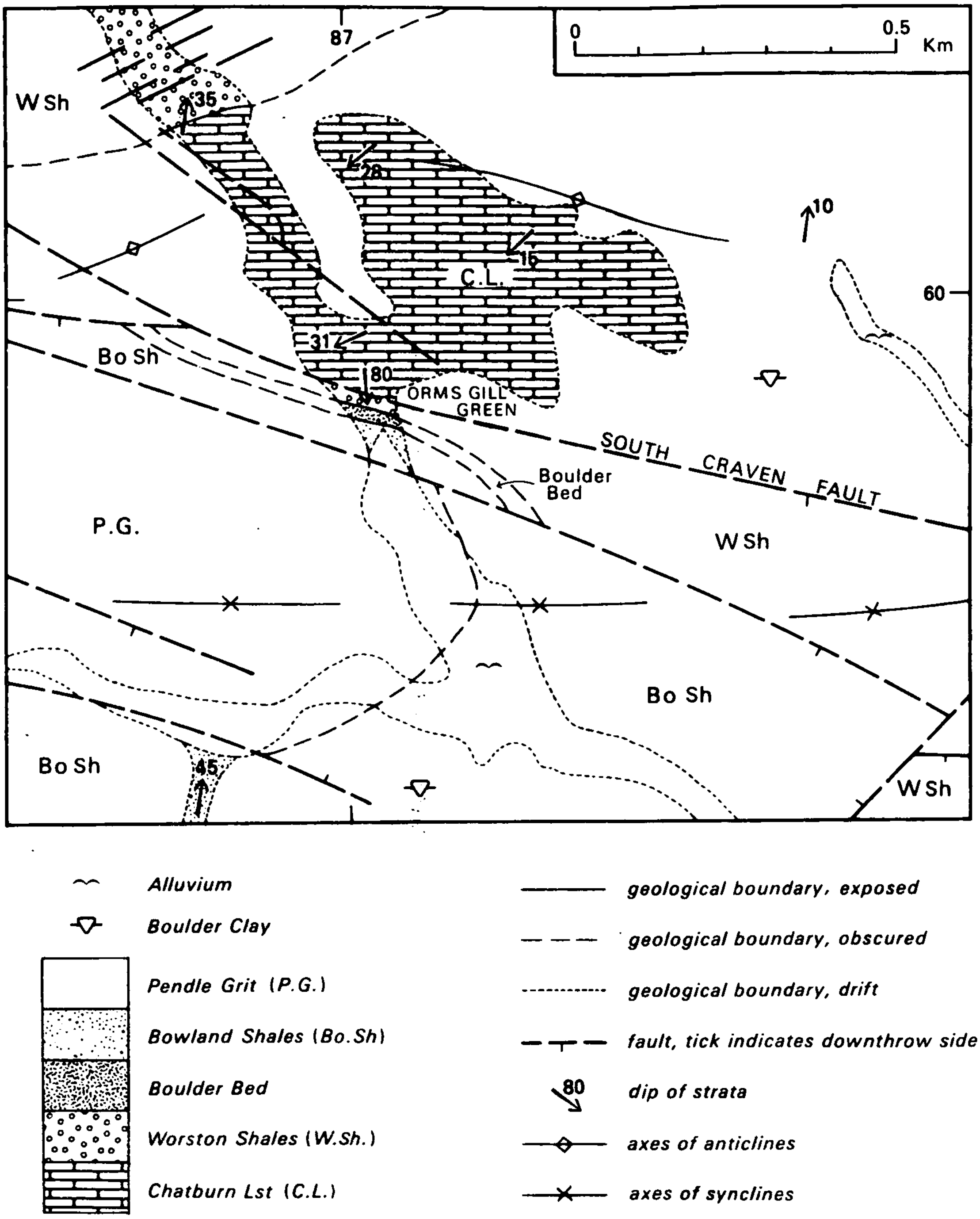


Fig.32 GEOLOGY AROUND ORMS GILL GREEN

Shales, which consist mainly of calcareous and silty mudstones with ironstone nodules and layers rich in crinoid debris, interbedded with thin laminated muddy limestones. The top of the Worston Shales is marked by the base of a boulder bed of angular limestone clasts set in a fine-grained bioclastic matrix representing an erosional interval before the deposition of the Bowland Shales. These dark grey, pyritic mudstones with thin muddy limestones are succeeded by the coarse-grained, feldspathic sandstones of the Pendle Grit.

The rocks are flexured into large open folds about 1 km in wavelength, trending east-west and with 15° to 45° dips on their limbs. In the Chatburn Limestone the folding is more complex, with tight folds 10 to 30 m in wavelength in the limestones and near-isoclinal folds in the shales. The South Craven Fault crosses the area, throwing down substantially to the south and represented by at least two fractures in the Orms Gill section.

Attention was first drawn to the area by the recognition of zones of alteration in the Chatburn Limestone outcrop, where the rock is locally dolomitised and silicified. The open-textured sponge-like appearance of this rock closely resembles mineralised ground illustrated from the Pine Point reefs in Canada (Beales and Jackson, 1966). Where silicified, the rock tends to form crags like Airton Green Rock [8727 5989] but elsewhere the dolomitic but unsilicified rocks are relatively soft and form gulleys, as seen on the east bank of Orms Gill [8695 5993]. Small strings and patches of sphalerite and chalcopyrite, commonly associated with quartz and secondary calcite veining, can be seen in the altered outcrops. The occurrence of dolomitisation promised, if widespread, to enhance the mineral potential of the area since the volume reduction which marks this type of alteration can open up the tex-

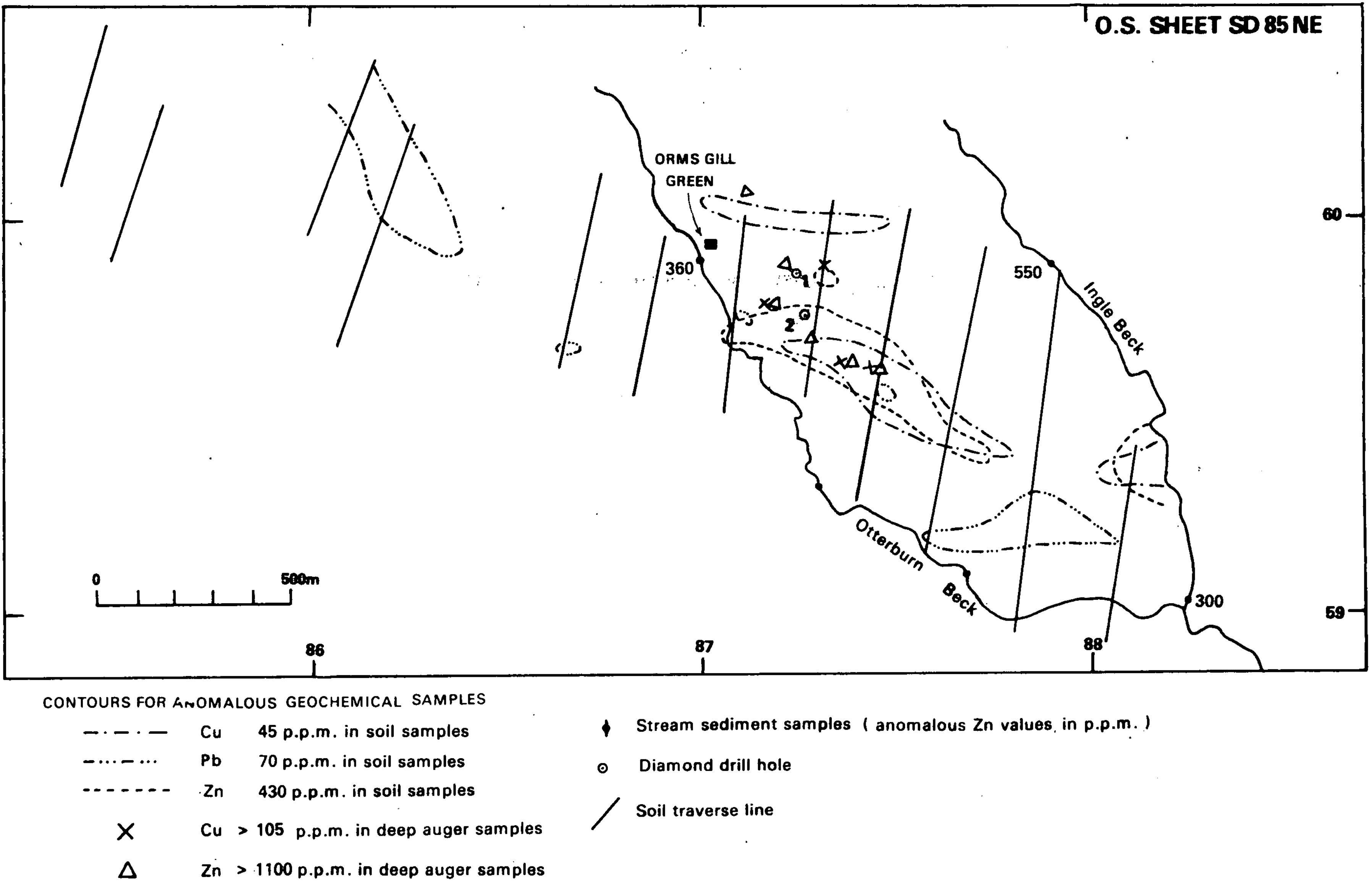


Fig. 33 Geochemical surveys at Orms Gill Green.

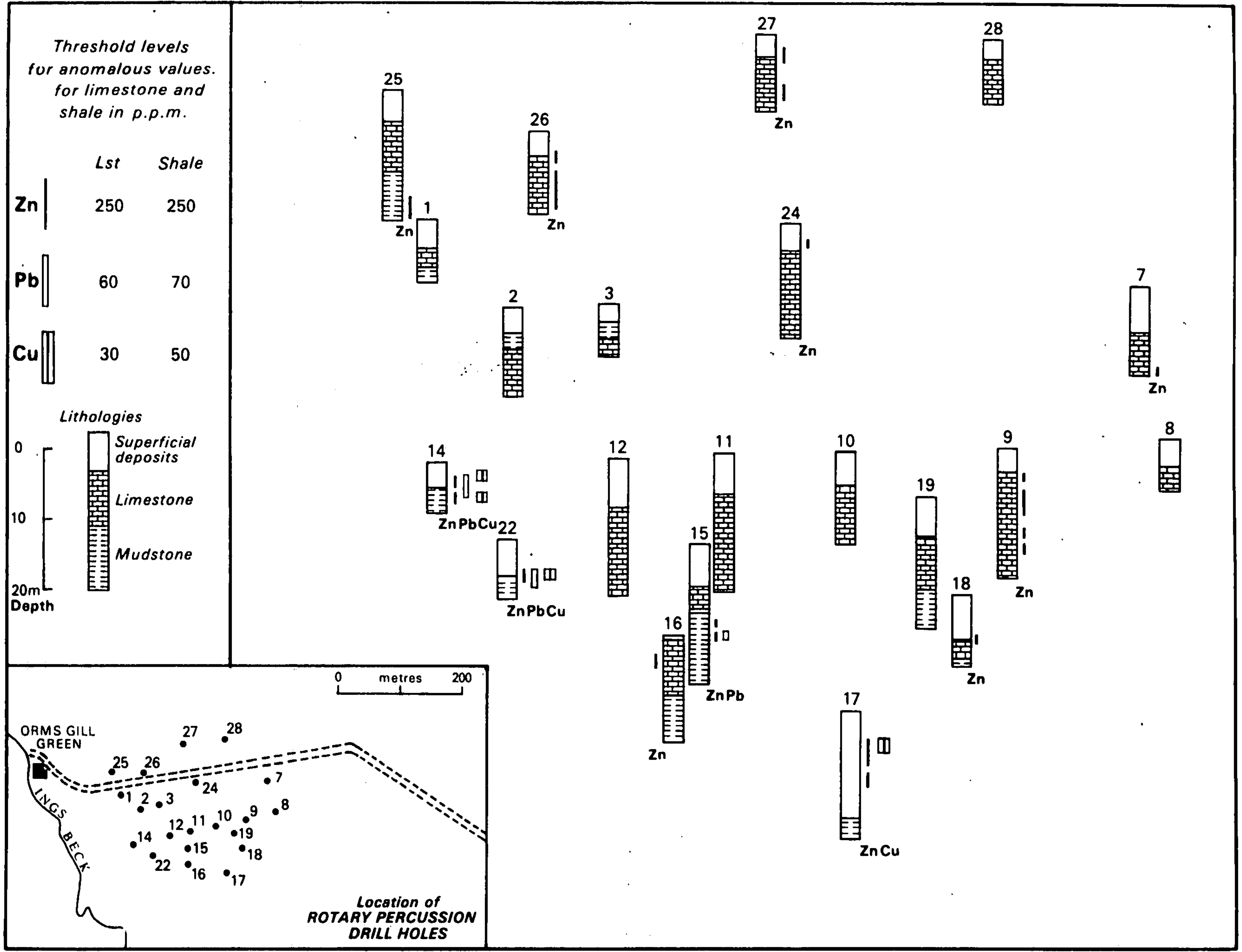


FIG. 34 ANOMALOUS GEOCHEMICAL VALUES OBTAINED IN SAMPLES FROM ROTARY PERCUSSION DRILL HOLES AT ORMS GILL GREEN

ture of tight carbonates and make them more receptive to metalliferous brines.

The reconnaissance drainage survey identified anomalous values for Cu, Pb and Zn in Orms Gill and Ingle Beck. Sphalerite, smithsonite and minor galena were found in pan concentrates from these streams, and water samples also contained anomalous Zn. The mineralogy of a number of samples suggested that the initial phase of mineralisation was sphalerite–pyrite–quartz veining, followed by remobilisation of the zinc and the formation of smithsonite. A later movement of Zn seemed to have resulted in its absorption by goethite.

In order to identify and extend the mineralised zones, soil samples were collected at 100 m intervals along lines 250 m apart and analysed for Zn, Pb and Cu. A contoured plot of the results (Figure 33) shows that the highest values for all these elements coincide along the South Craven Fault. The threshold values used in contouring are shown on Figure 33 and are derived from a simple statistical treatment to give the mean plus two standard deviations ($\bar{x}$ + 2s). Maximum soil values rise to 2500 pm for Zn, 170 ppm for Cu and 120 ppm for Pb. The position of the Fault is seen in both Orms Gill and Ingle Beck, but it is less certain across the intervening ground which is covered by till. The superficial deposits of the area consist mainly of overconsolidated, grey boulder clay with grit and limestone erratics, spread as a sheet over most of the ground and heavily drumlinised along NW–SE axes so that in places it is more than 30 m thick. In the immediate vicinity of Orms Gill Green, however, there are no drumlins and the till is less than 5 m thick.

Follow-up basal till sampling, to investigate the metal content at or near the till-rock interface, was undertaken in the area of the soil anomalies. The basal till data showed small areas of anomalous Zn and Cu lying within the Zn and Cu soil anomalies. Background values for Zn and Cu in the auger samples were about twice as high as in the soils.

A programme of rotary percussion drilling was undertaken to test the anomaly in basal till and its relationship to bedrock mineralisation. Samples for analysis were obtained from 25 holes up to 20 m deep, and the results are shown in Figure 34. Two cored boreholes were sunk in the positions shown on Figure 33, but core recovery was too poor to give useful geological information. In order to identify more accurately the anomalous values obtained from the rotary percussion work, samples were subdivided into two populations from the limestones and shales respectively. Anomalous values for Zn, Cu and Pb were calculated for these two populations using the $\bar{x}$ + 2s values:

	Limestone			Shale		
	$\bar{x}$	s	$\bar{x}$ + 2s	$\bar{x}$	s	$\bar{x}$ + 2s
Zinc	108	72	252	119	65	249
Copper	17	8	33	23	15	53
Lead	44	10	64	50	12	74

Anomalous values were recorded from the bedrock in ten holes (Figure 34); of these, holes 14, 15, 22, 16 and 17 lie close to the fault, but there is no correlation between mineral content and proximity to the fracture. It seems likely that there has been minor leakage along the South Craven Fault and slight enrichment of the adjacent limestones in localised areas.

The dolomitisation of the carbonates prior to mineralisation is interesting, but there is no sign in the drilling results that this is sufficiently widespread to be of economic interest.

LOTHERSDALE

The Lothersdale area lies 6 km north-east of Colne and is centred on the NE–trending Lothersdale Anticline (Figure 35). The rocks in the core of the fold crop out in the deep and fertile valley of Lothersdale whilst the surrounding moors are underlain by the beds on the anticlinal limbs. The whole area is well served by minor roads.

The oldest formation exposed is the Chatburn Limestone; only the uppermost 30 m of the Limestone are seen, consisting of dark grey, thinly bedded, partly oolitic limestones with thin shale partings (Earp and others, 1961, p. 36). These rocks are at present quarried at Raygill for aggregate. The overlying Worston Shales are about 300 m of calcareous micaceous mudstones and thin limestones which rest on the lower beds with minor unconformity, the break in sedimentation being marked by thin sandy beds at the base of the shales. The Pendleside Limestone is a black argillaceous limestone with chert bands and shaly partings, and is 75 m thick. The Bowland Shales above are unusually thin hereabouts comprising only about 80 m of mudstones; the turbidites of the Pendleside Sandstone are absent locally. The Pendle Grit consists of about 500 m of medium to coarse-grained sandstones with partings of micaceous shales.

The folding of the Namurian rocks is generally simple with moderate dips (20–40°) on the anticlinal limbs, but within the Dinantian rocks in the axial region the detailed structure is more complex, especially in the Chatburn Limestone inliers. These are periclinal so that the axial trace pitches to the south-west and north-east at 10° to 20°. In addition there are minor folds in the inliers trending just north of east which are unrepresented in the overlying beds, and these may be due to earth movements in pre-Worston–Shale times or to differences in competence. The local faulting appears to be entirely post-Carboniferous in age and unrelated to sedimentation changes.

The till-sheet which covers much of the lower ground of Lothersdale consists of a stiff grey boulder clay with grit and limestone erratics. It is generally less than 10 m thick in the west but thickens eastwards to about 30 m around Lothersdale village.

Baryte was formerly worked at Raygill [941 453] where several small east-west faults in the Chatburn Limestone are mineralised. Only Main Vein was extensively worked, to a depth of about 60 m. From 1876 to the mine closure in 1895, 35 045 tons of baryte were won. In addition to baryte and calcite, the veins contain minor amounts of fluorite and diagolite, a carbonate of manganese. The occurrence of Mn minerals encourages the view that it might be fruitful to test Mn haloes as a guide to hidden sulphide deposits in the Craven Basin.

About 3 km east of Raygill, the Cononley Mine [985 458] worked Pb ore along a mineralised section of the Glusburn Fault (Eddy, 1883). Seven shafts were sunk to a maximum depth of about 90 m and the main orebody was stoped over a vein length of about 500 m. Between 1848 and 1863 annual production of Pb ore varied betwen 329 and 550 tons, but declined rapidly thereafter. Sphalerite, smithsonite, baryte and witherite were also present.

In order to compensate for the major lithological changes in the underlying geology, the geochemical

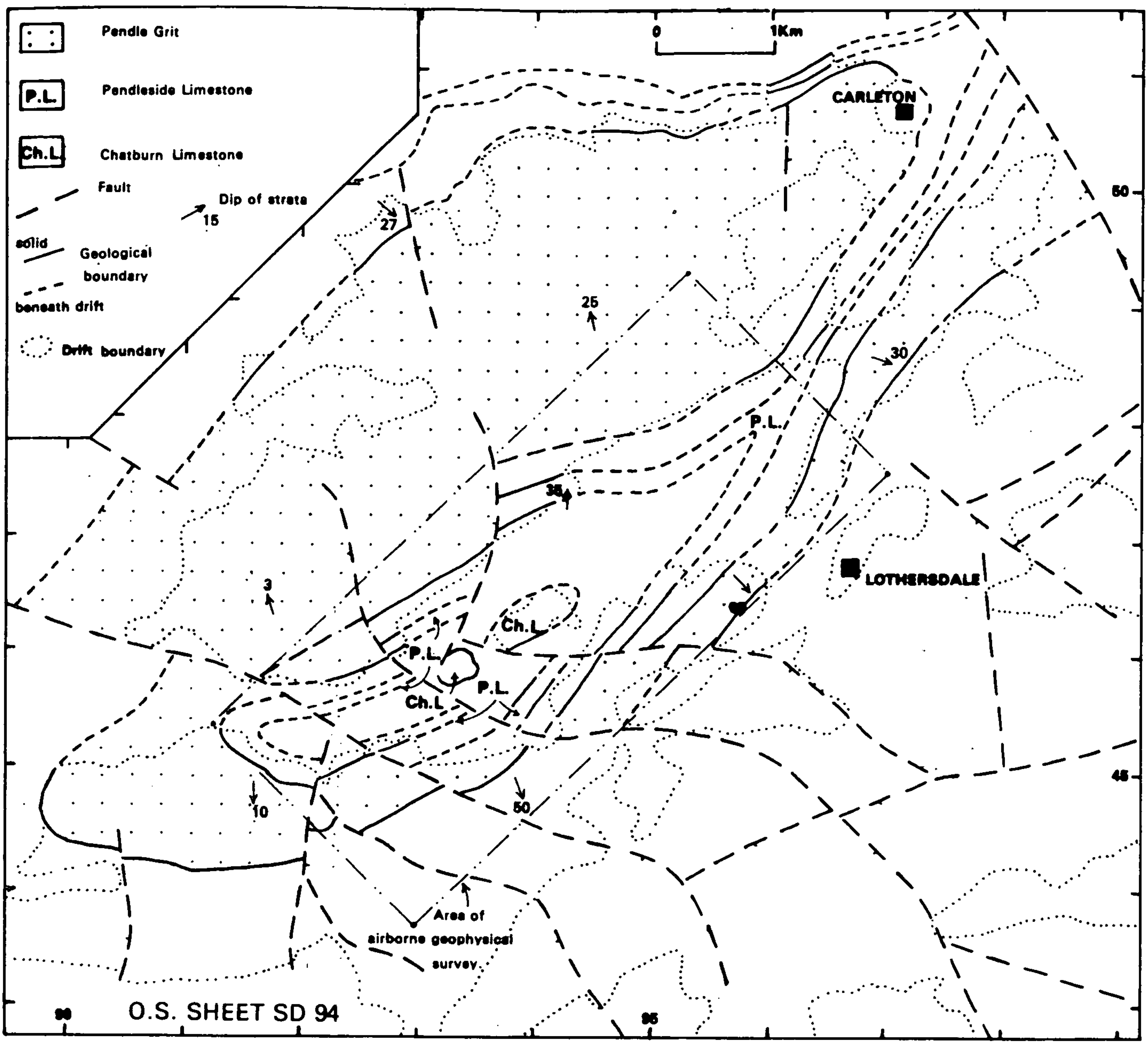


FIG. 35 GEOLOGY OF THE LOTHERSDALE ANTICLINE

samples collected were divided into two groups; those from areas underlain predominantly by limestones and calcareous shales, and those from areas of grits and sandstones.

A preliminary soil-sampling programme covered 35 km^2 (Figure 36) extending from Carleton in the north-east to Kelbrook Wood in the south-west and including the old mines at Raygill and Cononley. Soil samples were collected at approximately 500 m intervals, supplemented by closer sampling on a 300 × 150 m grid in the area between Raygill and Cononley Mines. The samples collected were analysed for Cu, Pb, Zn and Ba.

The accompanying table gives the arithmethic mean and standard deviation values (in ppm) calculated for Cu, Pb, Zn and Ba. Anomalous values are considered to be those above the mean plus two standard deviation level. In all cases the highest erratic values (approximating to 2–3% of the population) were excluded from the calculations.

	Arithmetic mean $\bar{x}$	Standard deviation (s)	$\bar{x}$ + 2s	Maximum
Copper				
Limestone	22.50	12.25	47.00	50.00
Grit	20.00	10.80	41.60	145.00
Lead				
Limestone	45.00	12.90	70.80	150.00
Grit	98.50	51.50	201.50	6200.00
Zinc				
Limestone	78.60	47.50	174.00	270.00
Grit	83.00	43.70	170.40	1030.00
Barium				
Limestone	422.90	197.00	816.90	1135.00
Grit	386.50	138.32	663.14	>10%

The distribution of the anomalous samples is shown in Figure 36.

The number of samples with anomalous values is low and there is little obvious pattern in their distribution. Samples collected close to the Cononley Mine contain, as expected, higher than normal values for all four metals.

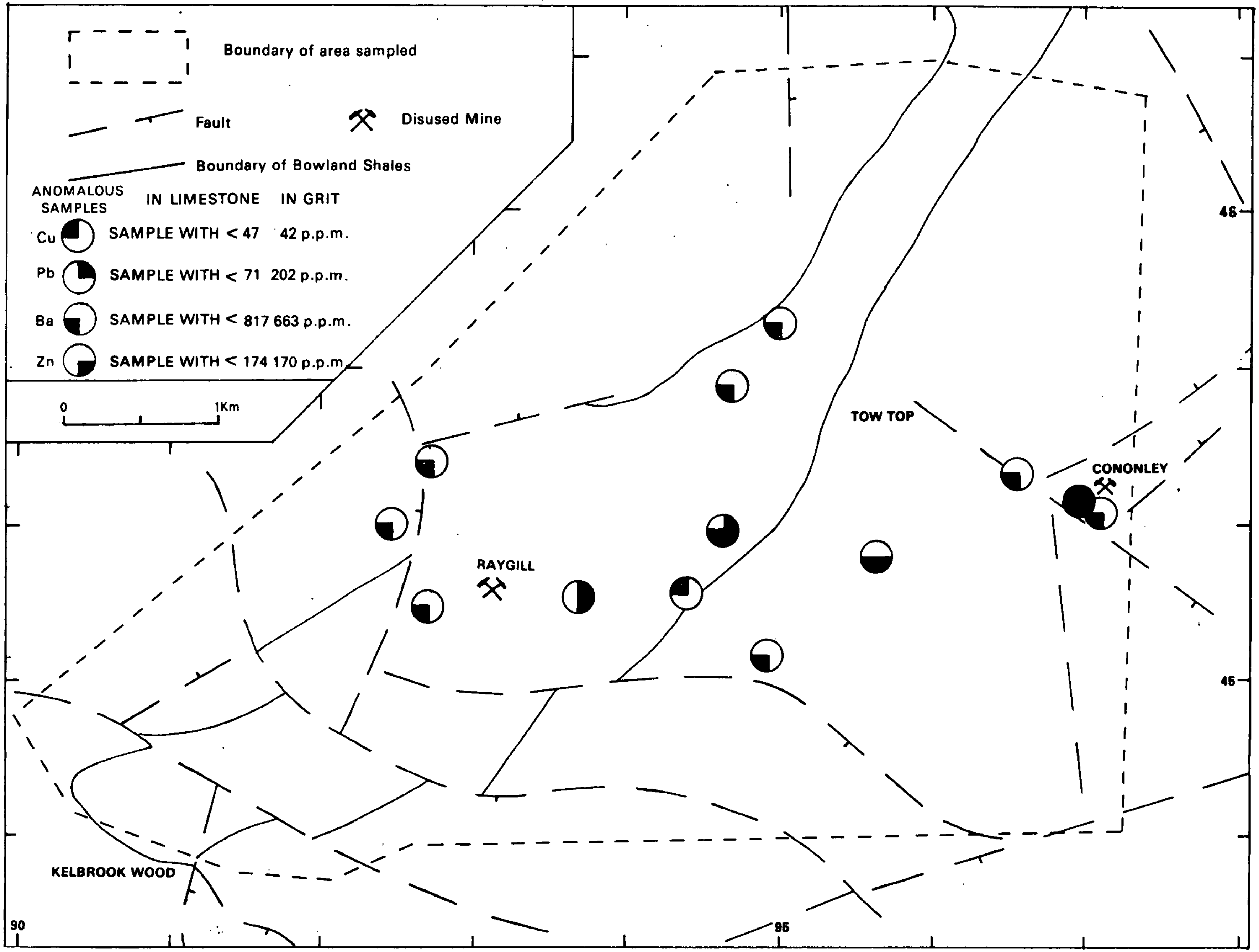


FIG. 36 GEOCHEMICAL SOIL SURVEYS AT LOTHERSDALE

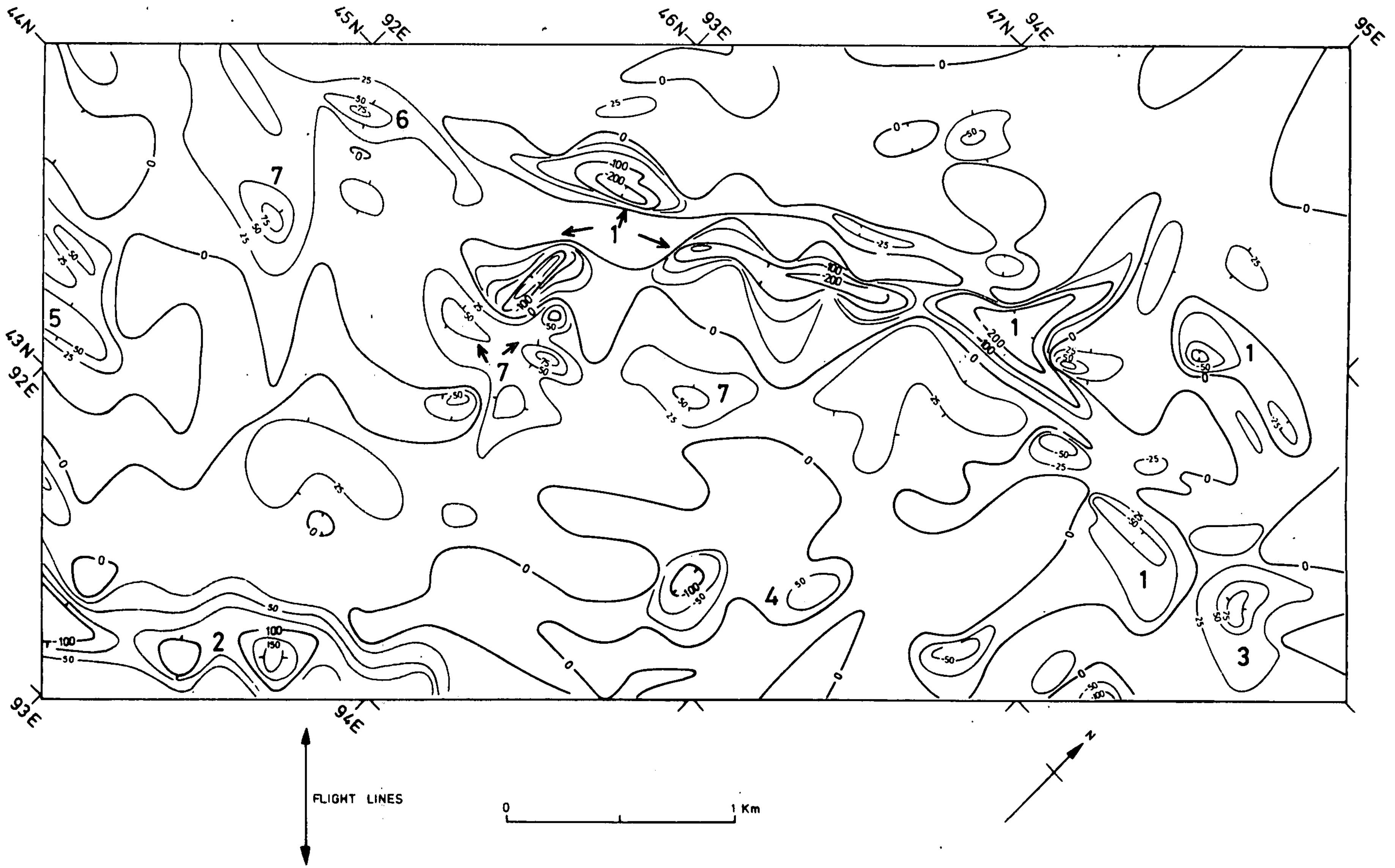


Fig. 37 Airborne electromagnetic map (in - phase component) of the Lothersdale Anticline, with contours at intervals of 25 p.p.m. . Anomalies numbered 1-7 are referred to in the text

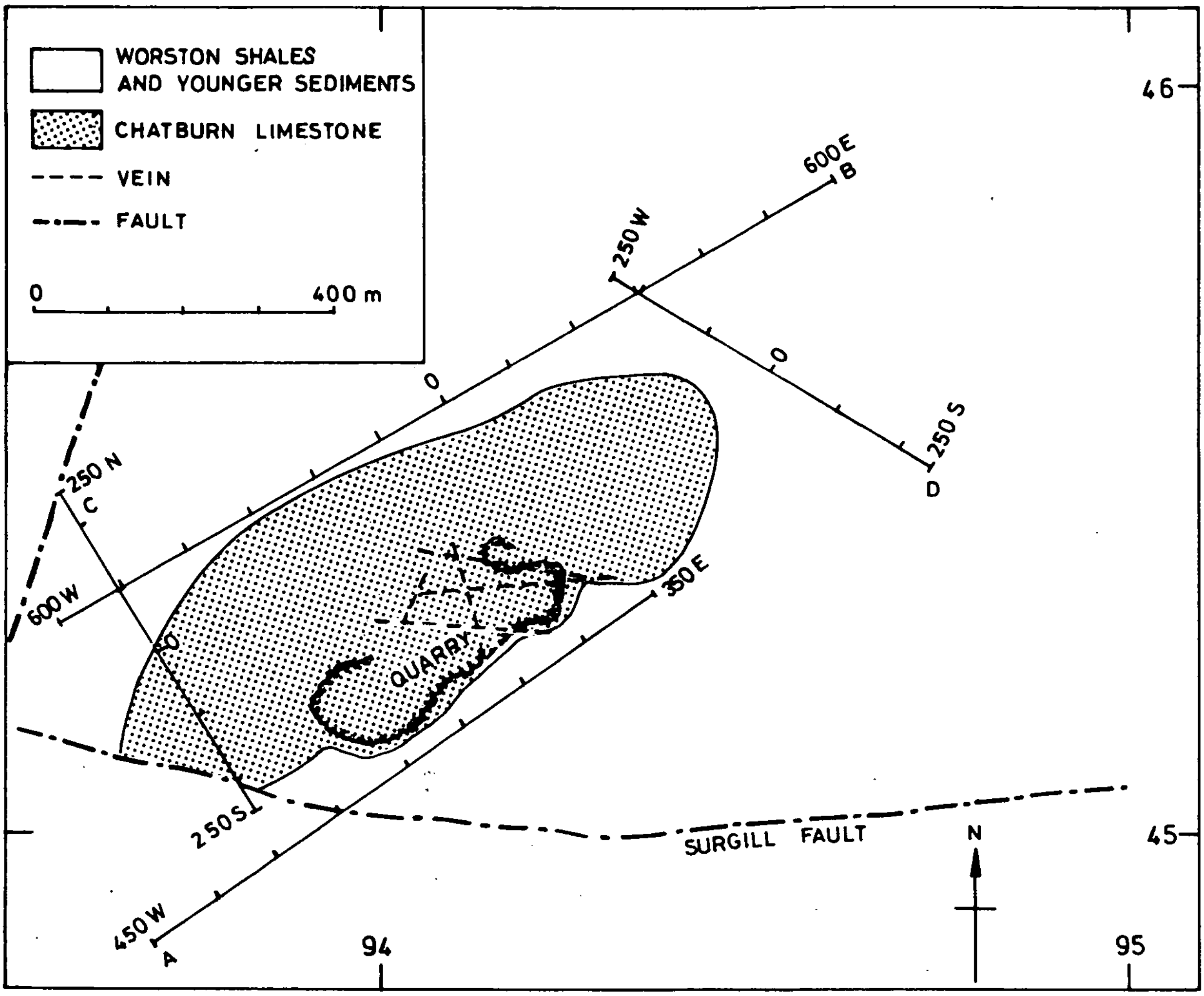


Fig.38 **Sketch map of the Lothersdale Quarries, with the locations of IP traverse lines**

The scattered high values for Ba probably indicate minor mineralisation associated with faults, as do isolated high values of Pb and Zn.

The only area within the main part of the Craven Basin covered during the 1973 helicopter-borne geophysical survey was the small block, 5.7 km long and 2.8 km wide, centred on the inlier of Chatburn Limestone at Lothersdale (Figure 37). The survey was regarded as a trial because two main difficulties were anticipated, namely extensive interference by power lines on the EM equipment and restricted depth of penetration by the EM equipment due to the presence of low resistivity shales overlying the Chatburn Limestones. The survey was conducted under standard conditions (Burley and others, 1978) using EM equipment, a proton magnetometer and radiometric equipment. The flight lines were 200 m apart and oriented in a north-west to south-east direction and a total of 96 line km was covered. The survey area was outlined by the coordinates [3930 4420, 3970 4460, 3950 4480 and 3910 4440]. The results of the survey were compiled as 1:10 560 maps of the in-phase component of the EM field, the ratio of the in-phase to the out-of-phase components, and the magnetic field. The radiometric data were not produced in map form and remain only as flight profiles.

The original contoured maps of the in-phase component of the EM field were combined and simplified to produce the map shown in Figure 37. This map is dominated by linear negative anomalies (1 in Figure 37) due to overhead power lines crossing the area and these unfortunately conceal any other EM data in the vicinity of the small, mineralised inliers of Chatburn Limestone. The most obvious feature due to a geological cause occurs in the southern corner of the area (2 in Figure 37), where an anomaly of more than 150 ppm extends for a distance of at least 1 km over the outcrop of the Bowland Shales. These beds are known elsewhere to give rise to EM anomalies, particularly when the bedding is disturbed by faulting. Within the Lothersdale area some of the other smaller EM peaks could also be due to shale horizons, whose exact position is doubtful beneath extensive drift cover. Anomalies 3 and 4 appear to coincide with a boundary between shales and the underlying Pendle Grit and anomaly 5 occurs over a faulted boundary between the same horizons. Anomaly 6 occurs over the lower part of the Pendle Grit, but shales are known also at this horizon. A group of anomalies (7 in Figure 37) occurs over horizons just below the Pendleside Limestone.

It seems that most of the EM anomalies in the Lothersdale area are due to conductive shales and are not likely to indicate economic mineralisation. None of the airborne EM anomalies in the area were investigated on the ground but exploration for mineral veins using EM methods will be hampered in this geological environment by the necessity of identifying anomalies due to these stratigraphical conductors.

To test whether the Raygill veins or similar mineralisation could be traced in the Chatburn Limestone beneath a

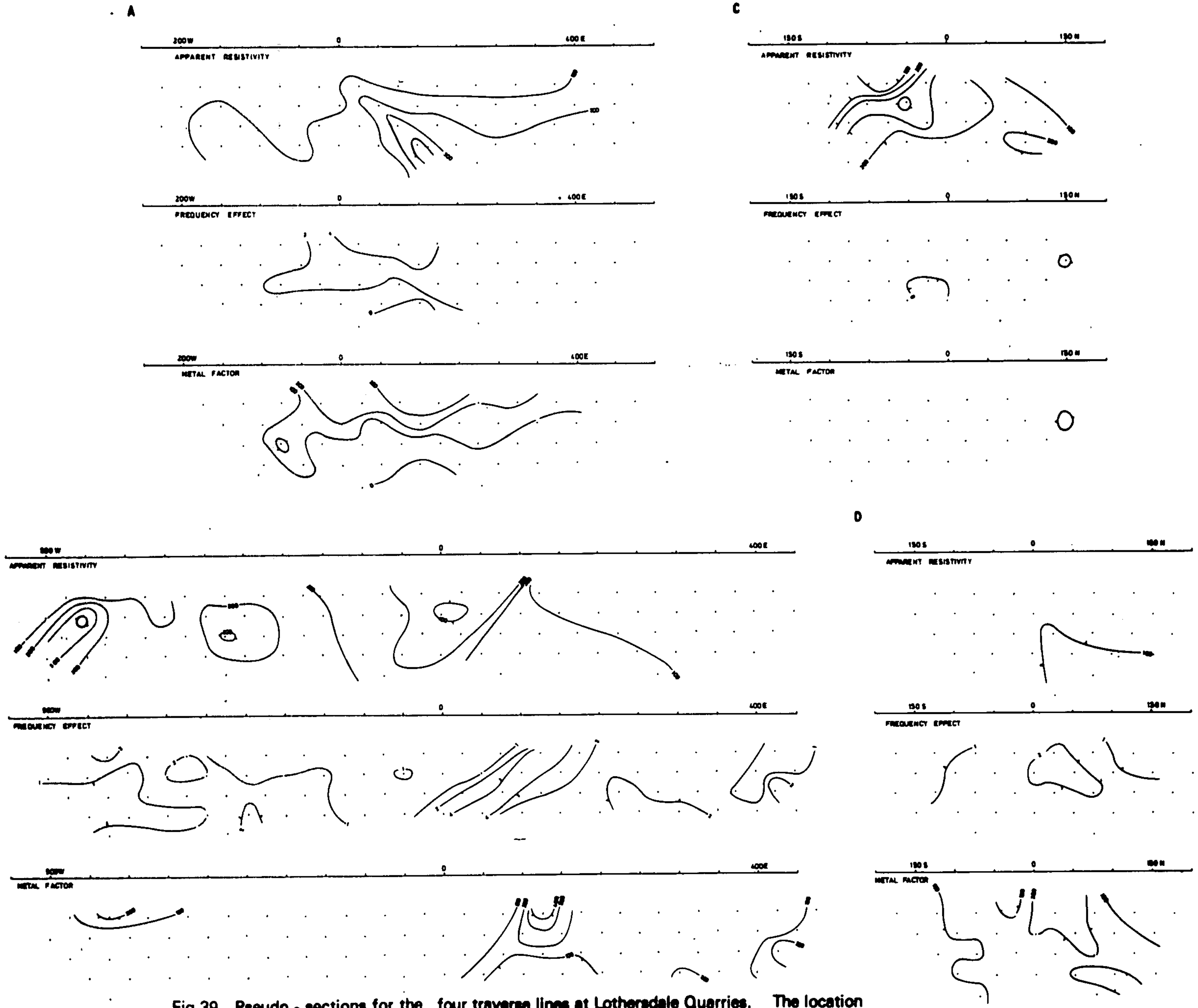


Fig.39 Pseudo - sections for the four traverse lines at Lothersdale Quarries. The location of the traverses A to D are shown in Fig.38

shallow cover of Worston Shales, a trial IP survey was carried out (Figures 38, 39). In addition, local resistivity measurements were made to determine the position of the limestone beneath the shales. Using frequency-domain IP equipment (Burley and others, 1978) operating at 3 Hz and 0.1 Hz, four traverses were laid out around the edge of the limestone inlier, and measurements of the apparent resistivity and percentage frequency effects were made using a dipole-dipole array (a = 50 m).

The resistivity values vary between 50 and 500 ohm metre and there is a clear correlation between the higher values and the areas where limestone is at or close to the surface. The overlying shales of the Worston Shale Group appear to give values less than 100 ohm metres. Low-frequency effects (0.5–1.5%) occur over both limestones and shales and tend to increase at the contacts between the two rock-types. Along traverse B the highest frequency effects measured in the area occur as a narrow band coincident with the change of resistivity from higher to lower values. The top of the limestone lies close to rockhead at this point but the resistivity values decrease rapidly with the northerly plunge on the anticlinal fold and east of 350E there is no sign at all of higher resistivity values at depth (i.e. at n = 5). On traverse A the limestone surface, as indicated by the resistivity values, extends westwards at depth to about 150W to 200W, where it is thrown down to the south by the Surgill Fault. The higher frequency effect (and metal factor) values occur in this area of shallow limestones but probably represent a similar effect to that seen at the contact on B as the values decrease with depth. On traverse C all of the frequency effect values are low and most of the resistivity values are high, but the effect of the shale can be seen near the surface at 100N. On traverse D the limestone is indicated at depth by the higher resistivity values at n = 5 and n = 6 but the frequency effect values are generally low.

The only frequency feature of interest, therefore, is the group of values reaching 6% at 100–150E on traverse D, but, as this is situated at the limestone–shale boundary, it is likely to be a characteristic of the shale at this horizon or a geophysical effect of the interface. The resistivity values generally indicate the presence of limestone at depth but the rapid rate at which this effect disappears indicates that there would be little chance of detecting limestone, and consequently any mineralisation, with the array type and size used more than 100 m away from the outcrop. It is difficult to quantify the dip of the concealed limestone, but the fairly steep angles implied above would be consistent with the dip values observed in the quarry.

It is concluded that this study provides no indications of unknown sulphide mineralisation. The geophysical surveys were greatly hampered by artificial conductors, and geochemical contamination marks all the old workings. The interpretation of EM anomalies obtained from airborne surveys is difficult in a succession of alternating limestones and mudstones. These lithologies and the junctions between them in many cases would tend to conceal any weak anomalies caused by sulphide mineralisation.

The relationship between the host-rocks of the Chatburn Limestone and the cap rocks of the Worston Shales remains promising. The mechanism of retaining metalliferous brines in a structural trap has produced some mineralisation within the core of the anticline. Exposures of the limestone are limited, however, and with present techniques it is not practicable to explore further the axial part of the fold beneath thick shale cover.

RIMINGTON

This area lies about 4 km north-east of Clitheroe. The land is mostly pasture and there is good access on minor roads. This geological account is based mainly upon the revised 1-inch geological map of the Clitheroe district published in 1960 and the accompanying memoir (Earp and others, 1961).

The Chatburn Limestone in the Rimington area is probably about 900 m thick overall but only the uppermost 300 m are exposed at Rimington. The beds are predominantly dark grey, pyritous, well-bedded limestones but shale partings are also common. During sedimentation, the transition to the overlying Worston Shales was marked by earth movements and a change in the pattern of deposition to a deeper water, low energy environment. Large reef knolls lie close to the base of the Worston Shales, and accumulated as lime-banks. Much of their present upstanding topography is due to erosion prior to the deposition of the Worston Shales, which rest unconformably upon them. The total Worston Shales sequence is probably about 1000 m thick but much of this succession is occupied by reef; for example the thickness of the Twiston reef is estimated at about 300 m. The reefs are generally composed of pale grey, poorly bedded calcilutites and micrites but with bedded, crinoidal biocalcarenites on their flanks.

The structure of the area is dominated by the NE-trending Clitheroe Anticline whose northern limb is truncated by the Horrocksford Hall Thrust. The upfold exposes the Chatburn Limestone in its core, but the north-eastern termination of the anticline is problematical. It is mapped as ending against the most easterly of the Skeleron veins but it is now known to continue under thick drift at least as far as Martin Top and the structure may be continuous with the anticline near Middop Hall [838 454].

The boulder clay in the Rimington area is patchy, covering much of the lower ground, but thinning against the Chatburn Limestone ridge and the reefs. It is thicker and more continuous to the north-east around Martin Top and is only penetrated here by the deepest valleys.

The Skeleron Mines at Ings Beck [814 452] have had a long history of sporadic exploitation going back to the reign of Elizabeth I and were last worked about 1920 (Williamson, 1959; Raistrick, 1973). Several veins within the Chatburn Limestone were worked, initially from bell-pits south-east of Hollins farm [8137 4510] and then from shafts [8156 4495, 8160 4488 and 8185 4510]. These were all joined by an adit driven north-eastwards from the side of Ings Beck [8150 4493] to command five veins trending NW–SE and one aligned NE–SW. The ores were galena, argentiferous in places, and baryte, with fluorite, sphalerite and smithsonite also present. There was little alteration of wall rock apart from some limited dolomitisation. The mining appears to have been limited by the area of the lease and the costs of drainage and pumping, but there is no doubt that the veins were small and very variable in ore content.

The mineral potential of the area seems to lie along the Chatburn Limestone outcrop along the axis of the Clitheroe anticline. It seems possible either that the Horrocksford Hall Thrust might provide a structural trap to the north, or that the Skeleron mineralisation might be trapped against the north-easterly plunge of the fold around Martin Top. These views were encouraged by the stream sediments and pan concentrates collected during the reconnaissance geochemical survey from the Stankhill Beck and Ings Beck catchments, 3 km south of Gisburn,

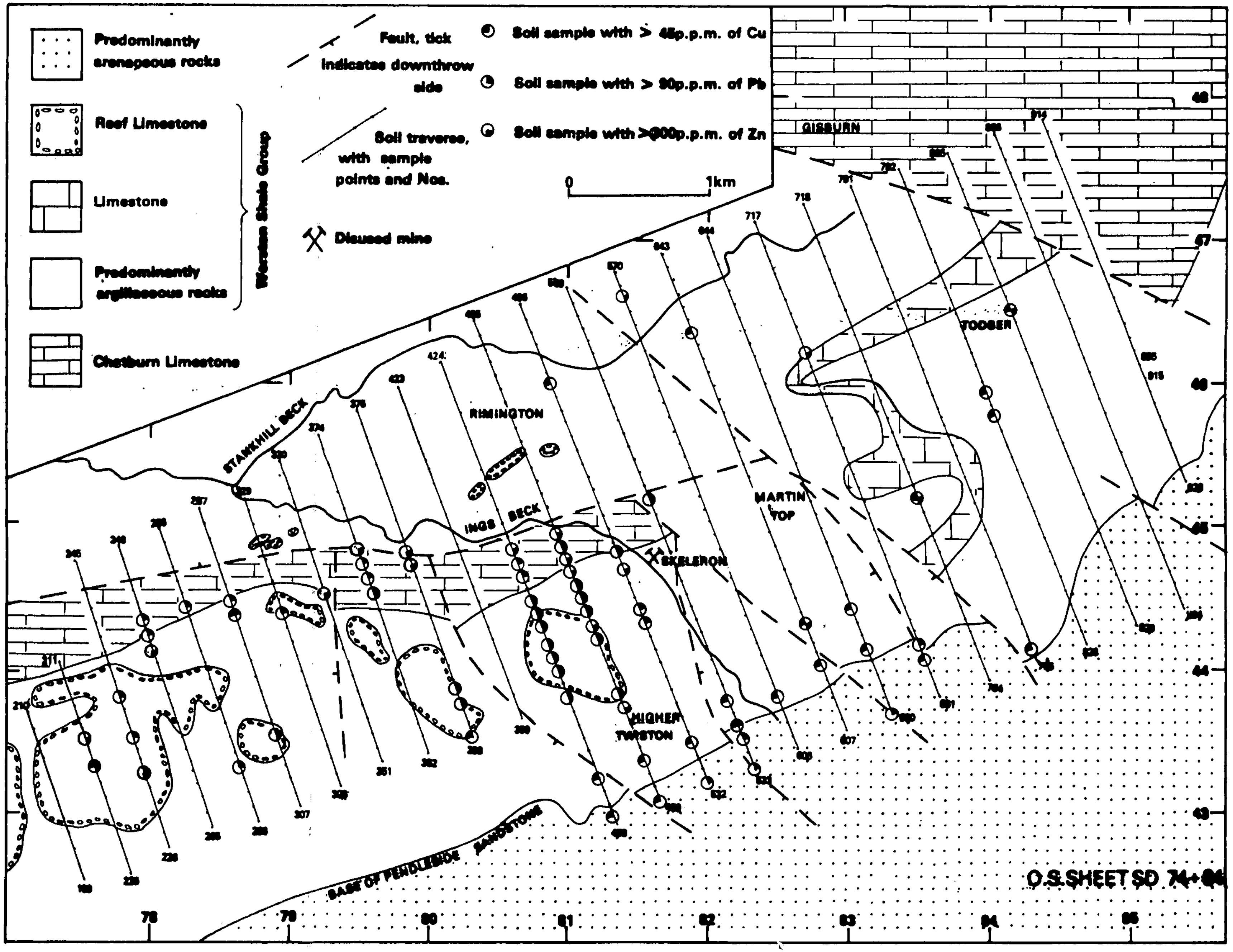


FIG. 40 GEOCHEMICAL SOIL SURVEYS AND SIMPLIFIED GEOLOGY AT RIMINGTON

which yielded a number of anomalous values for Cu, Pb and Zn (Figure 3). The values in both stream sediments and pan concentrates were generally high in this area, in the latter rising to more than three times the calculated threshold level. Downstream from Skeleron Mine the anomalous values are probably due to contamination from the old workings.

The geographical area outlined by these data is 7 km long and is primarily associated with the outcrops of the Chatburn Limestone and Worston Shales although the presence of mineralisation at higher stratigraphical levels is evidenced by high values obtained from the material collected in streams draining the north-east flanks of Pendle Hill immediately north of Barley [822 405] where both galena and barytes were identified as grains in these pan samples. The source of these mineral grains has not been identified.

As a follow-up, some reconnaissance soil sampling on a 350 × 100 m grid of an area of 20 km^2 (Figure 40) was carried out enclosing the zone indicated by the stream sediment and pan concentrate data. Samples were collected from an average depth of 80 cm. Anomalous values, at the $\bar{x}$ + 2s level were calculated (Cu 45 ppm, Pb 90 ppm and Zn 300 ppm) for each of these three elements, and are shown in Figure 40. Maximum values for these elements are 140, 380 and 1100 ppm respectively.

Figure 40 shows that the area lacks broad geochemical anomalies, many of the anomalous values being isolated. There is some correlation between the geology and the anomalous values, in that the high Pb and Zn values generally lie over limestone outcrops, particularly reefs. High copper values form a distinct zone which is closely associated with the base of the Pendleside Sandstone. There does not appear to be a very marked association between high metal values and the main faults. One of the soil traverse lines passed close to the old Skeleron Mine, and it is assumed that the few anomalous values in this area are indicative of that mineralisation.

The most significant area of high values is closely associated with the Twiston reef, north-west of Higher Twiston. Samples from the two traverses that cross this reef give values up to 230 ppm Pb and 800 ppm Zn; no anomalous Cu values are recorded from the knoll. The area about Martin Top where a linear, N-trending IP anomaly is recorded does not provide a matching geochemical anomaly, the values in this area for each of the elements being only at background levels. This may be due to the thick drift hereabouts.

Initial geophysical work in the Rimington area comprised a Turam survey over the Chatburn Limestone outcrop (Figure 41). The principal anomalies coincided with alluvium flanking Ings Beck and Twiston Beck. Such relatively conductive ground within an area of otherwise almost drift-free limestone would account for the anomalies, and no other significance is attached to them.

The subsequent IP/resistivity surveys in the Rimington area were intended not only to explore the Horrocksford Hall Thrust and Martin Top locality (traverses east of 1100W on Figure 41) but also to establish whether there were any geophysical indications of the Pb–Zn mineralisation on Twiston reef picked out by the geochemical work (traverses west of 1000W on Figure 41). The two surveys were linked by a small overlap, since the two sets of data were recorded 12 months apart, but they proved to be comparable.

It was intended initially, as in other areas, to use both the VLF/EM and IP methods, but the numerous overhead power lines gave rise to VLF anomalies of such large amplitudes and wave-lengths that it was considered impractical to attempt to obtain useable VLF data.

The major part of the IP survey was carried out using a broadside dipole-dipole array, since the lithologies in the area are very varied, the dips generally steep and the structure in the east of the area is unknown, and it was considered that the normal practice of using linear arrays across the strike of the feature of interest would provide data difficult to interpret. Use of the broadside dipole-dipole array has the advantage of providing uniform cover over the area relatively quickly, as well as providing a good signal-to-noise ratio at the receiver. 100 m dipoles were used and were moved along parallel traverses 100 m apart. The apparent resistivity and chargeability data are plotted in map form in Figures 42 and 43 respectively. In addition, three traverses were measured along strike (400S, 500S, 1050S) using the normal dipole-dipole array to provide data in pseudo-section form to assist in interpreting the resistivity and chargeability maps. Resistivity depth soundings were carried out for the same purpose using expanding Wenner arrays at locations E1, E2, E3, E4 (Figure 41).

The apparent resistivity data (Figure 42) clearly delimit the outcrop of the Chatburn Limestone and the Twiston Reef. Apparent resistivities for these lithologies are generally above 500 ohm-m. Corresponding chargeability values are generally below 5 milliseconds. To the east of Twiston knoll a strong chargeability anomaly appears to follow the limestone–shale contact. However, an iron water-main is known to run approximately along this line and the anomaly is, therefore, considered artificial. Further east a chargeability feature trends east-west with values up to 10 milliseconds and is probably caused by pyritic shales in the Worston Shales. A similar anomaly north of Twiston knoll is probably a westward extension of this horizon. The next feature of interest to the east is the small area of moderately high chargeability values (> 10 ms) on lines 1000W and 1100W. These values coincide with the principal veins of the Skeleron mine and relate either to unworked mineralisation or to clay in the veins.

East of line 1000W the apparent resistivity values fall gradually along an elongate feature to reach an approximate background value of 150 ohm-m at Martin Top. If this background value is representative of drift-covered Worston Shales then the resistivity contours seem to show that the top of the Chatburn Limestone along the axis of the Clitheroe Anticline dips eastwards beneath gradually thickening cover, and this view is supported by low chargeability values coincident with the resistivity feature. These features are terminated by a NNW-trending resistivity low, coincident with a chargeability high, which both probably represent a fault throwing down Worston Shales to the east. The significance of the chargeability anomaly is uncertain since it may be due in part to an old iron water-pipe running south from Martin Top.

The pseudo-section data from traverses 400S, 500S and 1050S confirm the locations of the anomalies described above, and support the structural interpretation made of the resistivity and chargeability maps. The interpretation was confirmed by deep power-auger holes at Martin Top which proved that between 500W and 450W the subcropping lithology changes from limestone to shale. The depth soundings E1–E4 indicate that limestone is present immediately beneath the drift at each of these four sites.

It is concluded that the mineralisation in the Rimington

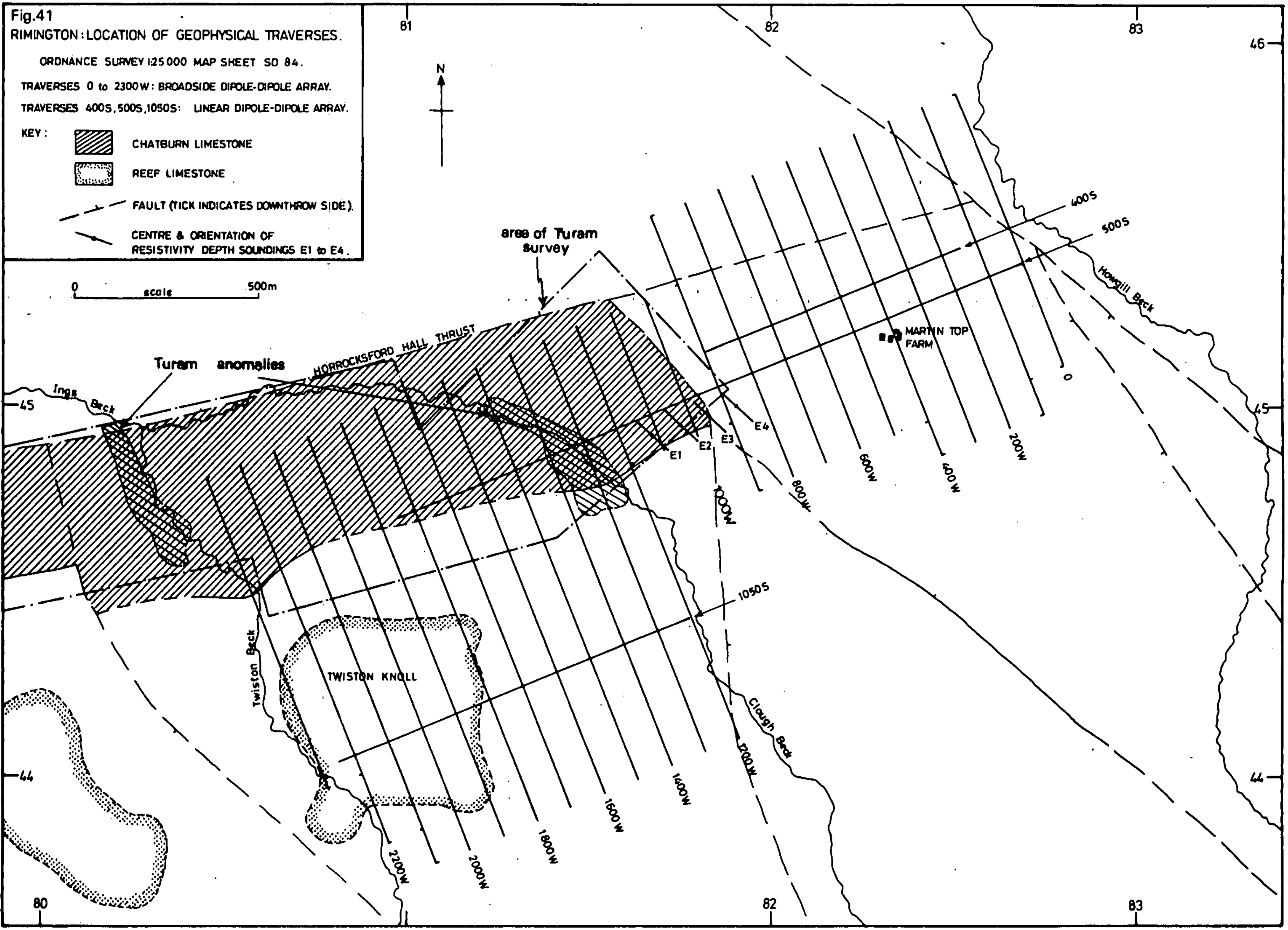
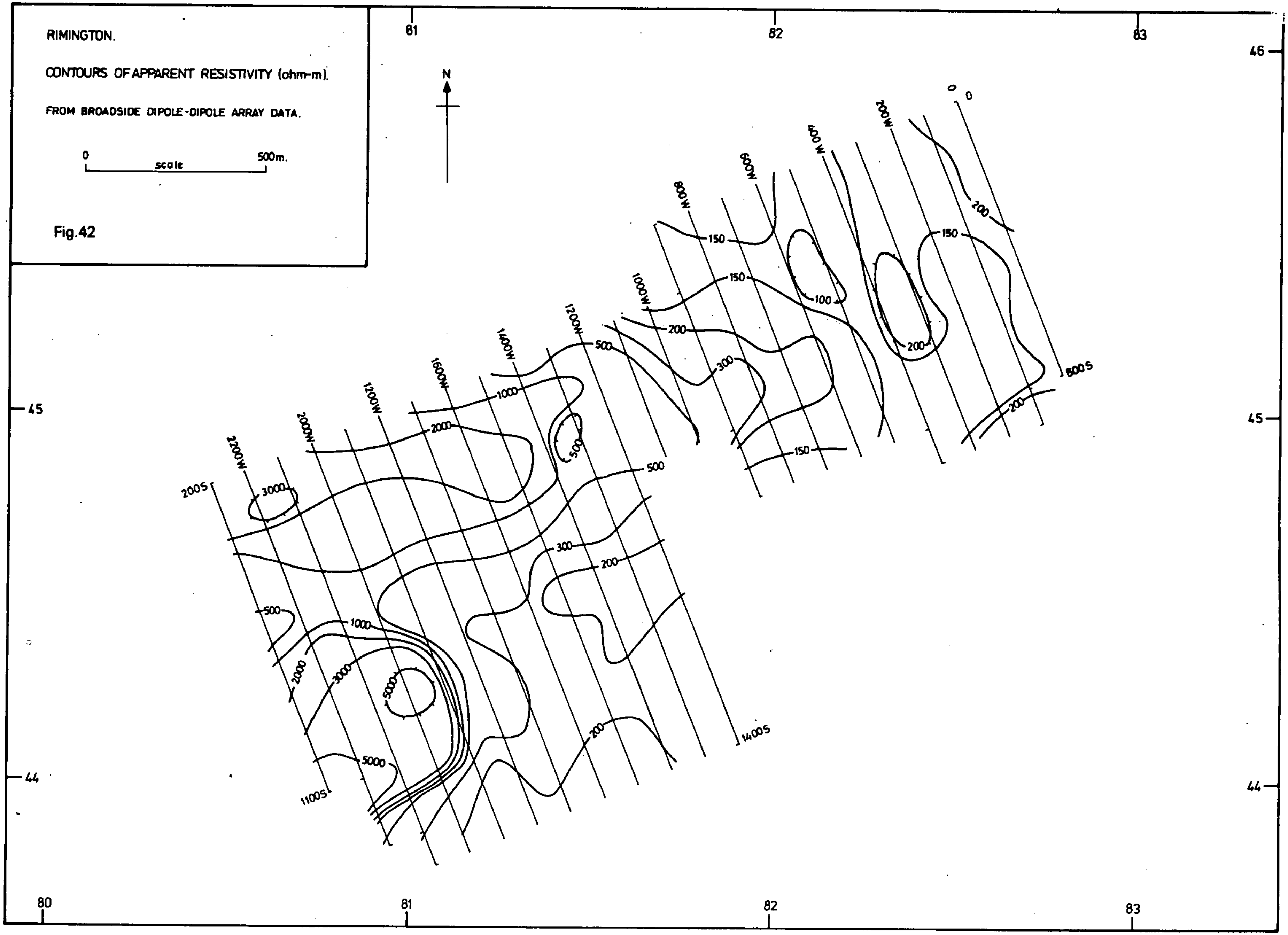


Fig.41
RIMINGTON: LOCATION OF GEOPHYSICAL TRAVERSES.



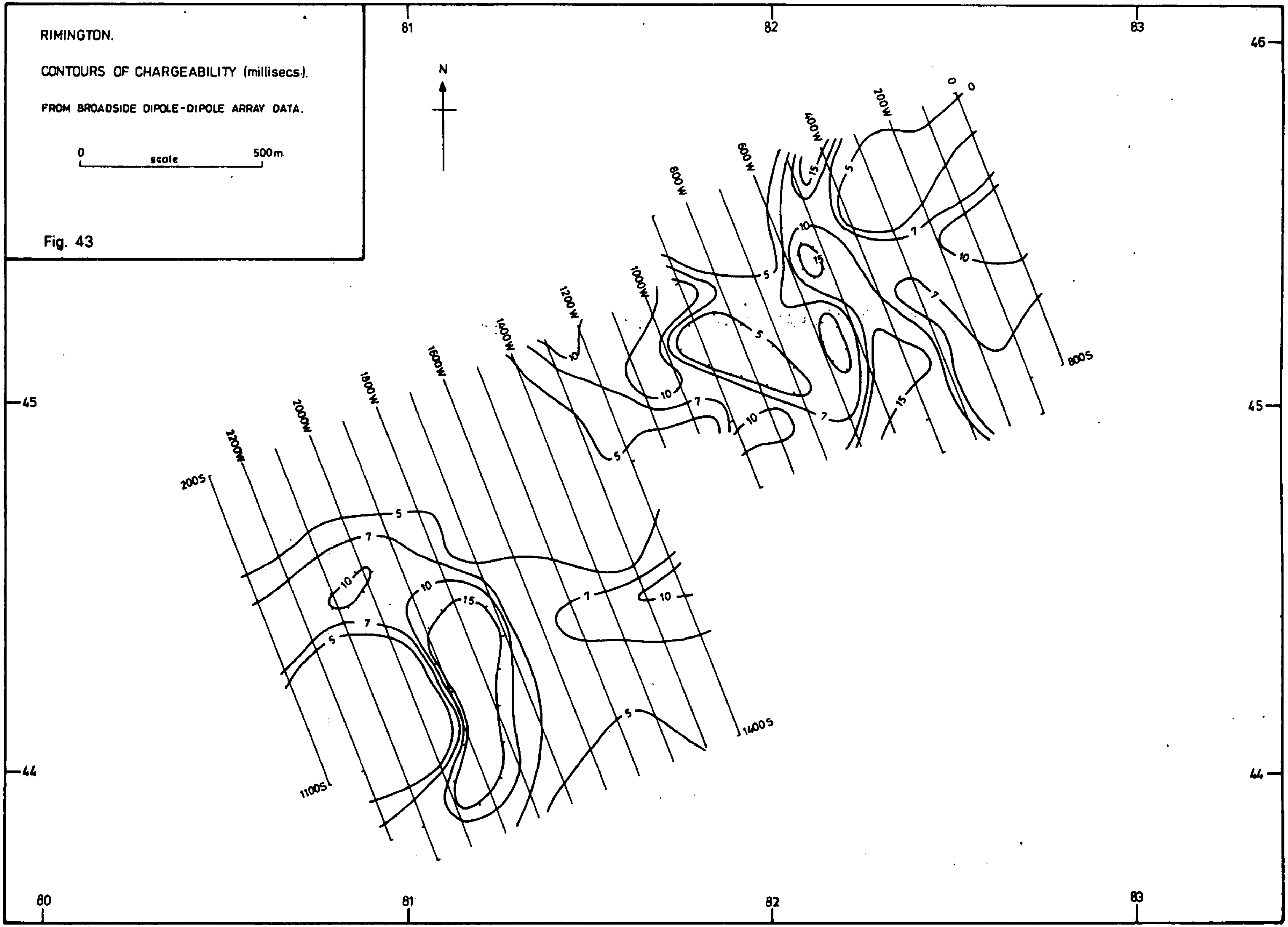
RIMINGTON.

CONTOURS OF APPARENT RESISTIVITY (ohm-m).

FROM BROADSIDE DIPOLE-DIPOLE ARRAY DATA.

0 scale 500m.

Fig.42



RIMINGTON.

CONTOURS OF CHARGEABILITY (millisecs).

FROM BROADSIDE DIPOLE-DIPOLE ARRAY DATA.

Fig. 43

area takes two forms. Firstly, the Skeleron veins appear to have been emplaced by the trapping of metal-rich brines within joints and small faults in the Chatburn Limestone beneath a cover of Worston Shales. Similar veins may lie undetected within the nose of the Clitheroe Anticline beneath Martin Top but there is no evidence of more widely disseminated mineralisation beneath this drift-covered area. Secondly, the mineralisation of the Twiston reef seems to be concentrated upon its upper surface just below the shale capping, and does not extend downwards to any significant extent. In neither case does there seem much prospect of mineralisation on an economic scale.

HOW HILL

This area lies about 9 km south-west of Settle on upland farming land at about 350 m OD. Access is by farm track only and the surrounding country is extensively afforested since the locality, owned by the North West Water Authority, lies within the catchment of Stocks reservoir.

The area was re-mapped for the present study (Figure 44) following detailed work on the stratigraphy and palaeontology by Parkinson (1935). The oldest rocks exposed are dark grey, fine-grained limestones with chert bands and lenses, and thin mudstone partings. These beds are Asbian in age and are correlatives of the Pendleside Limestone, resembling the lower part of this formation as seen to the south-west at Brennand and Sykes. About 30 m of these rocks were proved in an unbottomed sequence in the boreholes on How Hill (Figure 44). They grade upwards into a succession of reef limestones and breccias, proved in the boreholes to be at least 25 m thick and probably much thicker in full sequence. The reef limestones are pale grey and fine- to medium-grained, largely unbedded but with thin bands of bioclastic debris and patches of tufa. The breccias are crudely stratified and consist mainly of limestone clasts with rare pebbles of chert and sandstone set in an argillaceous or calcilutite matrix. The clasts are rounded to sub-angular generally, but incipient brecciation is also present in which the limestone is only partly fragmented and the fractures filled with micrite. The breccias appear to mark a break in sedimentation accompanied by considerable erosion, and the overlying Bowland Shales rest upon them with strong unconformity. The lower part of the Shales succession comprises dark grey calcareous mudstones, interbedded with black, flaggy, bioturbated limestones and thin bands of limestone debris locally derived from the eroded breccias beneath the unconformity. Higher in the Bowland Shales the mudstones are silty and pyritic, and sandstone bands become common towards the top, marking the transition into the Pendle Grit.

The principal structure of the area is a NE–trending anticline passing through How Hill. The fold is a simple one in the Namurian rocks with dips of 15° to 30° on its limbs, but in the Dinantian rocks, the structures are more intense and commonly have a different trend. There are three anticlinal areas, lying respectively to the west of Halsteads, on How Hill, and crossing Nursery Beck and Fair Hill. These are aligned about 10° east of north and are separated by faults of similar trend (Figure 44). The major folds have minor folding of similar orientation on their limbs, locally giving dips of 40° to 60°. It has been argued (Moseley, 1962) that the contrast in structures affecting the Dinantian and Namurian rocks at Sykes is due to differences in competence under stress, and a similar case could be made at How Hill. It seems more likely, however, that some of the structures in the older rocks, particularly those with a different trend, were imposed prior to the deposition of the Bowland Shales.

The drift of the area is a grey, lodgement till with local erratics. It is thickest in the valleys, and on the north side of Dob Dale Beck it reaches a maximum thickness of about 15 m. On the higher slopes much of it is partly soliflucted.

Interest in the mineral potential of the area was initiated by the recognition of widespread dolomitisation and silicification, extending for about 400 m along the eastern slopes of How Hill [746 595]. The alteration gives a vuggy rock, more open-textured than the unaltered reef limestone and, therefore, potentially a better host-rock to mineralising brines. Minor Zn sulphide mineralisation is associated with the alteration. It seemed possible that the dolomitisation might have taken place during the pre-Bowland Shales erosion. This possibility was encouraging since it would increase the chances that the rocks had been dolomitised long before the circulation of metalliferous brines. A small vein carrying galena and sphalerite had been worked on a small scale just west of Halsteads [741 593]; trials show that both the dark limestones and the reef limestones were mineralised and that calcite and silica were gangue minerals. In addition, minor patches of sphalerite and smithsonite were observed in brecciated limestones in Nursery Beck [7484 5962].

Stream sediment samples collected during the reconnaissance survey produced only a few anomalies marginally higher than the calculated threshold $\bar{x}$ + s values for Cu, Pb and Zn (Figure 3). Analyses of pan concentrates produced inconsistent data, the values correlating with the amount of precipitation and run-off. Although the surface data did not clearly delineate a target, they were adequate to warrant soil sampling. The distribution of the soil and auger hole samples is shown in Figure 45. Anomalous soil values for Zn are closely associated with the outcrop of the dark and reef limestones and the extent of the anomalies may be partly controlled by the drift. The values of Cu and Pb are also slightly above background. Three samples from immediately north of Halsteads are anomalous for Pb and Zn and probably relate to the old vein workings. Two high values close to Nursery Beck are due to the sphalerite and smithsonite mineralisation exposed there.

Auger-hole samples taken from close to the bedrock–overburden interface were collected on a small grid on How Hill where the highest soil values had been obtained (Figure 45). The data from these holes confirmed that the high values persisted at depth and were indeed commonly enhanced at depth by factors of up to 10 times. Figure 45 shows the close spatial relationship between the anomalous soil values for the three elements (Cu > 30, Pb > 55, Zn > 90 ppm), and also the position of the anomalous values obtained from the augering programme. The main anomalies to the south-east of How Hill terminate along the fault.

Investigation of limestone outcrops on How Hill with a portable XRF analyser showed a positive response for Zn, with some of the highest count rates being obtained adjacent to joint and fracture surfaces. The joints have a preferred direction of around 300°, approximately normal to the anticlinal axis.

To test for the possible presence of conductive sulphides in the limestones on How Hill, both at outcrop and beneath shale cover, and to provide structural information, IP and VLF-EM surveys were carried out. The IP survey was laid out along parallel traverses across the anticline (Figure 46). Lines deviated in the south to avoid Halsteads and in the north to permit the use of a firebreak

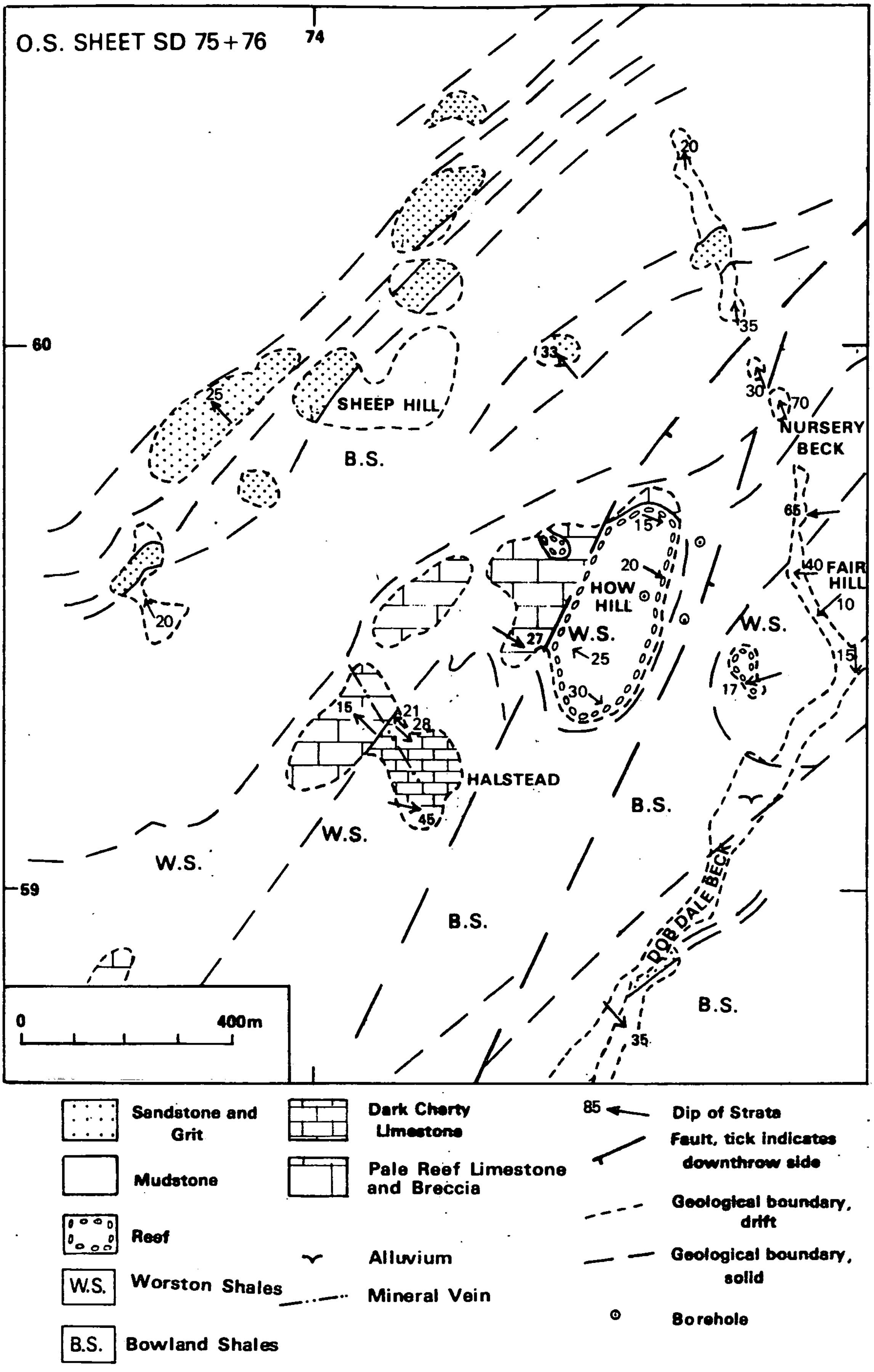


Fig.44 Geology of the How Hill area

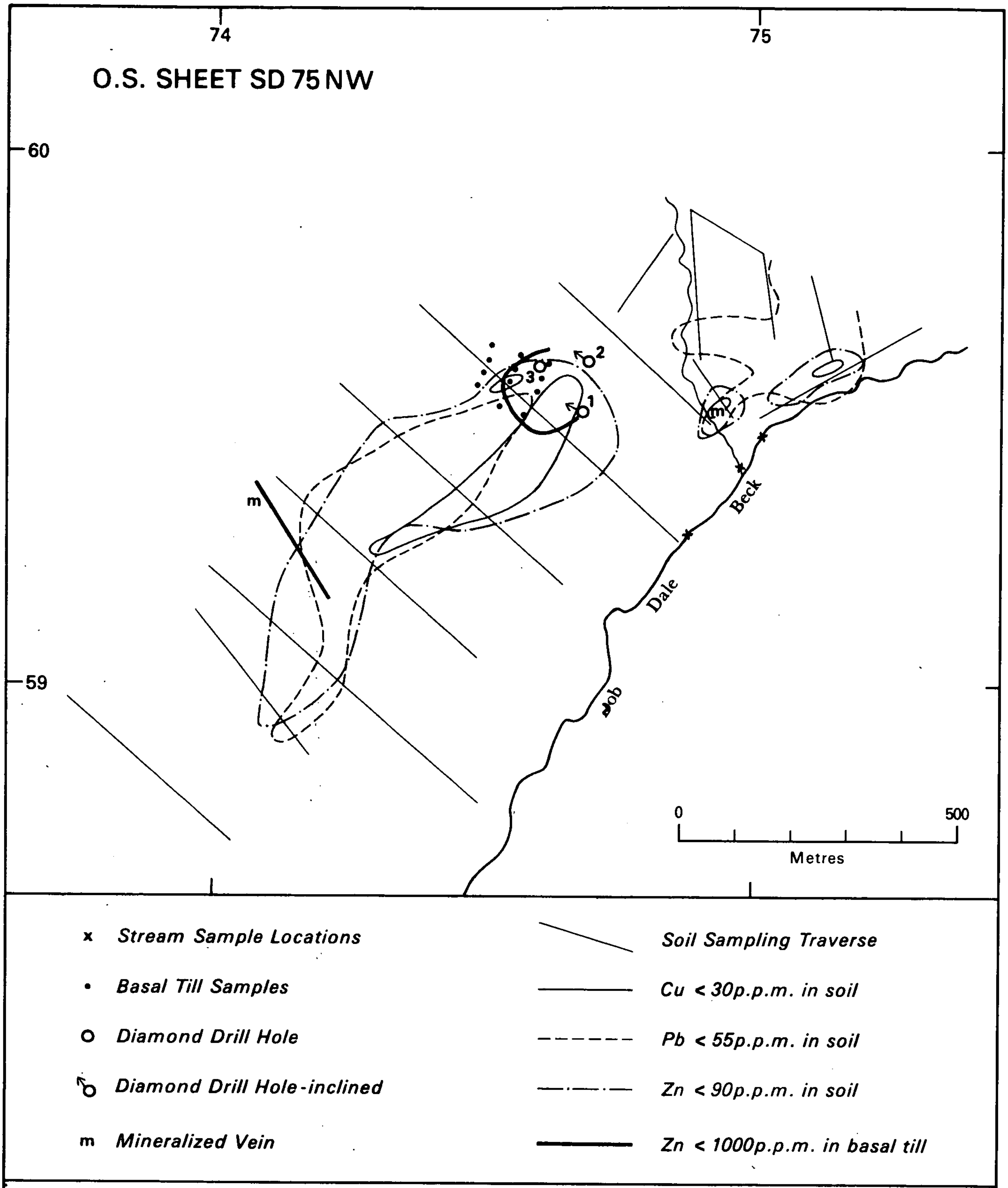


Fig. 45 GEOCHEMICAL ANOMALIES AT HOW HILL

in the forest. VLF-EM measurements were made along the IP traverses 400N to 1000N to provide information on faulting. The instrument was tuned to the transmitting station FUO (Bordeaux, France. 15.1 kHz). The IP measurements were made using the standard dipole-dipole array. 50 m dipoles were used and measurements were generally made at the n = 2, 3, 4 and 5 dipole spacings. Extraneous noise prevented acquisition of satisfactory chargeability data on occasions and was probably caused by electric fences in use locally and by the intermittent operation of electrical machinery in the farm buildings.

The contoured resistivity values for the n = 2 and n = 4 dipole spacings are shown in Figures 46 and 47 respectively. The values at n = 2 closely reflect the surface geology, and the structure around the exposed reef limestone is evident from comparison with the values at n = 4.

Along the north-west side of the area the limestone–shale contact at surface is well defined. However, it is clear that the top surface of the dark cherty limestone dips at a moderate angle to the north-west, the reef limestone dipping away a little more steeply than this limestone just north of Halsteads Farm. The rapidly thickening shale cover above the limestone prevents any measurement of chargeability values in the underlying limestone; the limestone being almost undetectable when both the transmitting and receiving dipoles are on the shale. On the south-east flank of the anticlinal area of How Hill, limestone is present at a fairly shallow depth, and this reappears further to the east where it is exposed in Nursery Beck. The filtered VLF data (Figure 48) indicate the presence of a number of north-south trending conductors to the east of the reef which are interpreted as faults, and it is therefore considered that immediately east of the reef there is a 'wedge' of limestone beneath a few tens of metres of shale cover. This limestone has been downfaulted relative both to the reef of How Hill and to the limestones of Nursery Beck. To the north, the VLF data suggest that the fault bounding the reef on its east side turns abruptly from a northerly to a north-easterly trend. The resistivity data indicate that the limestone–shale contact follows a similar trend, the limestone outcrop being gradually pinched out between the fault and shale. However, the structure cannot be investigated further in this direction because of the forestry plantation.

On the south-west side of the reef a zone of low resistivity values marks a deep depression, probably filled with boulder clay. A strong VLF anomaly picks out the fault to the west of How Hill. To the south of the reef both the till and the shale cover above the limestone thicken rapidly so that the limestone is undetectable on traverse 150N.

The chargeability values show no consistent pattern between traverses and it is not possible to contour the data satisfactorily. Isolated negative values were recorded and these are likely to be due to the local noise. Very few values above 15 ms were recorded and these are also isolated. Only on traverses 400N and 600N are significant groups of moderate (10–15 ms) values recorded. These coincide with the northern limit of the dark limestones north of Halsteads and with the breccias west of How Hill. Both groups of anomalies occur upslope of the high geochemical values (Figure 45). The reef limestones exposed downslope to the east do not show any anomalous chargeability values.

To explore the downward extent of the Zn anomalies on How Hill, and test the relationship of mineralisation to the reef limestones and to the bounding faults, three cored boreholes (Figures 45, 49) were drilled by a JKS 300 rig, which penetrated a total of 357 m of rock. Boreholes 1 and 2 were inclined at 60° to the west and borehole 3 was vertical. The lithological correlation between the boreholes is good. There is a wide range of dips in the cores, as was anticipated close to the axial zone of the anticline. Some of the inclinations may be depositional dips, particularly in the breccias, since such high-energy deposits commonly accumulate on steep palaeo-slopes. Using the base of the breccias in boreholes 2 and 3 as a datum gives an apparent easterly dip between the holes of more than 60°. There may be intervening faulting — indeed there is intense calcite veining at about 90 m in borehole 2 — but it is difficult to be certain of faulting in the core. Alternatively, the faults mapped to the east of How Hill and delimited by the VLF data may lie just to the east of the boreholes.

The cores obtained from the three holes (averaging in excess of 90% recovery) were examined for Zn content with a portable XRF instrument. Data obtained by this method from sliced cores provide only a general indication of the presence of mineralisation. None of the results from these three holes show values in excess of 0.1% Zn. However, this is very close to the lower limit of detection of the instrument. Visible mineralisation in the cores is very sparse, holes 1 and 2 having scattered specks of pyrite and smithsonite in all the main lithologies. In hole 3, very weak mineralisation again occurs in all the principal lithologies in the form of tiny specks and stringers of pyrite. Precise chemical analyses of core for Cu, Pb and Zn also gave low results (Figure 49), values for zinc exceeding 100 ppm in only a few samples. In holes 1 and 2 the higher Zn values were obtained at 33–43 m (hole 1, maximum 690 ppm) and 27–40 m (hole 2, peak value 1000 ppm) in limestones near the sub-Bowland-Shale unconformity. Other isolated anomalous Zn values also occurred over sections 72–89 m (hole 1) and 101–105 m (hole 2), both generally associated with breccias. Values from the vertical hole no. 3 gave very low results with only small sections (representing no more than 1 metre of core) in excess of 100 ppm. Brecciated and banded limestones from the higher levels of this hole showed values of up to 210 ppm. The dark grey, bedded limestones encountered below about 40 m in this hole gave consistently low values.

A total-count gamma log was obtained for holes 2 and 3, but the logs indicated no variation of radioactivity which could not be attributed to normal compositional changes of the sediments. In hole 3 generally higher readings were obtained above 50 m, which coincided with the reef limestones and breccias.

The dolomitisation and silicification cropping out on the east side of How Hill is present in all three cores, within the reef limestones and breccias. It is rare within the underlying dark limestones. The distribution of the alteration is patchy and appears to be guided by major joints and fractures. The silification seems to have followed the dolomitisation, both processes being secondary. As some of the basal limestones in the Bowland Shales are seen in the cores also to be affected, the alteration cannot date from pre-Namurian times. No significant mineralisation is associated with the alteration at How Hill, despite the geochemical and geophysical anomalies here.

The drilling programme was limited in extent to the highest geochemical anomalies and the analysis of the cores showed little Zn enrichment whilst Pb and Cu rarely exceeded background levels. There was no strong correlation between lithology and sulphide occurrence in the cores, but on the ground the main soil and auger anomalies seem to have been produced at the apex of the anticline where the reef limestones were capped by Bowland Shales. The small amount of sulphide enrichment present was concentrated along joints, fractures and bedding planes. Although the main faults of the area are not marked by geochemical anomalies, since most are drift-covered, they still may have been channels for brine circulation.

In conclusion, the mechanism of trapping brines seems to have worked only to a limited extent at How Hill, where there are suitable host and cap rocks. Tectonic

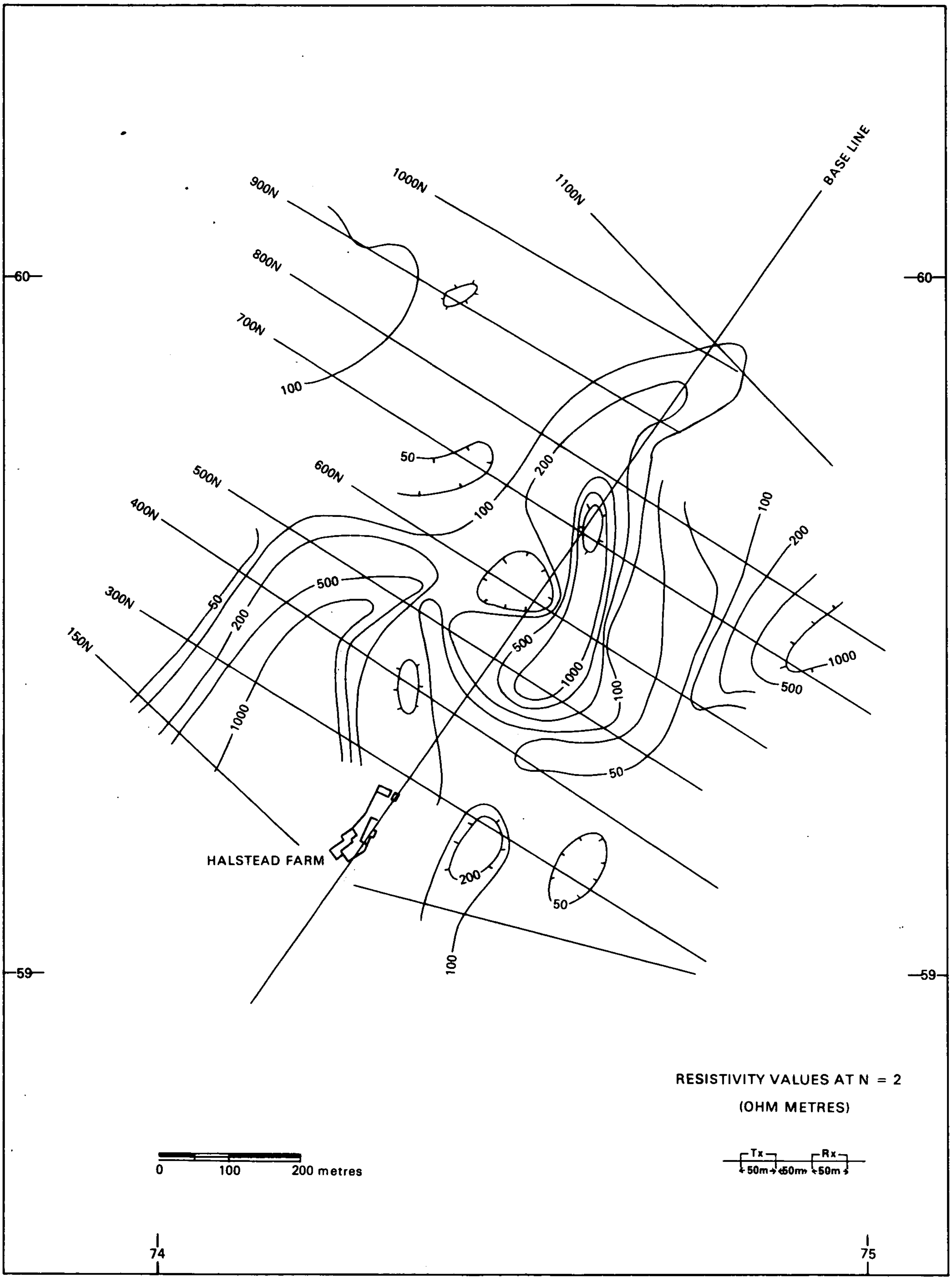


Fig.46 RESULTS OF GEOPHYSICAL SURVEYS AT HOW HILL

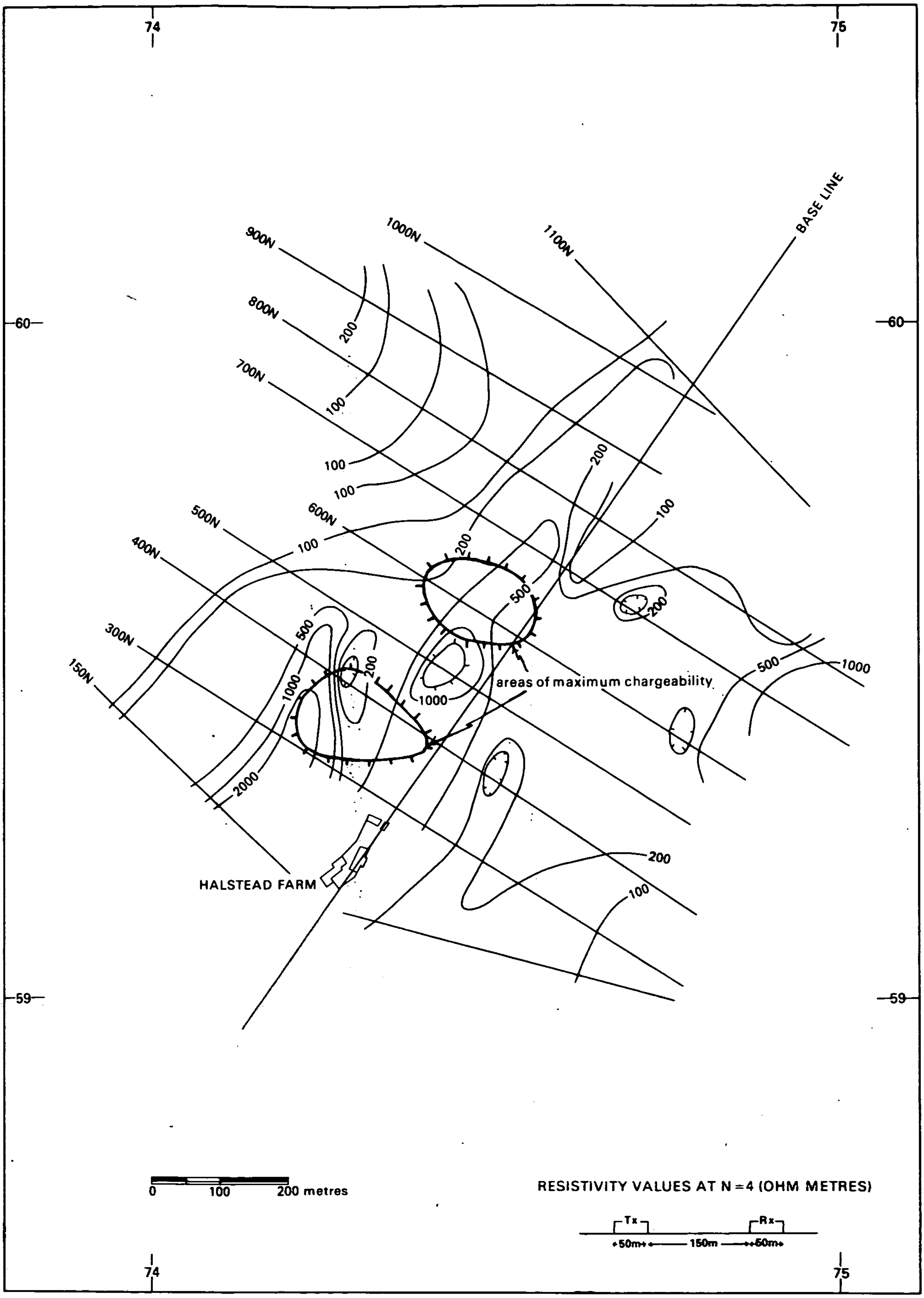


Fig. 47 RESULTS OF GEOPHYSICAL SURVEYS AT HOW HILL

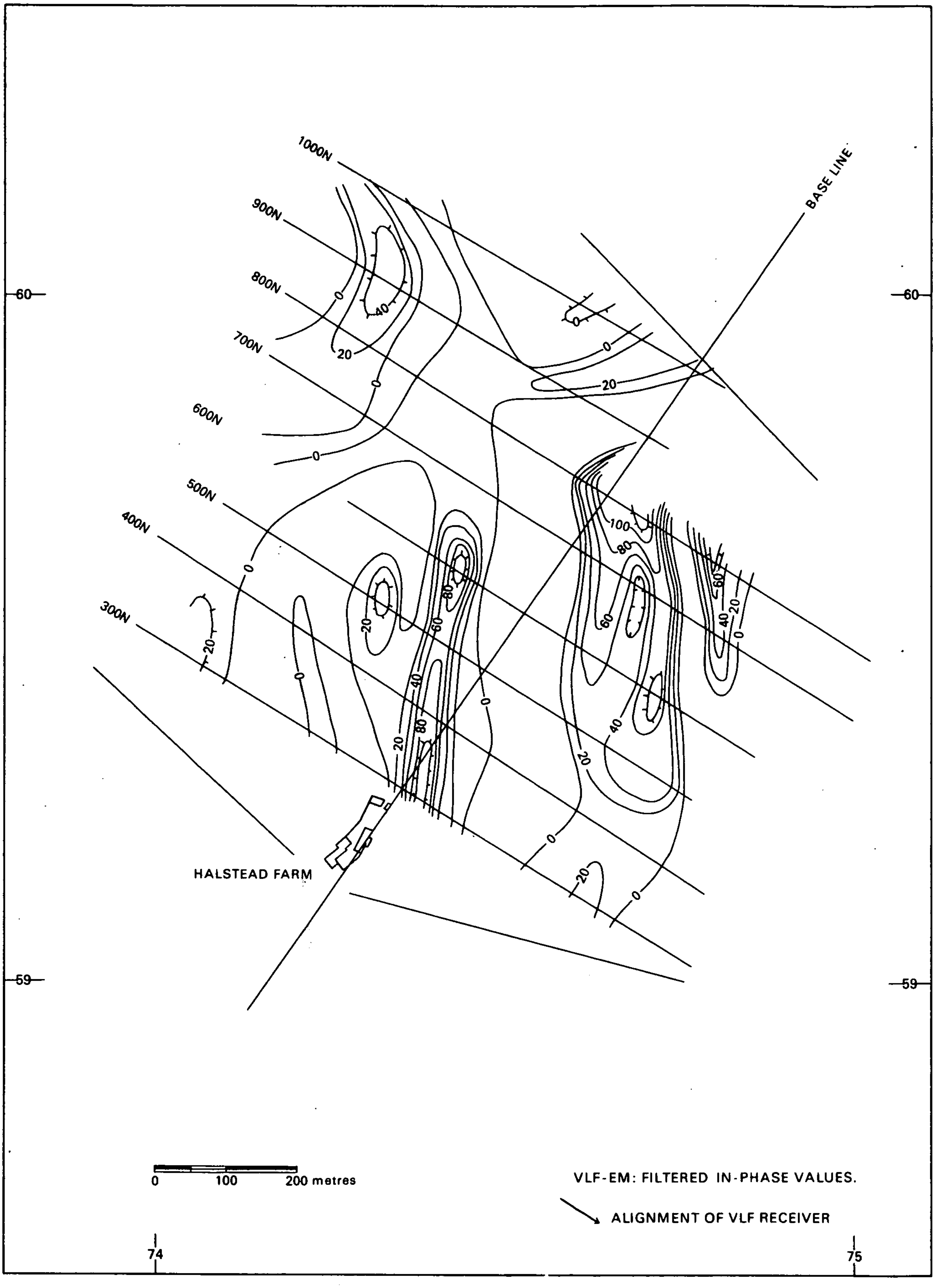


Fig.48 RESULTS OF GEOPHYSICAL SURVEYS AT HOW HILL

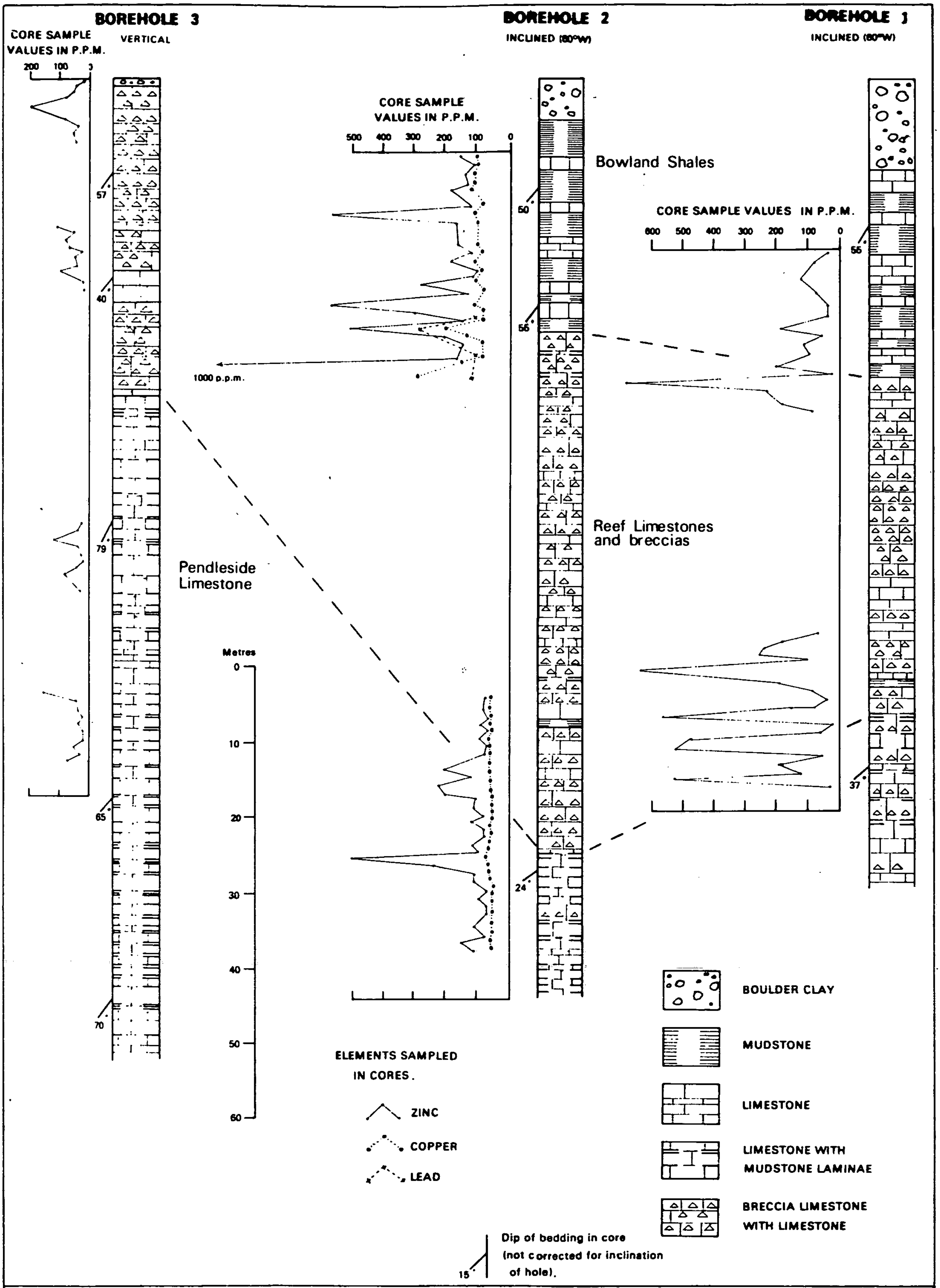


FIG. 49 LOGS OF BOREHOLES AT HOW HILL, WITH DETAILS OF THE GEOCHEMICAL SAMPLING FOR COPPER, LEAD AND ZINC

deformation may have allowed excessive leakage of metalliferous brines away from the area, or only insignificant amounts of metals were in the original brines.

COPTER SYKE

This area lies to the north of Stocks Reservoir, 3.5 km north-north-east of Slaidburn, at an altitude of between 190 and 300 m on land used for rough grazing. Attention was drawn to the locality by anomalous Zn values found during the geochemical stream sediment survey (Figure 3).

The geology shown in Figure 50 is taken from Parkinson (1936). The Worston Shales comprise calcareous mudstones with thin flaggy and often cherty limestones. The Pendleside Limestone is locally missing, but where present has a variable lithology of limestone breccias, cherts, cementstones and minor shales. Widespread erosion followed the deposition of the Limestone and produced the carbonate clastics. The overlying lower Bowland Shales are composed of black shales and limestones with minor cementstones and sandstones and a few conglomerate limestone beds. The Upper Bowland Shales are calcareous with minor sandy horizons and are overlain by the Pendle Grit, which varies between fine sandstone and conglomerate, with minor shaly horizons. The area is crossed by major SW–NE folding and also by minor flexures in the pre-Namurian rocks which can be locally intense, as at Brennand.

Follow-up of the anomalous Zn values in both stream sediment and pan concentrates discovered vein mineralisation with sphalerite in Bowland Shales close to a NW–trending fault in Copter Syke (Figure 50). Here the red-brown sphalerite occurs in narrow veins accompanying quartz, calcite and limonite. Pyrite mineralisation has been noted further north in White Syke where veins are associated with the same fault, here striking at 310°. Along the fault intermittent mineralisation is indicated by anomalous Zn values obtained in stream samples but no evidence of mineralisation was found where the fault crosses Flat Clough Beck and Copped Hill Clough. In both Copter Syke and White Syke mineralisation appears to be restricted to the shales, there being no indication of mineralisation or alteration of the Pendleside Limestone in these sections.

Soil samples collected from an area extending north-west and south-east from Copter Syke showed only low values for Cu, Pb and Zn, all the values for Cu and Pb and most of the Zn determinations falling in the local background range. Two high Zn values (190 and 280 ppm) occur south-east of the stream along the line of the fault. It seems clear that the mineralisation is intermittent and minor along the NW–trending fault.

AGDEN

The Agden area is situated 6.5 km south-west of Hellifield in mixed farming country at about 180 m OD. The drift cover is extensive and consists of a till-sheet 5 to 10 m thick which is only penetrated by the deepest valleys. The solid rocks exposed in Agden Beck are dark grey, calcareous mudstones with flaggy limestone bands of the Worston Shales sequence. They dip at 15–25° to the north-west. A NW–trending fault marked by calcite veining crosses the stream [7980 5365] and a 10-cm calcite

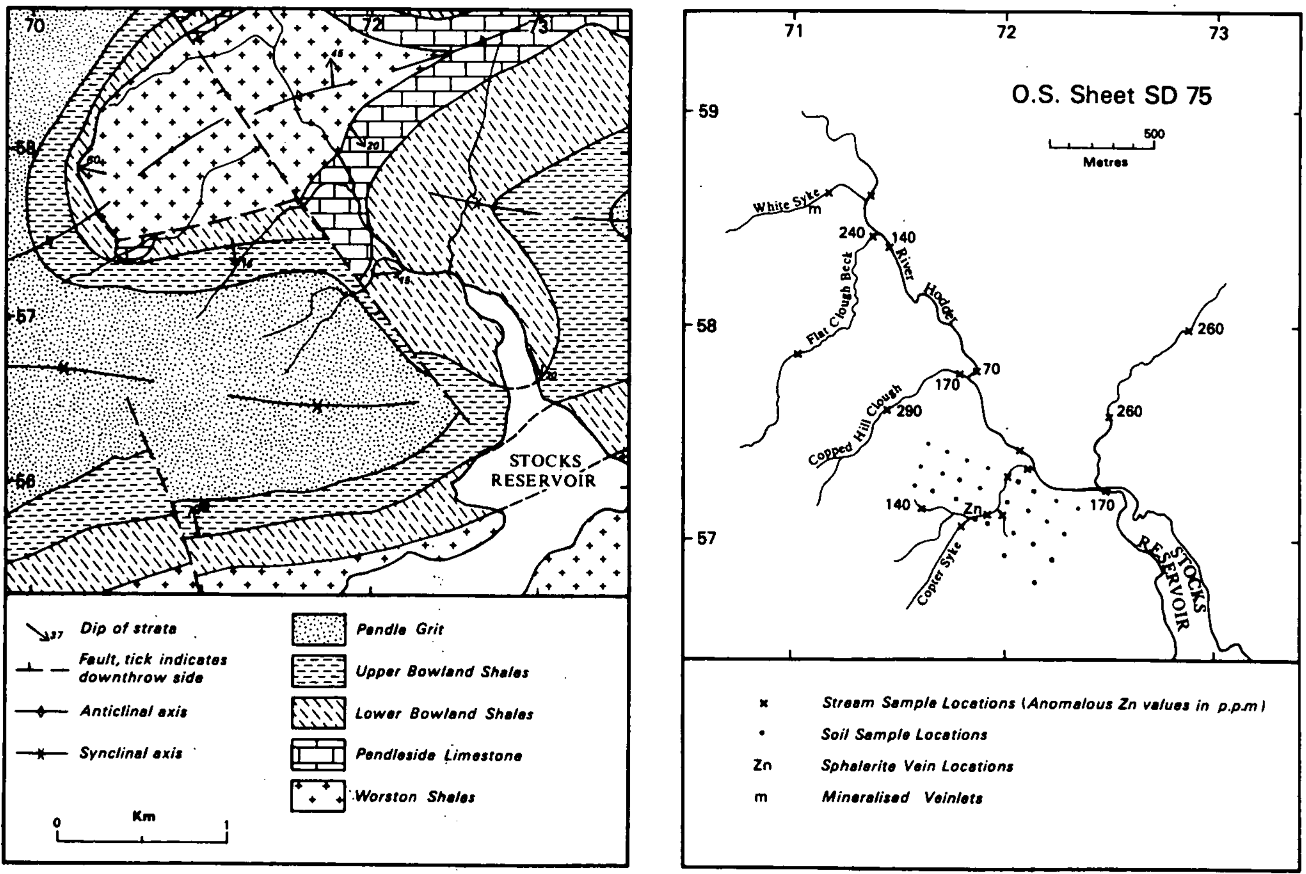


Fig.50 Geological Sketch Map and Geochemical Sampling adjacent to Copter Syke

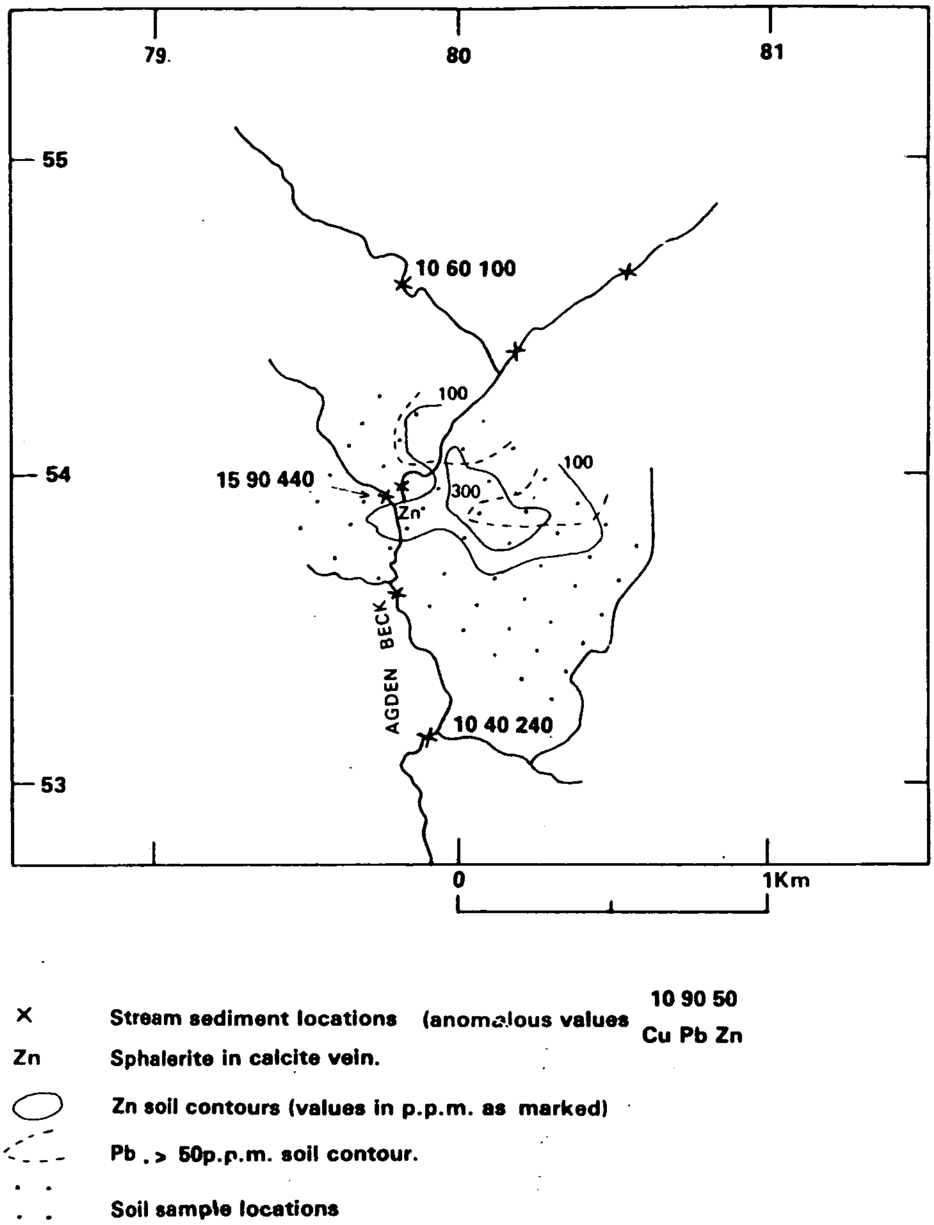


FIG. 51 GEOCHEMICAL SURVEYS AT AGDEN

vein containing red-brown sphalerite is also seen a short distance downstream [7984 5353].

Analysis of stream sediment samples from Agden Beck showed anomalously high Zn values in two samples (Figure 51), and Pb and Zn values in three pan concentrate samples from the same stream system also gave anomalously high values in excess of 1% Zn, accompanied by values in excess of 200 ppm for Ba.

Soil samples were collected on a 100 × 150 m grid covering an area of about 0.75 km^2, which includes the site of the visible mineralisation, and the soils were analysed for Cu, Pb and Zn. Values for Cu are low (5–25 ppm) and fall within the general background range for soils of the Craven Basin area. Similarly, values for Pb are low with only a single sample in excess of 100 ppm. Zinc values (40–760 ppm) show a wider range than the other two elements, with eleven samples in excess of 200 ppm. Contoured plots (Figure 51) of both the Pb and Zn values show a high degree of coincidence. The evidence from the geology and the geochemistry indicates that the anomaly identified from the soil data (although not quite closed to the north-east) is probably a reflection of minor localised mineralisation similar to that observed in the exposures in Agden Beck. The values obtained and the present limited extent of the anomaly do not appear to indicate mineralisation of economic proportions.

BRENNAND

This area lies astride the Brennand and Whitendale rivers 4 km north of Dunsop Bridge and about 15 km north-west of Clitheroe. The ground is largely rough moorland used for grazing sheep. It lies between 300 m and 400 m OD and is entirely within the catchment area of the North-West Water Authority water intake on the River Dunsop [653 532]. The area is isolated but there is vehicle access from Dunsop Bridge to the Brennand and Whitendale farms, and from Brennand a steep, rough track allows cross-country vehicles to reach the high ground.

The major structure of the district is the Sykes anticline which trends north-eastwards and exposes inliers of Dinantian rocks along its axis at Whitendale, Brennand,

and farther to the south-west at Sykes. The fold persists in this direction for at least 12 km into the headwaters of the River Brock above Garstang. A modern account of the rocks in the inliers has been given by Moseley (1962). A summary of the stratigraphy established by mapping is compared below with the local sequence encountered in the Brennand mines and recorded on old mine-plans in the Institute's archives:

Data from records of the Brennand mines	*Thickness*		*Surface mapping*
	m	m	
Pendle Grit		up to 244	Medium to coarse sandstones, with siltstones and sandy shales
Bowland Shales			
Whetstone Shale	30	90 to 190	Dark grey calcareous and pyritic mudstones with argillaceous limestones up to 0.3 m thick. A thin Pendleside Sandstone is present in the lower part of the succession in the south
Great Ironstone Shale	50		
Trough House Rock	9		
Trough House Black Shale	6		
Trough House Rag	6		
Black Shale (cementstone at base)	43		
Little Ironstone Shale			
	144		
Worston Shales			
Red Bed Limestone	25	15	Limestone breccias interbedded with massive limestones.
Red Bed Shales	8	c.40	Interbedded fine-grained limestones and shales, the limestones about 0.60 m thick.
Lower Post Limestone	24		
Lower Post Shale and thin limestones	22		Pseudobreccia bands are present in Whitendale.
Bull Start Flint	6	c.90	Limestones, pale grey, fine-grained with patchy colouration and interbedded with cherts forming bands, lenses and nodules 5–15 cm thick and rarely up to 2.0 m thick. A massive 7.5 m chert is probably equivalent to the Bull Start Flint.
6 Fathom Shale	11		

The carbonates in the Worston Shales sequence are equivalent in age to the Pendleside Limestone and upper Worston Shales of the Clitheroe district. The chert in these lower limestones is probably penecontemporaneous in origin. It certainly post-dates lithification of the sediments, since in places the silica transgresses the bedding. There is a particularly thick (7.5 m) chert bed at Sykes (Moseley, 1962, p. 290) and a similar thickness is present in the Brennand mines, but this seems to be a localised development as the cherts in Whitendale are much thinner. Chert fragments are found amongst the limestone breccias at the top of the Worston Shales succession and as these clastics seem to represent a tectonic break prior to the deposition of the Bowland Shales, the cherts must have been emplaced before this erosional interval. It seems likely, therefore, that silica gel was exhaled on to the sea-floor shortly before the break and was disseminated as lenses and bands of chert at shallow depths amongst the newly-lithified carbonate muds.

The Namurian rocks are folded into a simple anticline with limbs dipping at 30–40°, but in the older rocks the structures are locally so intense as to produce very steep or overturned beds. In addition, the trends of the minor folds in the older rocks are generally oblique to the major flexure. It has been suggested that this is due to disharmonic folding (Moseley, 1962) of the competent grits and limestones, with slippage occurring within the Bowland Shales and Worston Shales. Alternatively, it seems possible that some of the structures in the limestones result from the tectonic movements pre-dating the deposition of the Bowland Shales.

The first record of lead mining at Brennand dates from the 16th century and the mines were also active between 1601 and 1621, when the galena was said to yield about 3% silver. Mining was sporadic until the last period of serious endeavour between 1866 and 1874 when shafts were sunk on the Lead Vein and Knowles Vein (Figure 52) and a level was driven from the River Brennand north-eastwards to the Lead Vein, commanding a working height of about 65 m on this fracture. The vein was the largest source of Pb ore and was worked on five levels, producing the following quantities:

1866	200 tons of Pb
1867	630 tons of Pb
1868	555 tons of Pb
1869	225 tons of Pb
1871	62 tons of Pb

In addition to galena, small amounts of sphalerite, chalcopyrite, malachite, fluorite and baryte were also produced. Minor Pb, Zn and Cu mineralisation can still be seen in situ on the north-east side of the valley opposite Brennand House.

It seems reasonable to assume that the proven mineralisation along the axis of the Sykes anticline is due to the trapping of metal-rich brines within the limestones beneath a capping of Bowland Shales, and part of the mineral potential lies in further deposits in the axial area, perhaps beneath thin shale cover. But the presence of penecontemporaneous silica introduces a new possibility not commonly encountered elsewhere in Craven. If silica was being introduced during sedimentation, might not the metals also have been exhaled in places on to the sea-floor and concentrated within the wet sediments? Certainly the minor Pb, Cu, Zn and F occurrences at Sykes [627 518] lie immediately below and within the thickest cherts, and at Brennand mine the Bull Start Flint was a particularly favourable horizon, but at neither locality was it clear whether the metals shared a common genesis with the silica or whether the cherts had been a particularly effective trap to later brines.

The prospects seemed sufficiently encouraging to justify testing the Brennand area for sulphide mineralisation using detailed geophysical surveys.

A reconnaissance VLF survey was carried out over the area to locate any strongly conductive features such as veins or faults and as an aid to the interpretation of the subsequent IP survey. Since the known veins do not show any preferred trend, measurements were made along two sets of perpendicular traverses (Figure 53) so as to minimise the possibility of missing a conductive feature. The instrument was tuned to the same VLF station (NAA, Maine, USA, 17.8 kHz) for both sets of traverses so that if necessary the data from both could be filtered and plotted on a single map. This method should permit detection of most of the conductors in the area except those aligned along, or close to, the wave-front from the

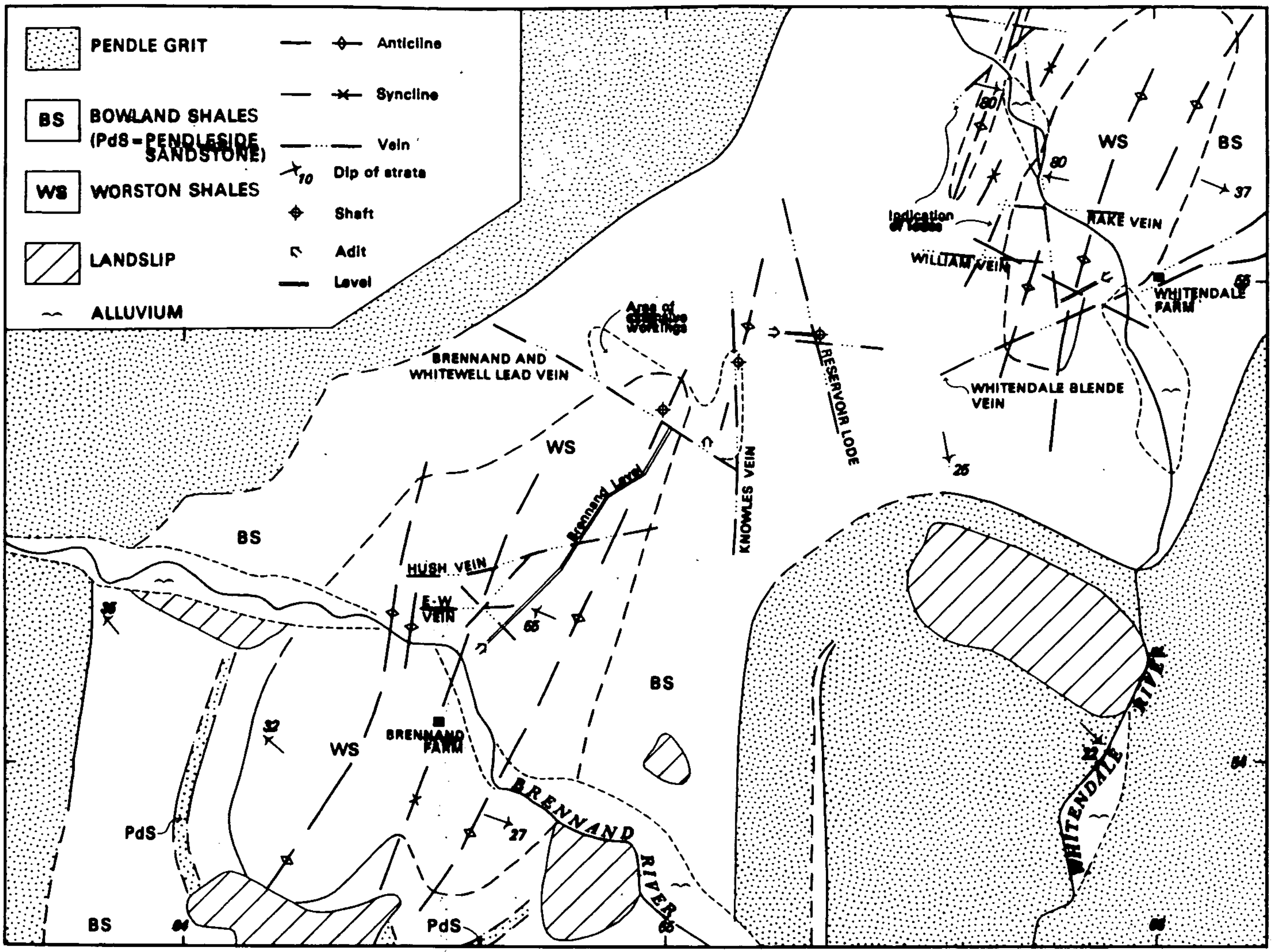


Fig. 52 GEOLOGY AND FORMER MINING ACTIVITIES IN THE BRENNAND AREA

station — in this case approximately north-south.

The VLF profiles are shown in Figure 54. There are no anomalies that might suggest the presence of strong, steeply-dipping conductors. The steady increase seen in the in-phase values from south to north on traverses 600E and 900E is almost certainly a topographical effect caused by the descent and ascent of steep slopes, and the broad 'W' shaped anomaly in the in-phase values seen south of 75S on these traverses is considered to be caused by the anticline where the conductive shales above the limestone dip gently in opposite directions. The difference in width of these two anomalies reflects the broadening of the limestone outcrop towards the west. Apart from this there are no well-defined features correlating between adjacent traverses. The filtered data, therefore, have little significance and are not included here.

Two sets of IP traverses were measured, covering parts of the Brennand and Whitendale inliers respectively, and aimed at locating mineralisation within the limestone. It was necessary in the Brennand valley to align the traverses along rather than normal to the strike (Figure 53), since the depth to the limestone increases rapidly away from the anticlinal axis. This problem was aggravated by the steep slopes flanking the limestone outcrop. Measurements were taken along four parallel traverses to cover the outcrop. The dipole-dipole array was used, with 50 m dipoles. On each traverse the transmitter was positioned to the east of the receiver. Measurements were taken at the n = 2, n = 3 and n = 4 dipole separations. As a check on the repeatability of the M values recorded by the receiver, two sets of readings were taken at each station and the values averaged. Repeatability was generally good at n = 2 and n = 3, but at n = 4 variations of 1–2 milliseconds between the computed chargeability values were common. Variations in the computed apparent resistivity values were generally less than 0.5%. For compiling these data into map form the resistivity and chargeability values values at n = 2 and n = 3 were averaged, this process partially smoothing the data and facilitating contouring. Thus, if R1, R2, R3 were apparent resistivity values at n = 2, plotted on a pseudo-section at positions 25N, 75N, 125N; and R4, R5 were values at n = 3, plotted at 50N and 100N, then at 50N on the map, (R1 + R2 + 2R4) ÷ 4 was plotted, and (R4 + R5 + 2R2) ÷ 4 was plotted at 75N on the map and so on.

A well-defined pattern is seen in both sets of values. The limestone outcrop appears as an oval-shaped area with resistivities generally betwen 200 and 500 ohm-metres. This feature is surrounded by the lower resistivities of the overlying shales. The cut-off is sharp near the south-west ends of traverses 200S and 300S and appears to correlate with NW–SE faulting encountered in the drainage level. The area of high resistivities coincides with an area where the chargeability values rarely exceed 5 milliseconds. This chargeability low is flanked by higher values up to, and occasionally over, 10 milliseconds, which are clearly related to the base of the Bowland Shales. Only the chargeability high at approximately 400E on traverse 300S is difficult to account for. It is cut

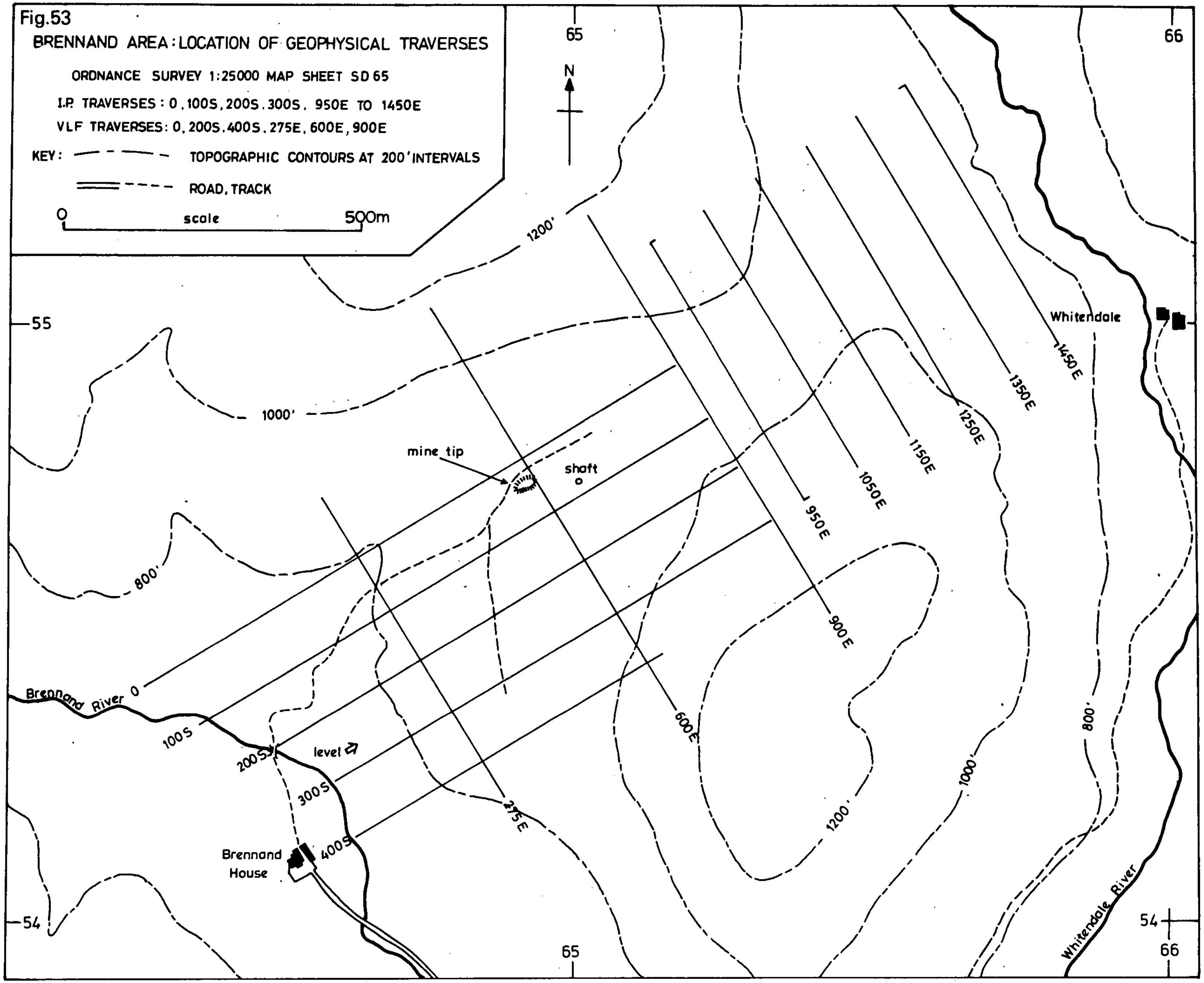


Fig.53
BRENNAND AREA: LOCATION OF GEOPHYSICAL TRAVERSES

ORDNANCE SURVEY 1:25000 MAP SHEET SD 65

I.P. TRAVERSES: 0, 100S, 200S, 300S, 950E TO 1450E

VLF TRAVERSES: 0, 200S, 400S, 275E, 600E, 900E

KEY: TOPOGRAPHIC CONTOURS AT 200' INTERVALS

ROAD, TRACK

0 scale 500m

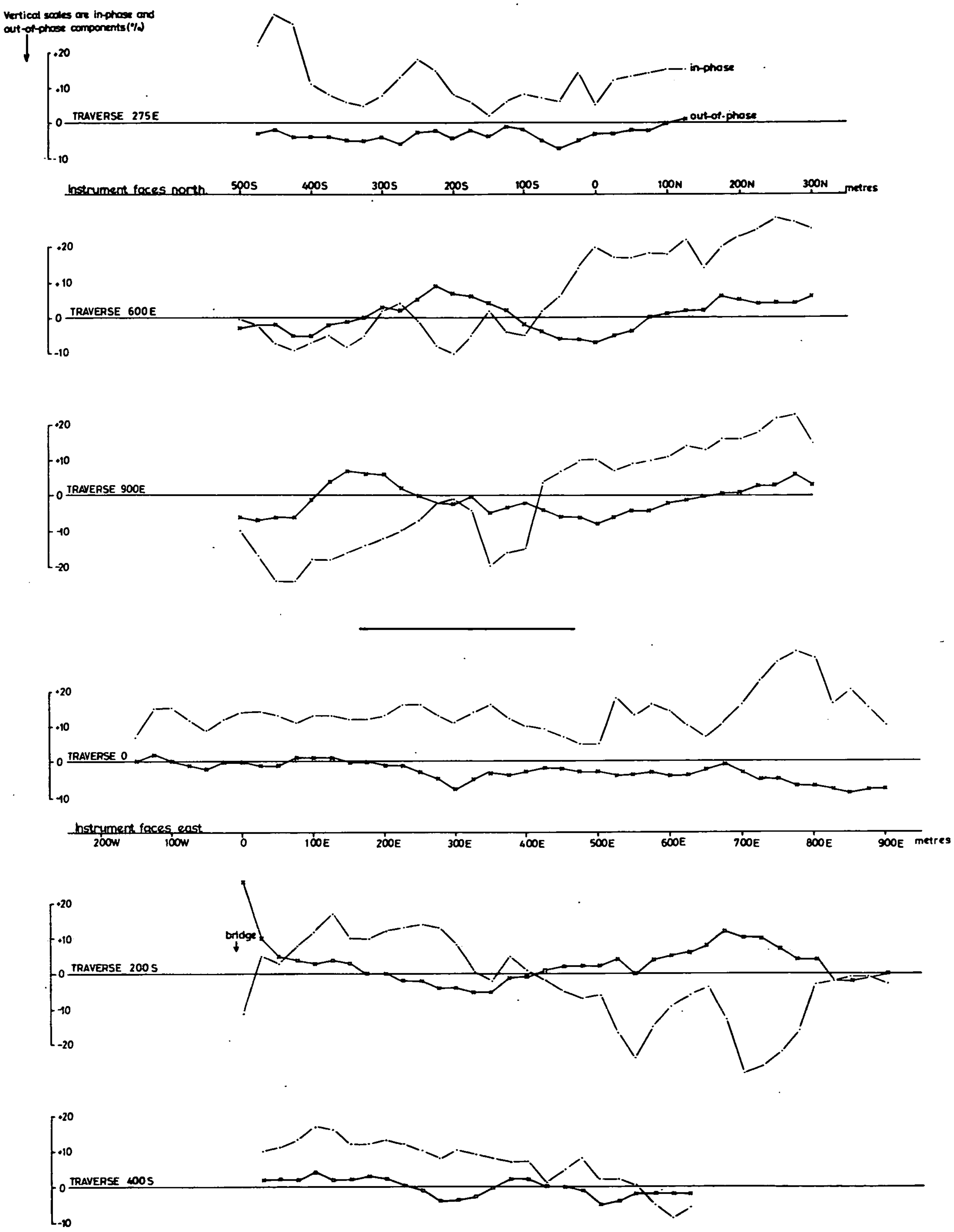


Fig.54 VLF profiles at Brennand

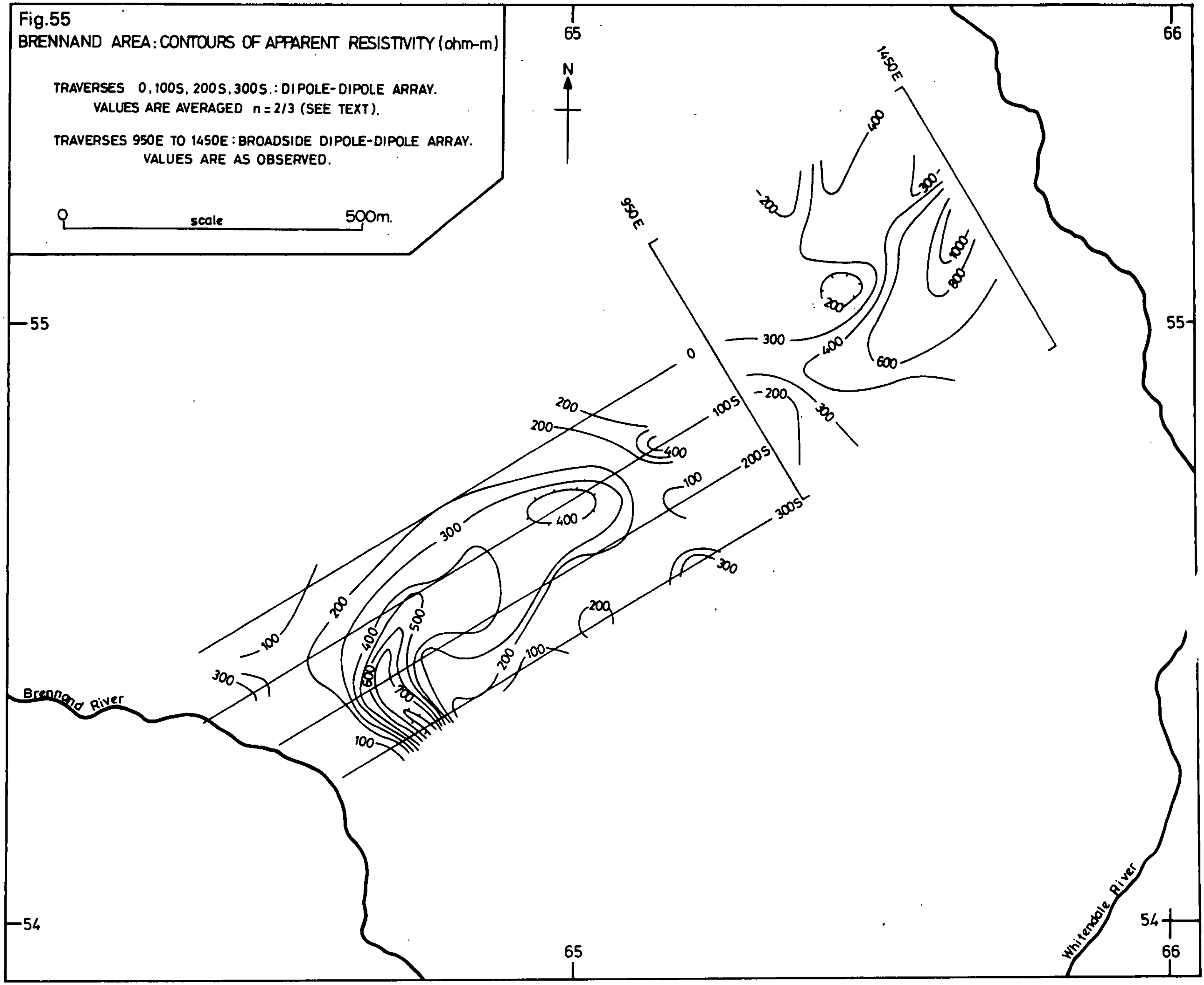


Fig.55
BRENNAND AREA: CONTOURS OF APPARENT RESISTIVITY (ohm-m)

TRAVERSES 0, 100S, 200S, 300S.: DIPOLE-DIPOLE ARRAY.
VALUES ARE AVERAGED n = 2/3 (SEE TEXT).

TRAVERSES 950E TO 1450E: BROADSIDE DIPOLE-DIPOLE ARRAY.
VALUES ARE AS OBSERVED.

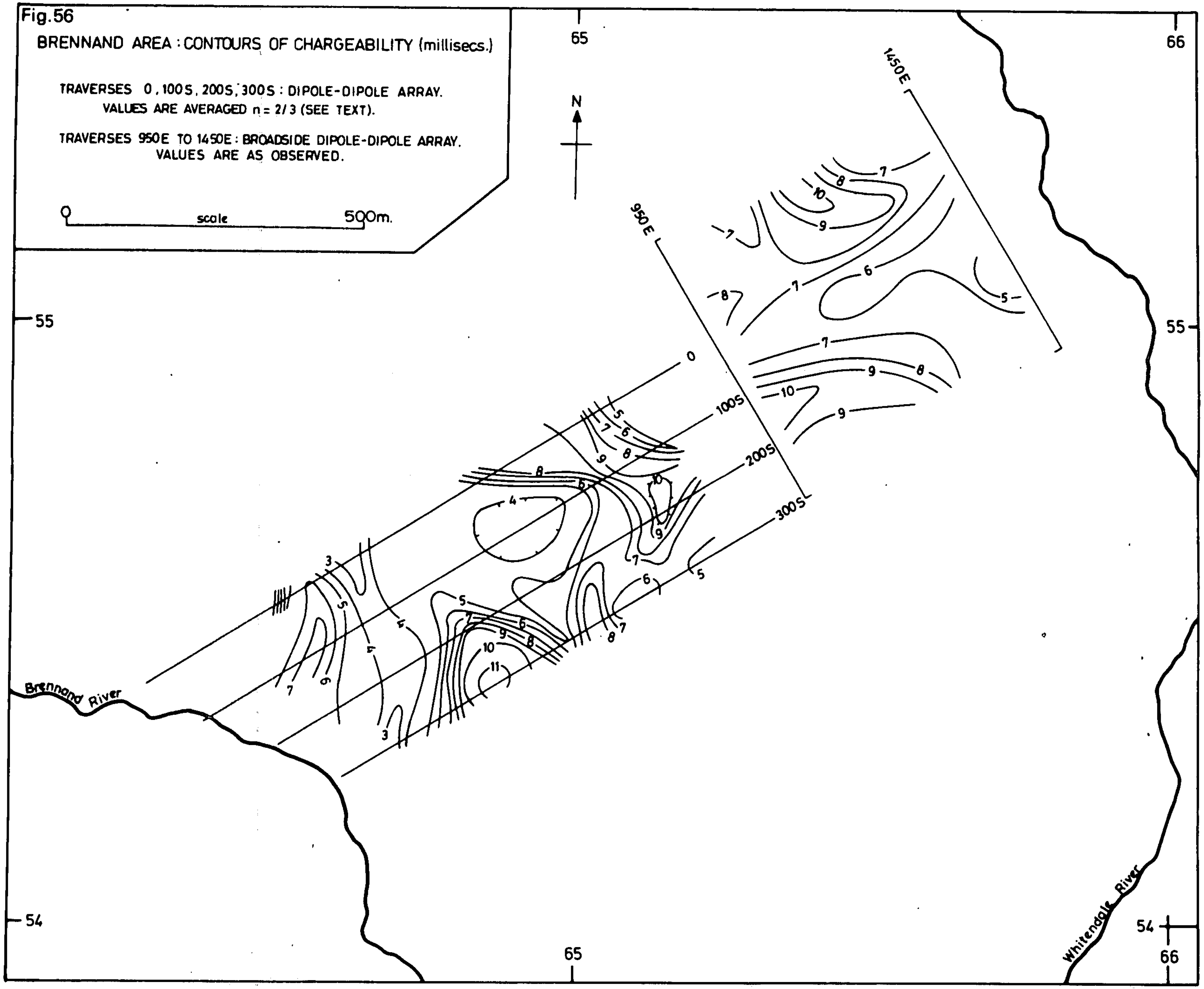


Fig.56

BRENNAND AREA : CONTOURS OF CHARGEABILITY (millisecs.)

TRAVERSES 0, 100S, 200S, 300S : DIPOLE-DIPOLE ARRAY.
VALUES ARE AVERAGED n = 2/3 (SEE TEXT).

TRAVERSES 950E TO 1450E : BROADSIDE DIPOLE-DIPOLE ARRAY.
VALUES ARE AS OBSERVED.

off on both sides by much lower values, and extends close to, and possibly into the limestone to the north. This feature is probably related to the structure which produces the very high resistivity values immediately to the east.

In the Whitendale valley, a broadside dipole-dipole array was used for the IP survey, so as to provide uniform coverage in the limited time available. Transmitter and receiver dipoles, each of 100 m, were moved along parallel traverses 100 m apart (traverses 950E to 1450E). The repeatability of the results when using this array is very good. Experience suggests that the depth penetration compares with that obtained using co-linear 50 m dipoles at the n = 3 separation. The contoured apparent resistivity and chargeability values are shown in Figures 55 and 56. No strong chargeability anomalies were recorded, and the limestone outcrop was marked by high resistivities and low chargeability values. The less resistive shales again give rise to the higher chargeabilities.

Neither the VLF nor the IP survey has provided any indication that there are significant quantities of sulphide mineralisation in the Brennand area. No favourable VLF anomalies were recorded, and the modest chargeability anomalies are related to the shales. A possible explanation of shale anomalies is that these are related to the interface between the shales and the limestone, either caused by the interface itself or by weak mineralisation at or adjacent to it; if the latter, then the mineralisation clearly does not extend very far down into the limestone. Only the moderate chargeability anomaly at 400E on traverse 300S may merit further attention, so as to determine the relationship of this anomaly to the shale–limestone boundary and to local faulting.

ASHNOTT

The Ashnott area lies 8 km north-west of Clitheroe, the ground lying at an altitude of 120–300 m. The lower ground is pasture and the higher moorland is grazed by sheep. An extensive till-sheet, generally 2–10 m thick, covers much of the ground so that solid rocks are exposed mainly on the hill-tops, and in the deep valleys where the streams have penetrated the drift.

The rocks range in age from Worston Shales to Pendle Grit (Figure 57). The oldest beds are reef limestones at the base of the Worston Shale sequence, exposed in the core of a NE-trending anticline. The reef consists of about 100 m of pale to medium grey, bio-calcarenite set in a fine porcellaneous calcilutite matrix. Although extensively fractured and jointed, the rock is generally well-lithified and tight in texture. Bedding is crude where present; most of the observed dips are to the west on the well-exposed western side of the reef but overall, the dips are probably quaquaversal and centred on the reef-apex. The overlying Worston Shales consist mainly of calcareous mudstones and siltstones, interbedded with cementstones and occasional bands of muddy limestone. The succession is well-exposed in stream sections in Ashnott Wood [694 485] and Crag Wood [690 479], and there is no doubt that the sequence is much thinner than in the classic Clitheroe sections or on the flanks of the Slaidburn anticline a few km to the north. It has been suggested that the hard rocks of the reef have behaved diapirically and have risen within the softer Worston Shales (Earp and others, 1961, p. 50) but it seems more likely that the original succession around the reef on the crest of the anticline was much thinner than the sequences in the surrounding parts of the basin. Furthermore, comparison with other Craven reefs suggests that many of the coarser beds in the Worston Shales consist of debris contemporaneously eroded from the upper part of the reef which is, therefore, marked by a strong local unconformity. This view is supported by the fact that whilst the porcellaneous cementstones of the *Bollandoceras hodderense* beds are present, none of the succeeding rocks of the Worston Shales, including the Pendleside Limestone, occurs hereabouts.

Immediately above the unconformity, the Bowland Shale Group is present as a thin condensed sequence about 40 m thick (Earp and others, 1961, Plate VII), and consists mainly of pyritic mudstones. The medium to coarse-grained sandstones of the Pendle Grit come on conformably above. These rocks are usually brown in colour but in places they are stained deep purple-red; for example near Crag House [686 476] and in Birkett Brook [683 485]. This colour results from strong oxidation close to the Permian land-surface and indicates that, though a Carboniferous succession several thousand metres thick was deposited hereabouts, erosion had proceeded sufficiently by early Permian times to expose the rocks close to the present land surface.

The rocks are folded into a NE–trending anticline with a wavelength of about 1.5 km, but in addition there are many smaller folds, particularly within the argillaceous part of the sequence. These folds are commoner and more intense close to the larger faults which generally trend north-westwards (Figure 57).

Mining for lead on Ashnott reef during the early 19th century was much more extensive than is now obvious from surface indications. There are the traces of five shallow shafts [6935 4815, 6928 4810, 6924 4808, 6933 4808 and 6931 4799] and at least one adit [6925 4811] into the reef. In addition, a drainage level has been driven from stream level in Ashnott Wood [6922 4838] for about 400 m south-south-west to the lowest workings beneath the reef. Exploration has shown (Cannell and Cannell, 1966) that the main workings lie on four levels extending to a maximum depth of 55 m below ground level. The upper parts of the mine were apparently worked from the shafts but the lowest two levels were more conventionally stoped and the debris discharged through the adit. In general the veins in the upper part of the reef were thin, presumably like the stringer of galena still visible near the adit mouth [6926 4811]. The extent of stoping lower down shows that the veins thickened downwards before ending abruptly near the base of the reef. Comparison with other Craven reefs suggests that this may have been due to the on-set of bedded limestones with thin shale partings in the lower part of the reef. There is some local geochemical contamination from the mines and also from an old washing and sorting floor on the northern slope of the reef. The farmer at Ashnott farm has lost hens ranging over this ground through Pb poisoning in the past.

Following the discovery of numerous stream sediment and pan concentrate anomalies in Crag Beck and Birkett Brook, a soil survey was carried out in 1975. Soil samples were taken at 70 m intervals along lines spaced 200 m apart. Values for Cu are generally within the background range 5–40 ppm, but 24 samples (11% of the total population) exceed this value, the maximum value recorded being 90 ppm. The distribution of these values is markedly linear, extending in a north-west direction for some 2.2 km. (See Figure 57). Lead values fall mainly in the background range 0–110 pppm but 27 samples (13% of total population) are in excess of this, the highest value recorded being 3000 ppm. The anomalous Pb values occur as a number of elongated areas following the same north-west trend as that of the Cu values.

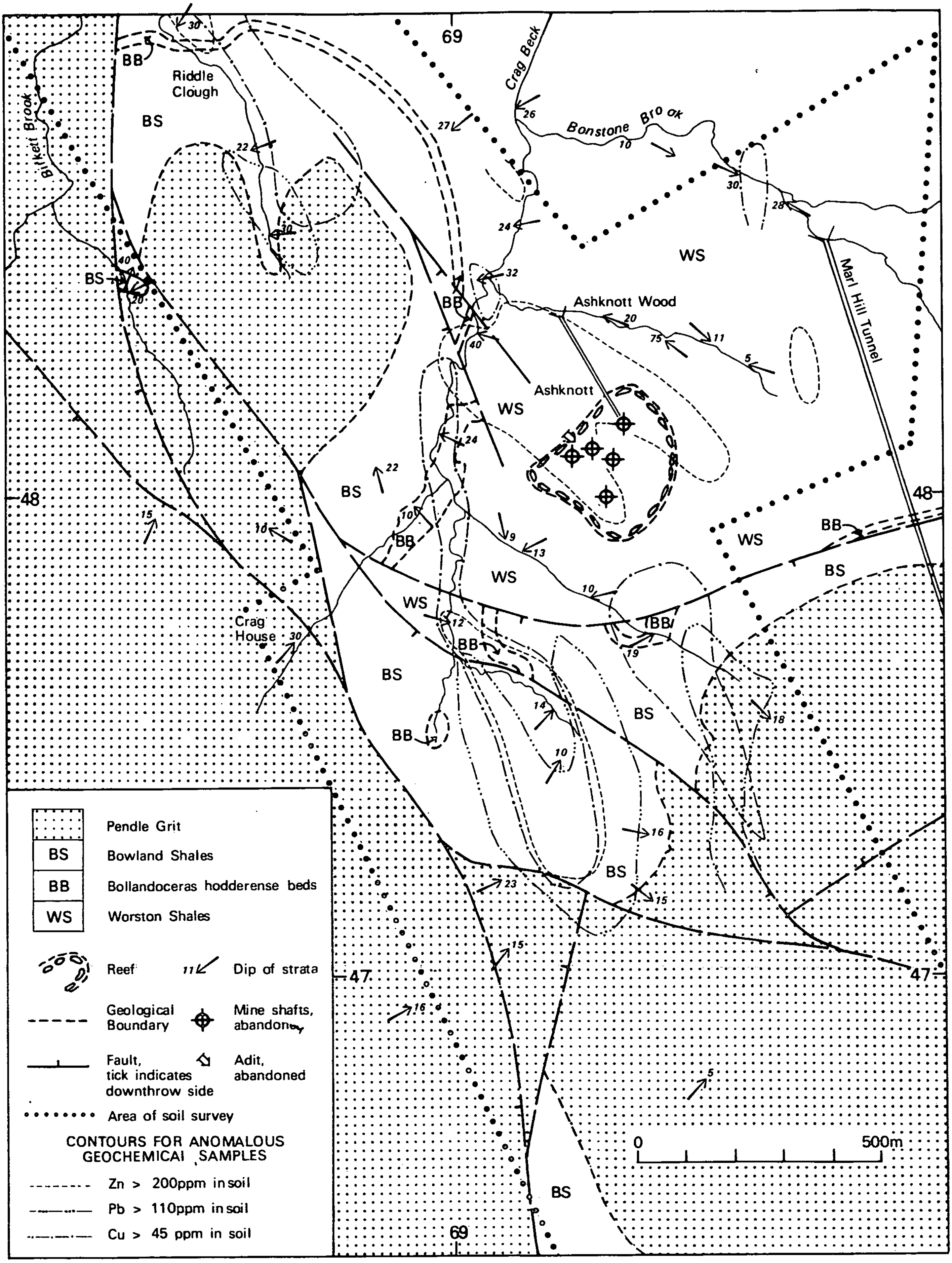


FIG. 57 GEOLOGY AND GEOCHEMICAL SURVEYS AT ASHNOTT

Anomalous Zn values (>160 ppm) extend over larger areas than the other two elements but they still demonstrate a linear north-westerly trend, the largest coinciding with the mineralised Ashnott reef. The highest values for Zn (530 ppm) and also for Pb (3000 ppm) both occur downslope to the north of the old mining area and are presumably due to contamination. The other anomalous areas are linear, their NW-trends tending to coincide with the major faults.

It seems likely that the mineralisation at Ashnott was due to the trapping of metal-rich brines within the well-fractured host rocks of the reef, beneath the cap rocks of the Worston Shales and Bowland Shales. The brines may well have reached the reef from the underlying Chatburn Limestone through local faults which are also mineralised. If this is the mode of occurrence then it seems unlikely that major mineralisation remains undiscovered within the Ashnott reef.

COW ARK

This area lies about 1.5 km north of the hamlet of Cow Ark and 8.5 km north-west of Clitheroe. The land rises to more than 300 m OD and is mostly pasture and moorland used for rough grazing. There are also small plantations of conifers. Access is by minor roads and un-made tracks. Much of the land hereabouts is part of the estate of the Duchy of Cornwall; the remainder is largely owned by local farmers.

There is no record of former mining in the area, and the nearest disused mines are at Ashnott, 1.5 km to the north-east. Parts of the area, however, were extensively dug in the past for marl to make tiles and field drains. Several small pits lie close to the Cow Ark–Newton Road, between Browsholme Heights and Marl Hill farm (Figure 58), and weathered calcareous mudstones from both the Bowland Shales and Worston Shales were worked. The remains of a horse-driven marl mill are still present on Browsholme Heights [6814 4675]. One of these marl pits (Crimpton Pit) provided the first indication of mineralisation in the area [6800 4672] as the excavation exposed crinoidal limestones faulted against Bowland Shales and containing veins of galena. The mineralisation was briefly recorded by E. G. Poole (*in* Earp and others, 1961) and stimulated the initial investigation of the area. A mechanical digger was used to clean the walls of the old working, which was about 5 m deep and 35 × 35 m in extent, and much more mineralisation was exposed. Galena occurred in replacement veins within the limestone which was itself much altered and inhomogeneous. Sphalerite occurred in cracks in the galena crystals but smithsonite was much more widespread both as discrete rhombic crystals and as microbotryoidal growths lining cavities. A mineral analyser indicated several percent Zn across several metres of the eastern wall of the pit where the limestone was replaced by a brown limonite-goethite clay. The mineralisation in the pit was sufficiently encouraging to justify a reconnaissance survey of the surrounding area.

Geology

The geology of the Cow Ark area was completely remapped for the present survey (Figure 58). The eastern part of the area was covered by the revision of the Clitheroe sheet (68) in 1953–1955, but in the west the Garstang sheet (67) has not been re-examined since the primary survey of 1870. The new geological interpretation incorporates substantial changes in the succession and detailed structure. The sequence is broadly comparable to that established around Clitheroe (Miller and Grayson, 1972) although there are rapid lateral variations locally in both lithology and thickness as shown in Figure 59. The oldest rocks proven in the area correlate with the Chatburn Limestone and were penetrated by several boreholes at Cow Ark although they do not crop out hereabouts. They consist of dark grey, bioclastic, bituminous limestones interbedded with micaceous and calcareous mudstones and siltstones. They are distal basinal turbidites, generally bioturbated and in places showing graded bedding and sole markings. At least 175 m of the Chatburn Limestone were proved in the boreholes but the base of the succession was not reached. The overlying beds are very variable and are grouped in the Clitheroe Limestone Complex. They include the 'reef' limestones which are banks of pale grey and fine-grained calcite mudstone, up to 100 m high near Clitheroe. In places the partly lithified rocks of the carbonate banks have been fractured and the cracks filled with micrites whilst elsewhere parts of the banks have been broken up by the high energy of the depositional environments into large blocks and boulders accumulating on the flanks of the bank. Between the reefs an interbedded facies accumulated in deeper and less turbulent water. Dark grey calcareous mudstones (Coplow Shales) or bedded crinoidal limestones (Peach Quarry Limestones) characterised this lower energy environment. The irregular top of the complex was marked by a break in deposition and some local erosion before the succeeding Worston Shales were laid down. The latter are turbidites and slumping occurs throughout the succession. The sequence consists mainly of dark grey calcareous mudstones and micaceous siltstones, generally finely laminated and with bioturbated horizons. Thin argillaceous limestone bands occur throughout and are often bioclastic or biosparitic. The overall thickness of the Worston Shales is variable since it was laid down on the irregular deeply-eroded top of the Clitheroe Limestone Complex. In addition, the thickness of the Worston Shales appears to be controlled by major structures in the basin. A maximum thickness of 150 m is proved for the Worston Shales around Cow Ark but this is a thin succession from an uplifted area; about 1000 m of these beds are recorded from local basinal areas elsewhere in Craven.

Upwards, the Worston Shales gradually become more calcareous and are overlain by the Pendleside Limestone consisting of grey porcellanous calcilutites interbedded with dark grey calcareous mudstones. The lowest part of this carbonate succession is marked by the *Bollandoceras hodderense* beds, which are thin calciluties with grey, brown or pink blotches. Up to 40 m of Pendleside Limestone have been proved at Cow Ark but the Limestone is locally often less than 10 m thick. At the top of the Dinantian succession there was a break in sedimentation before the Bowland Shales were laid down.

The Bowland Shales are composed of black pyritous shales, with thin bands of calcareous mudstone and siliceous limestone. In the Cow Ark area, much of the outcrop of the shales was reddened by oxidation in Permian times. The sequence passes upwards by gradation into the Pendle Grit, consisting of pink-grey, medium-grained sandstones together with coarse-grained, feldspathic sandstones.

Superficial deposits cover much of the area. Stiff, over-consolidated till is widespread; it is generally grey and stony and is proved to a thickness of 7 m in the boreholes at Cow Ark. Its maximum thickness hereabouts may be

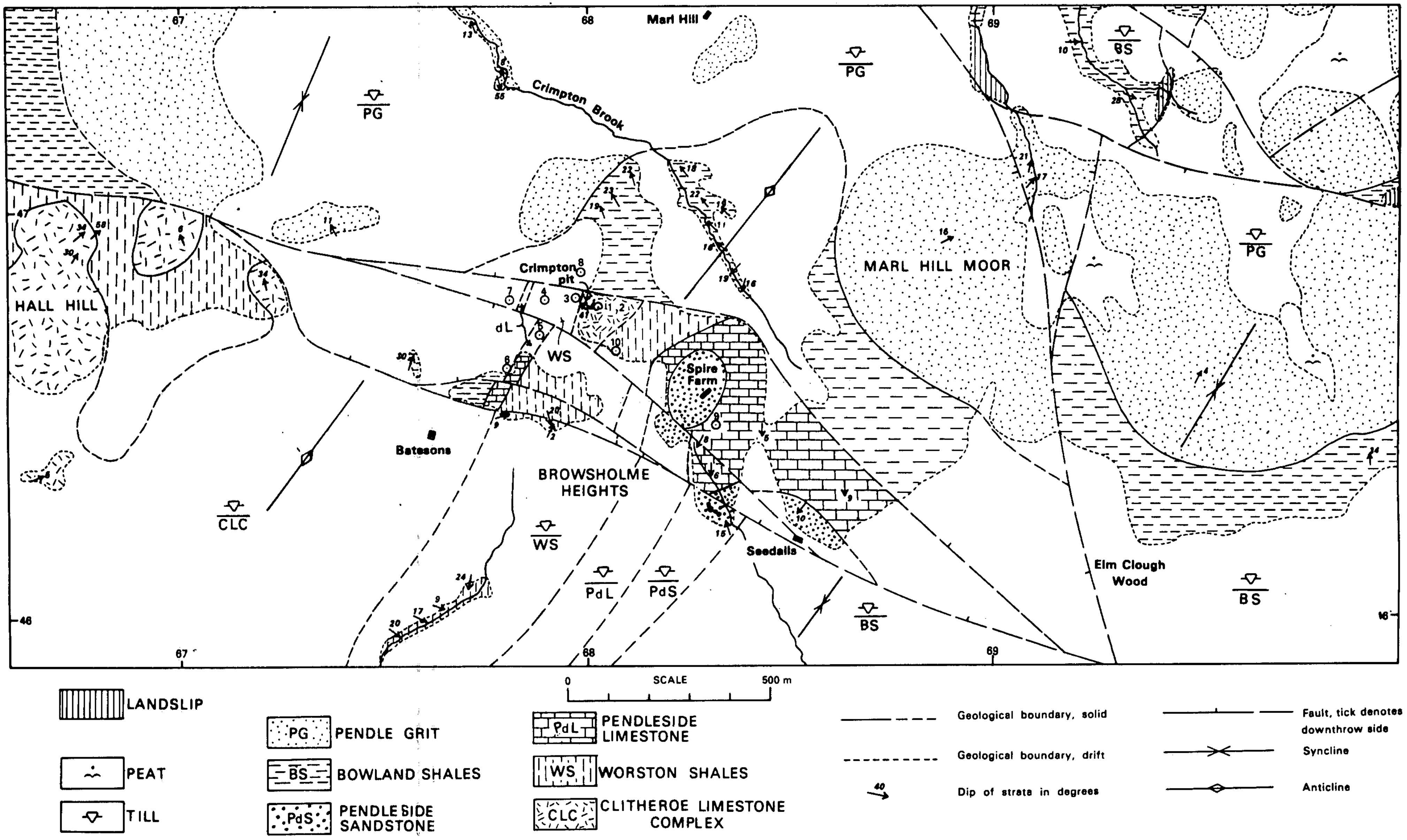


FIG 58 GEOLOGY OF THE AREA AROUND COW ARK

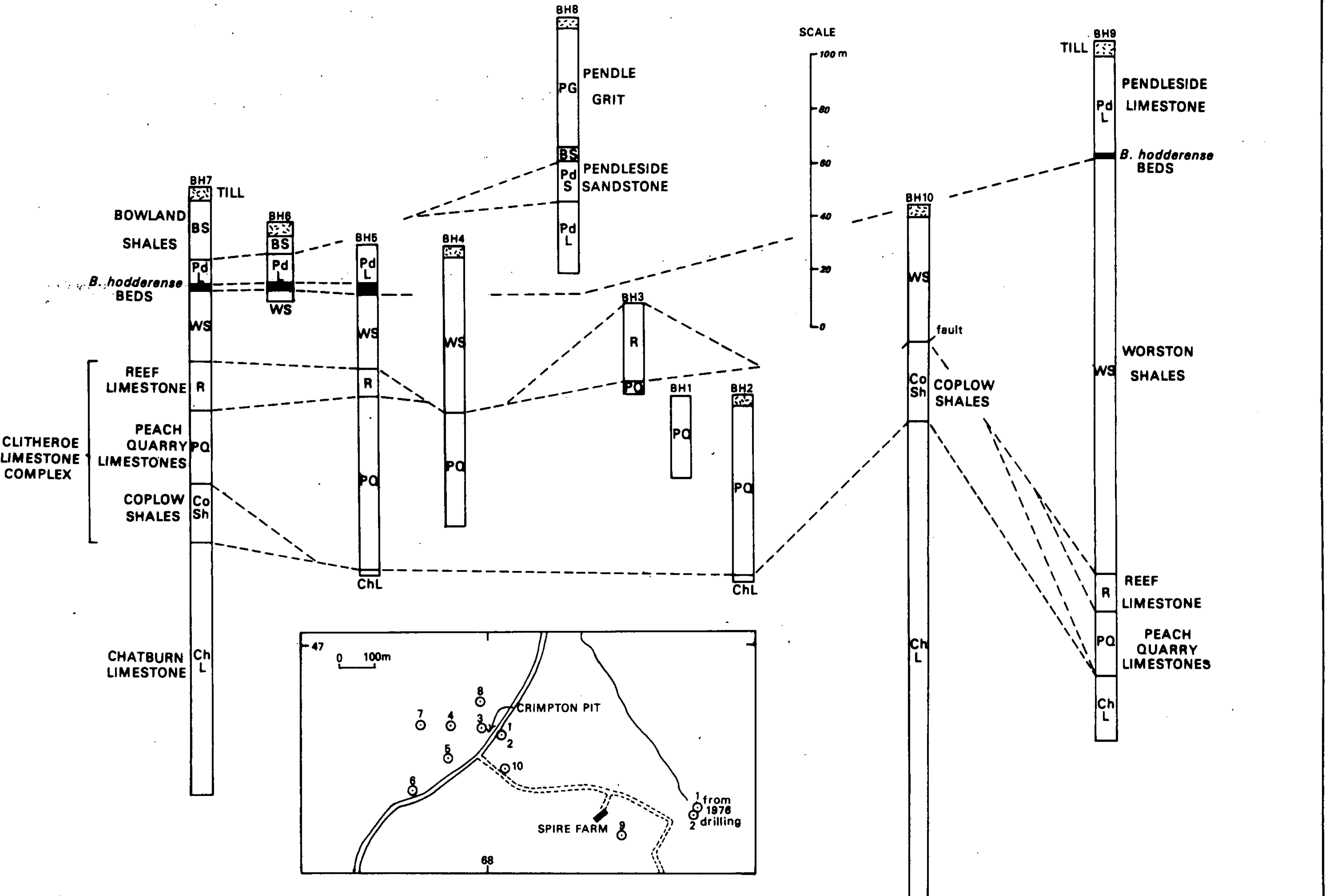


FIG 59 CORRELATION AND STRATIGRAPHY OF BOREHOLES AT COW ARK

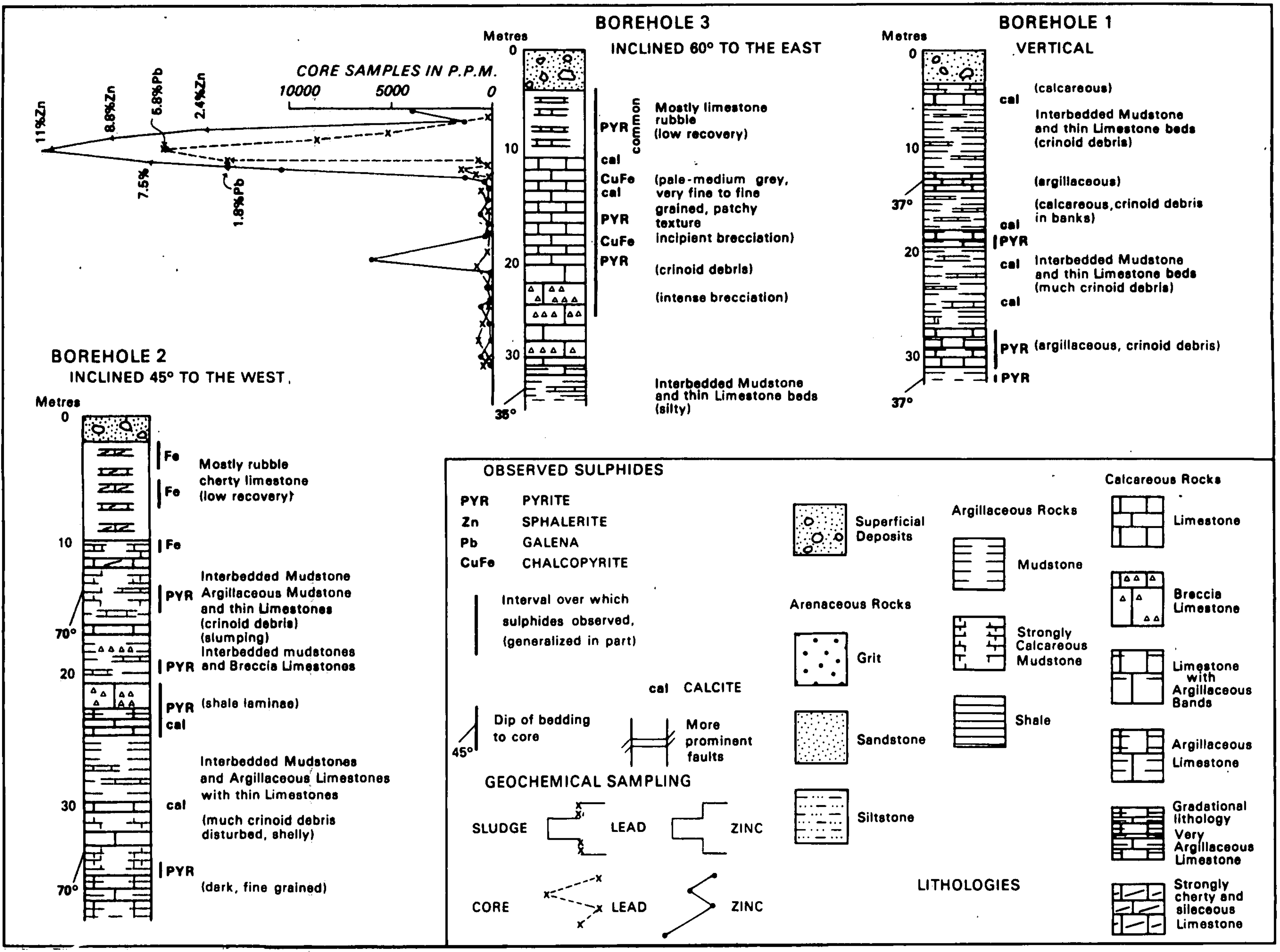
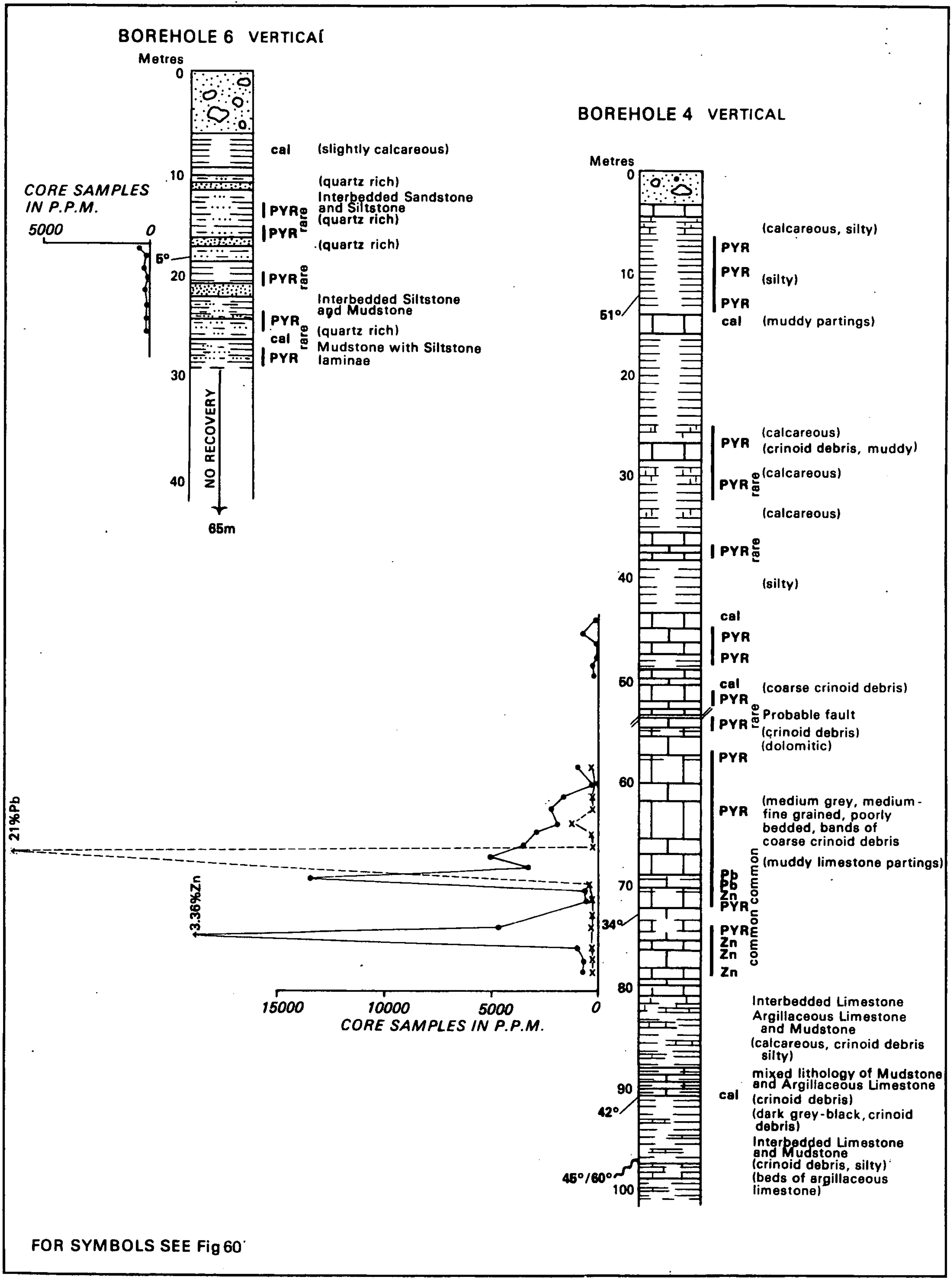


FIG. 60 LOGS OF BOREHOLES 1, 2 AND 3 AT COW ARK WITH DETAILS OF VISIBLE SULPHIDES AND GEOCHEMICAL ANALYSES



FOR SYMBOLS SEE Fig 60

FIG. 61 LOG OF BOREHOLES 4 AND 6 AT COW ARK WITH DETAILS OF VISIBLE SULPHIDES AND GEOCHEMICAL ANALYSES

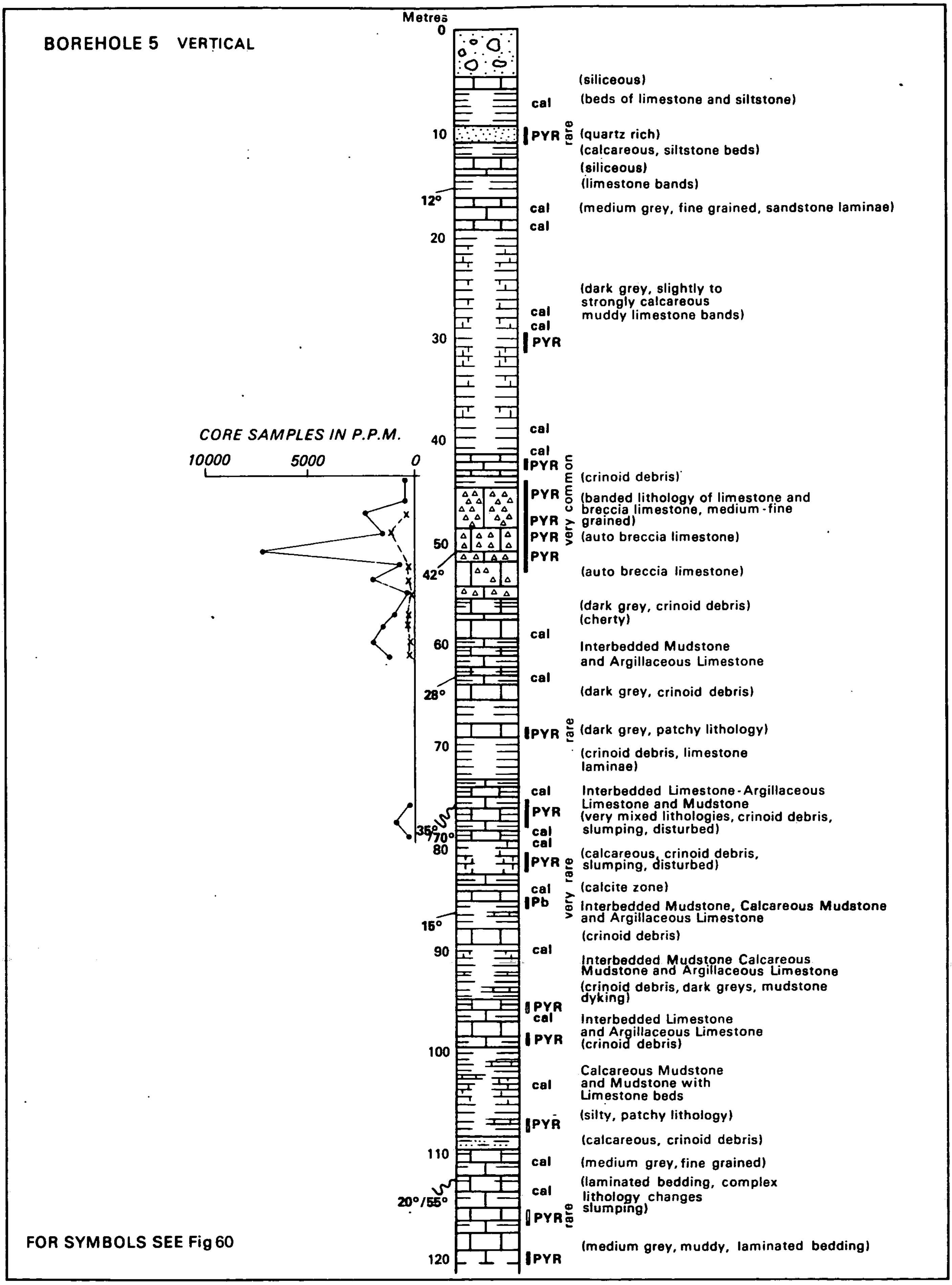


FIG. 62 LOG OF BOREHOLE 5 AT COW ARK WITH DETAILS OF VISIBLE SULPHIDES AND GEOCHEMICAL ANALYSES

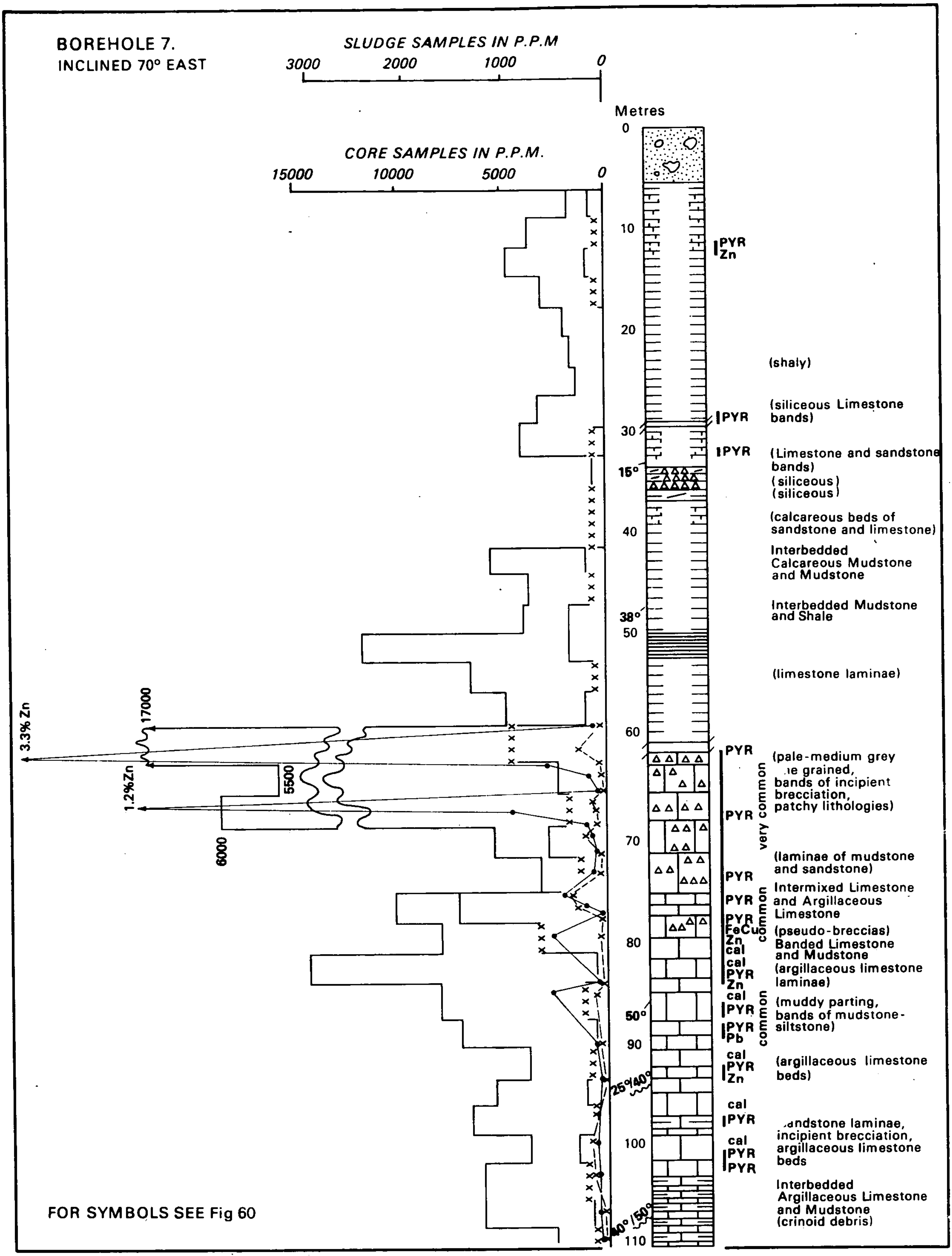


FIG. 63 LOG OF BOREHOLE 7 AT COW ARK WITH DETAILS OF VISIBLE SULPHIDES AND GEOCHEMICAL ANALYSES

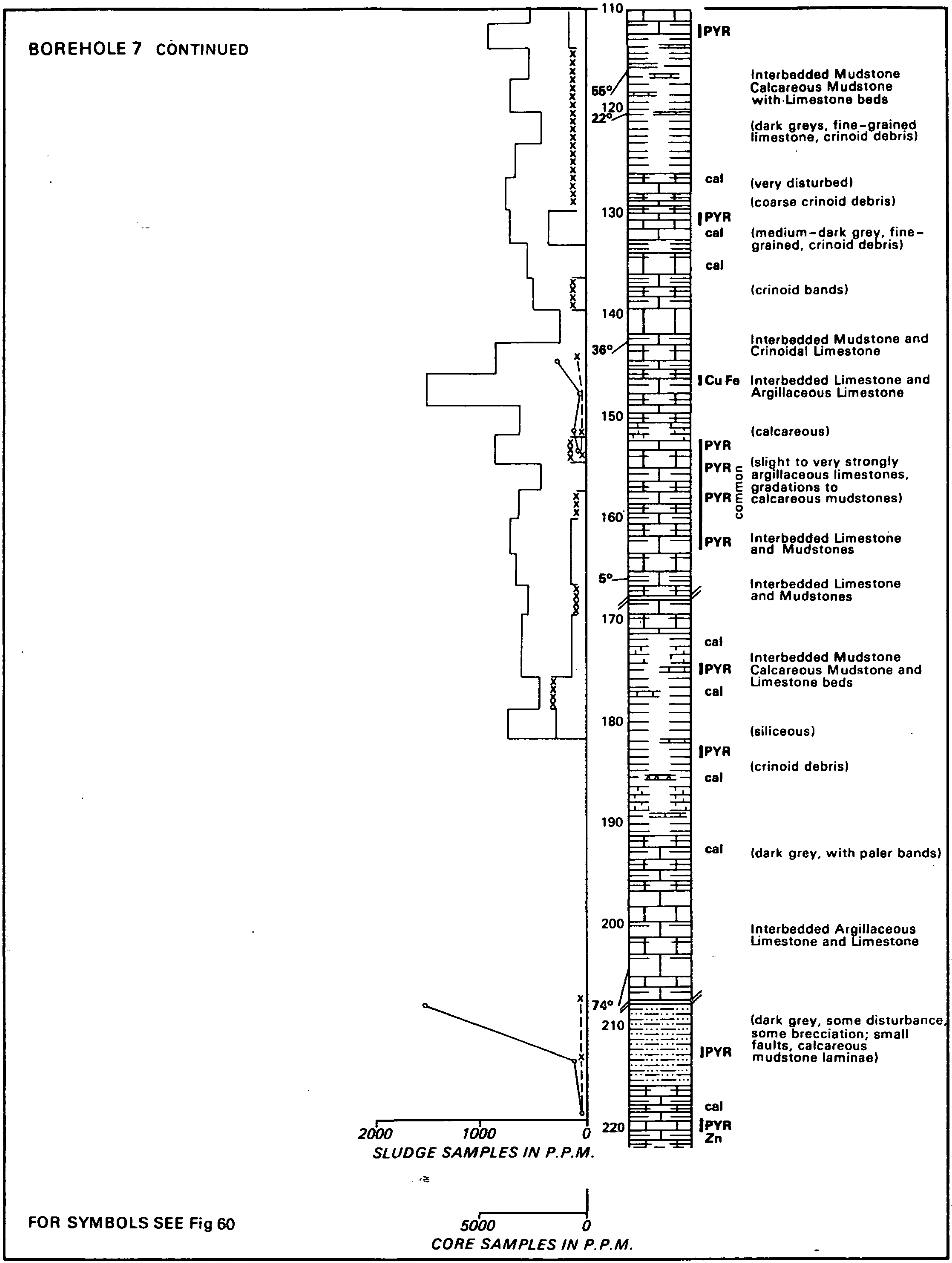


FIG. 63 (CONTINUED) LOG OF BOREHOLE 7 AT COW ARK WITH DETAILS OF VISIBLE SULPHIDES AND GEOCHEMICAL ANALYSES

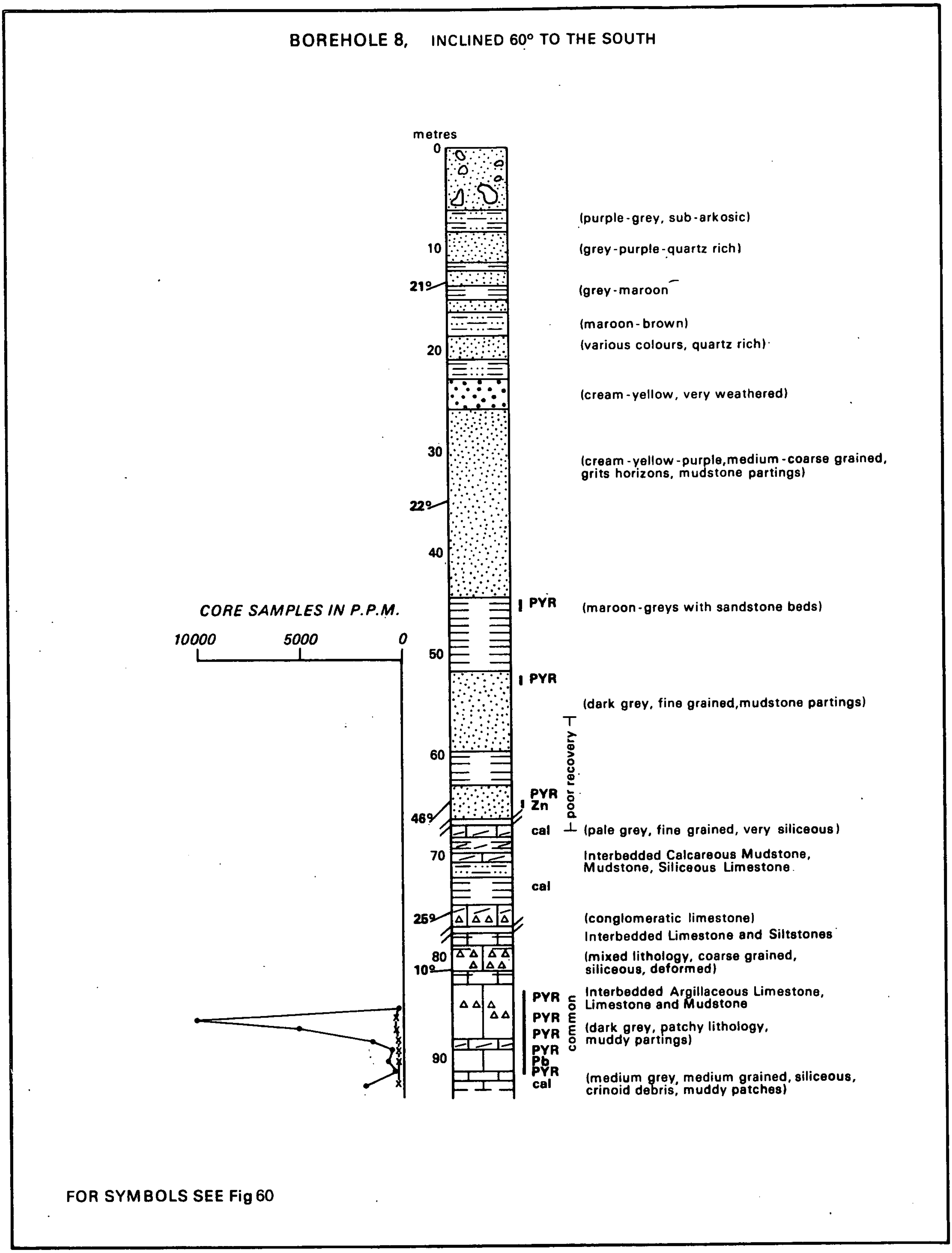


FIG. 64 LOG OF BOREHOLE 8 AT COW ARK WITH DETAILS OF VISIBLE SULPHIDES AND GEOCHEMICAL ANALYSES

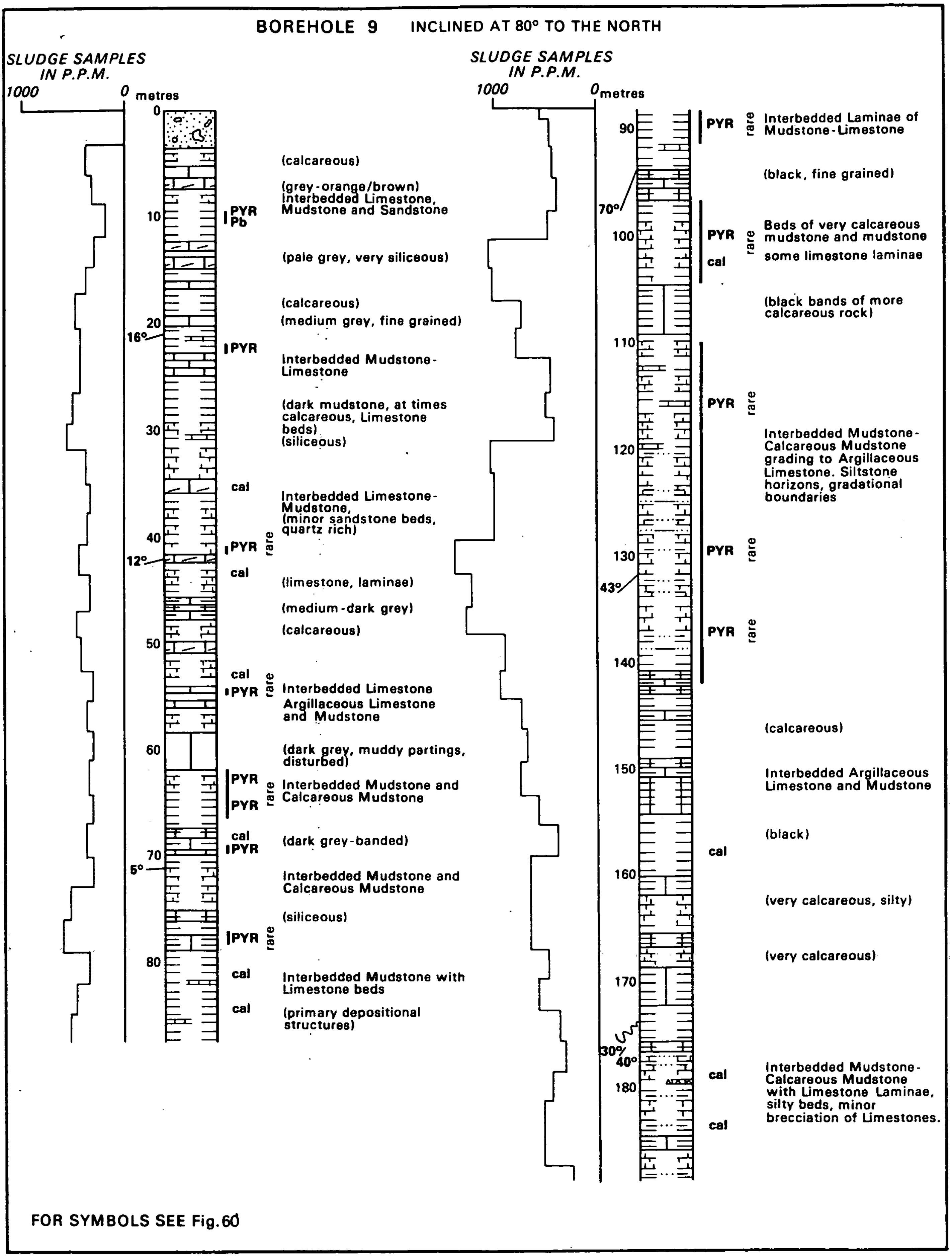


FIG. 65 LOG OF BOREHOLE 9 AT COW ARK WITH DETAILS OF VISIBLE SULPHIDES AND GEOCHEMICAL ANALYSES

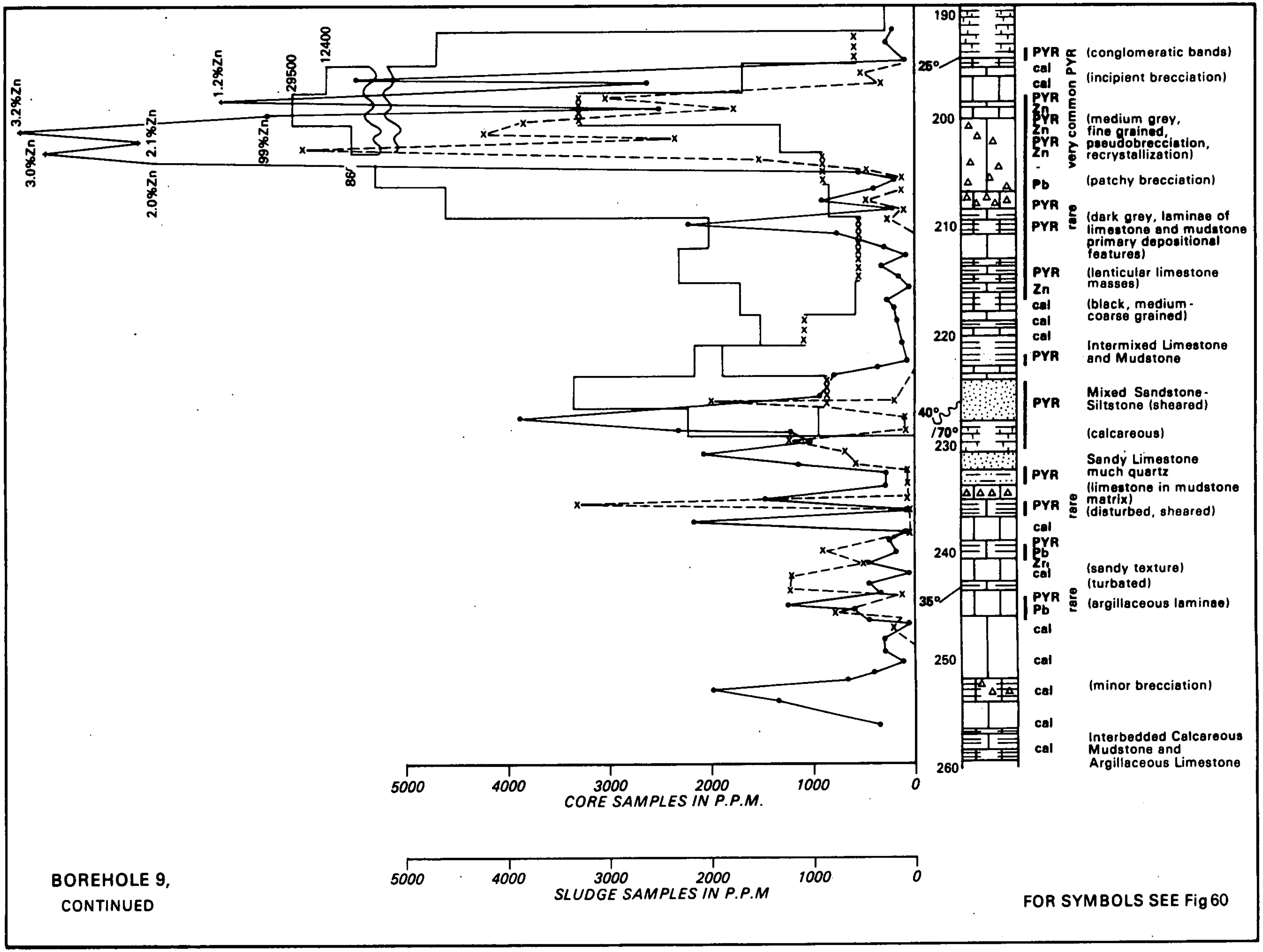
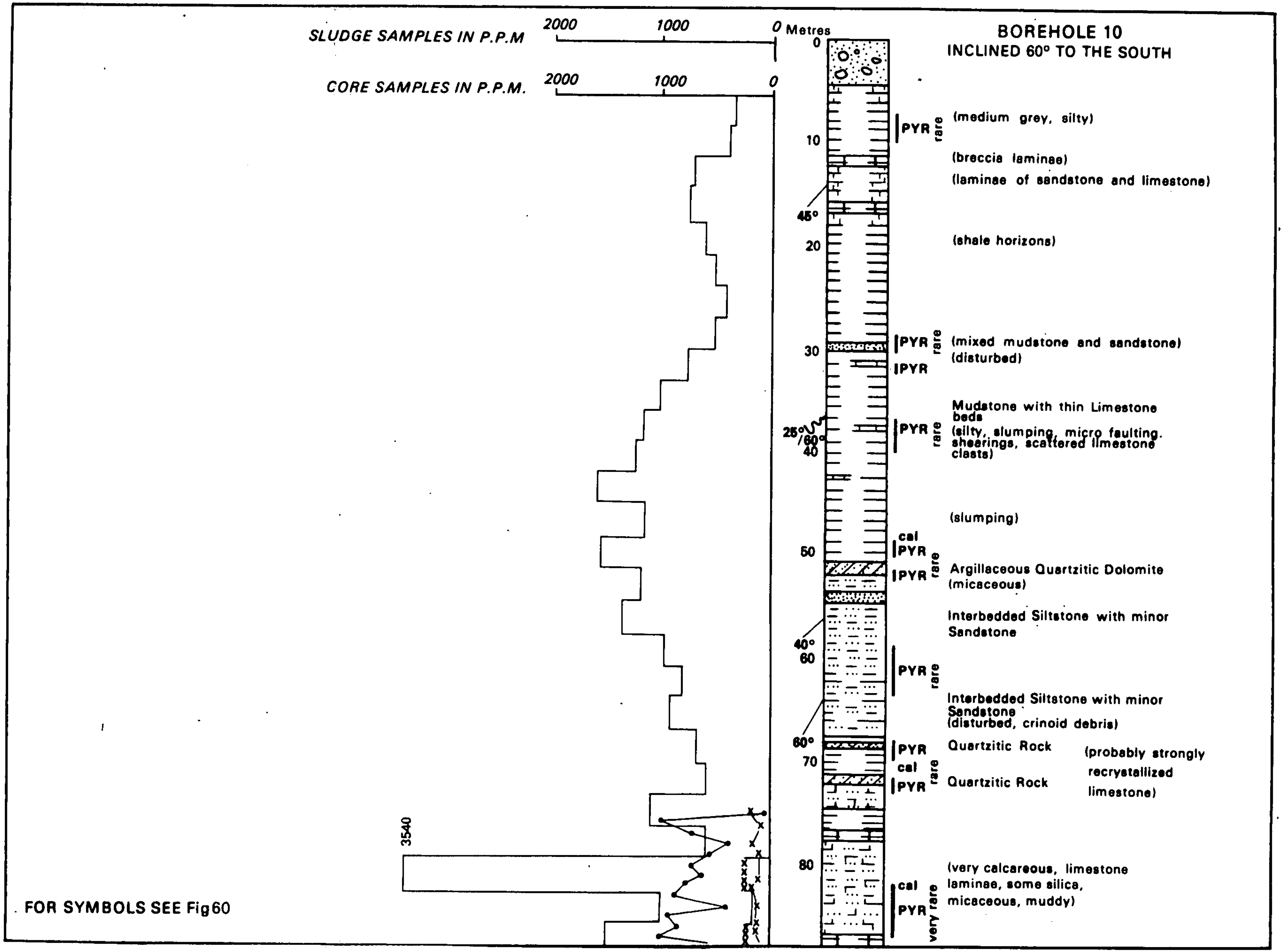


FIG. 65 (CONTINUED) LOG OF BOREHOLE 9 AT COW ARK WITH DETAILS OF VISIBLE SULPHIDES AND GEOCHEMICAL ANALYSES



FOR SYMBOLS SEE Fig60

FIG. 66 LOG OF BOREHOLE 10 AT COW ARK WITH DETAILS OF VISIBLE SULPHIDES AND GEOCHEMICAL ANALYSES

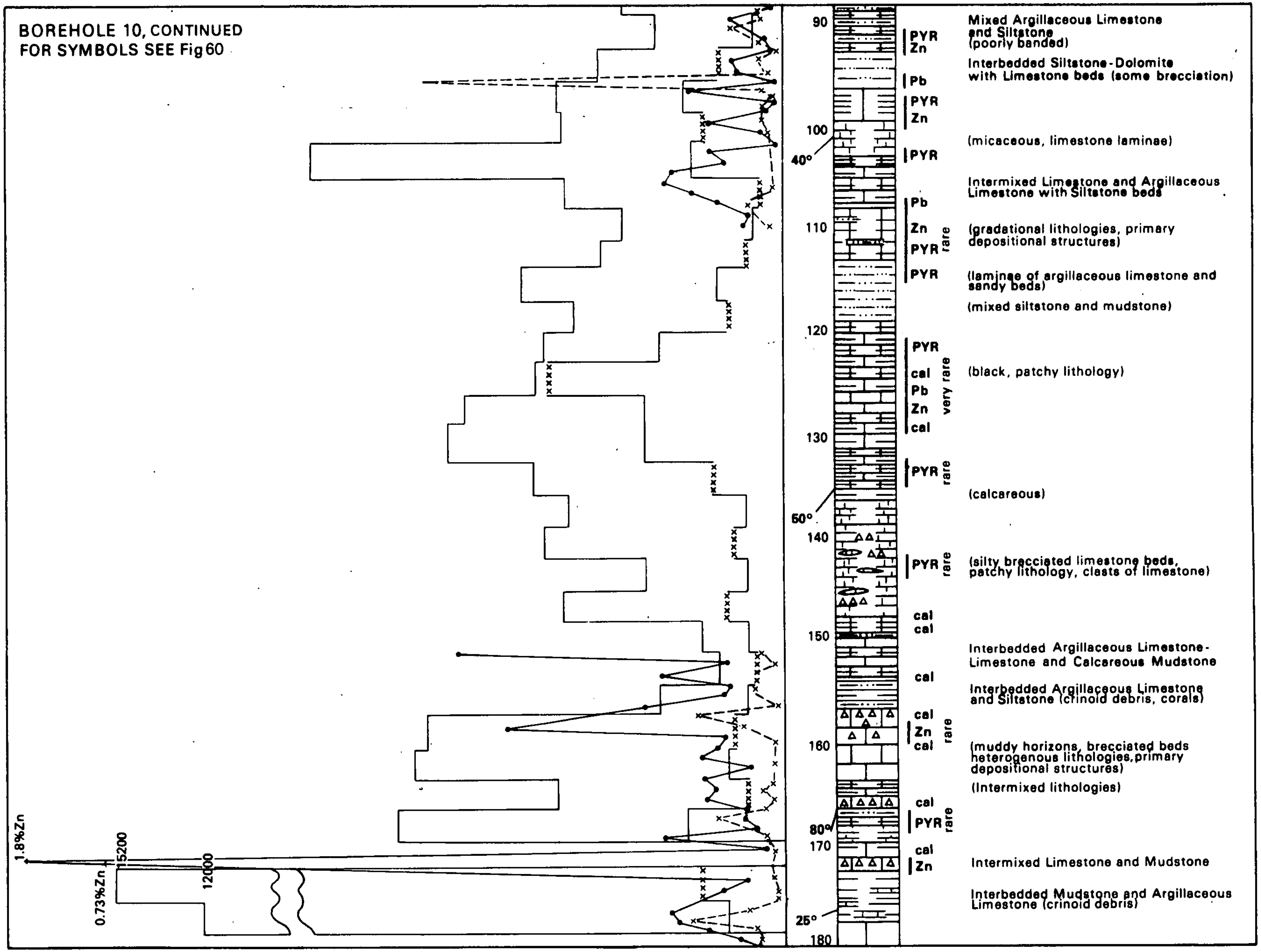
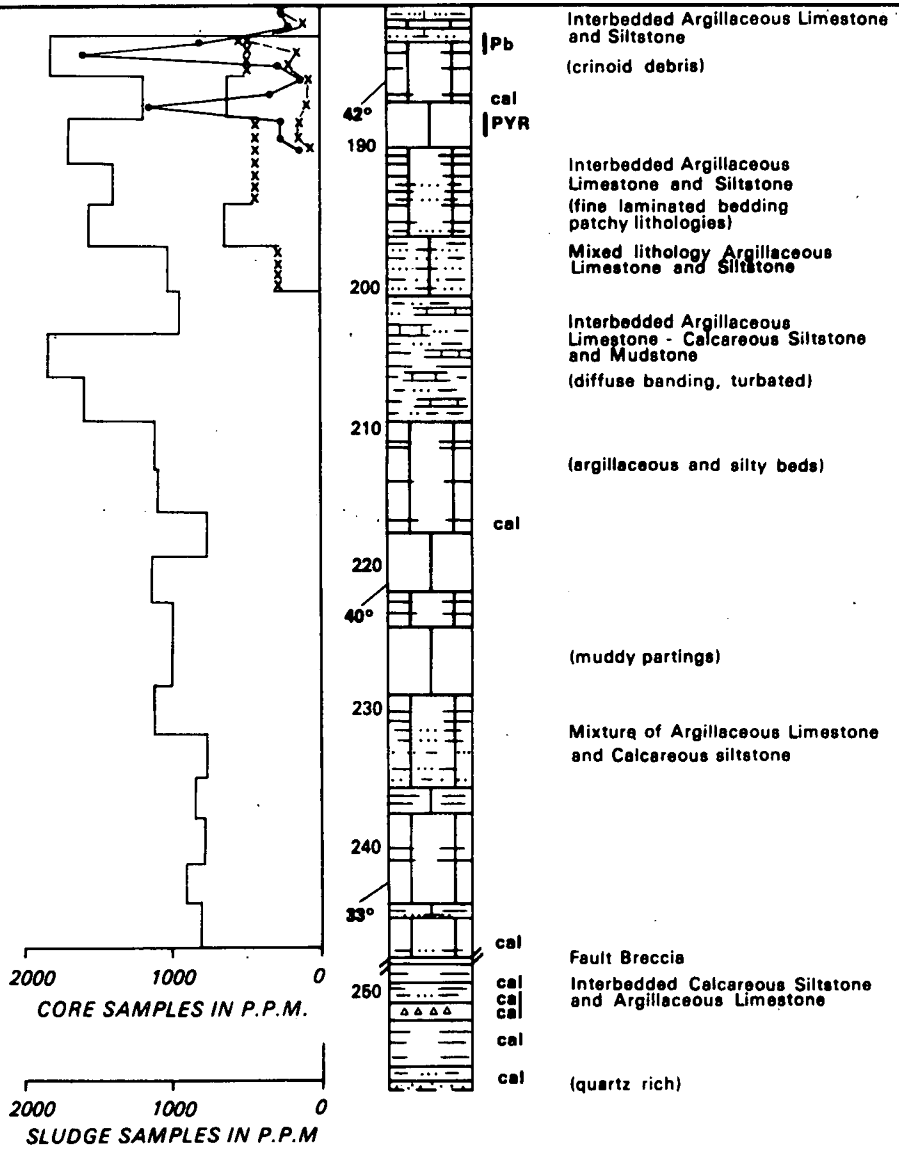


FIG. 66 (CONTINUED) LOG OF BOREHOLE 10 AT COW ARK WITH DETAILS OF VISIBLE SULPHIDES AND GEOCHEMICAL ANALYSES

BOREHOLE 10 CONTINUED



FOR SYMBOLS SEE Fig 60

FIG. 66 (CONTINUED) LOG OF BOREHOLE 10 AT COW ARK WITH DETAILS OF VISIBLE SULPHIDES AND GEOCHEMICAL ANALYSES

much greater. Thin peat is common as a surface layer in poorly-drained areas but elsewhere, on Marl Hill Moor for example, it is being eroded.

The locations and logs of the ten boreholes are shown in Figures 58 and 59, and Figures 60 to 66 give details of the geology, geochemistry and ore mineralogy of the cores.

Geochemistry
Geochemical investigations at Cow Ark were initiated with soil sampling surveys. Samples were collected from a 200 × 50 m grid, along traverses oriented in a north-westerly direction (Figure 67). The area covered by the grid included a small area of orientation survey which had earlier yielded soil values in excess of 200 ppm Zn and 100 ppm Pb. In two small areas, one adjacent to Crimpton Pit and the other between Spire and Seedalls farms, samples of basal till were also collected. All these samples were analysed for Cu, Pb and Zn. The anomalous soil values, defined by the level of mean plus two standard deviations ($\bar{x}$ + 2s), for each of the three elements show a very similar geographical distribution and are coincident for much of their area (Figure 67). The threshold values are 30 ppm Cu, 90 ppm Pb and 120 ppm Zn with peak recorded values of 120 ppm Cu, 260 ppm Pb and 1300 ppm Zn. Calculation of the coefficient of correlation for Zn and Pb gives a value of 0.03, which indicates that no linear relationship exists between the occurrence of these two elements. There is a marked linearity and parallelism in the area of the soil anomalies for each of the three metals, which shows some correlation with general geology, though in more detail the geological and geochemical trends do not necessarily coincide. In all instances there is a close spatial relationship between the position of the anomalous sub-surface samples and the surface geochemical data, the anomalous sub-surface values lying up-slope from the soil anomalies.

Contoured metal values obtained from the till auger samples are shown in Figure 67 and some of the resulting geochemical profiles are given in Figure 68. The distribution of the highest values closely fits the model of a restricted buried source subjected to both hydromorphic and mechanical dispersion. The profiles also illustrate the effect of hydromorphic dispersion related to relief. Figure 68 gives the results from two short traverses which show that the source of the high values lies close to holes numbered 2840, 2940 (close to the mineralised outcrop in Crimpton Pit) and 2860, a source which probably relates to leakage along a fault plane and which gives rise to a soil anomaly.

The interpretation of the soil and basal till data, both of which are limited to small areas, seems to indicate that mineralisation in the bedrock is localised. Comparison with the values of thousands of ppm from soils in similar geological conditions in Eire (Schultz, 1971) suggests that the mineralisation is probably of low tenor.

The data obtained from the bottom levels of auger hole 2860 show Zn and Pb values much in excess of the background figures. Elsewhere in the vicinity of the Crimpton Pit values somewhat above background values

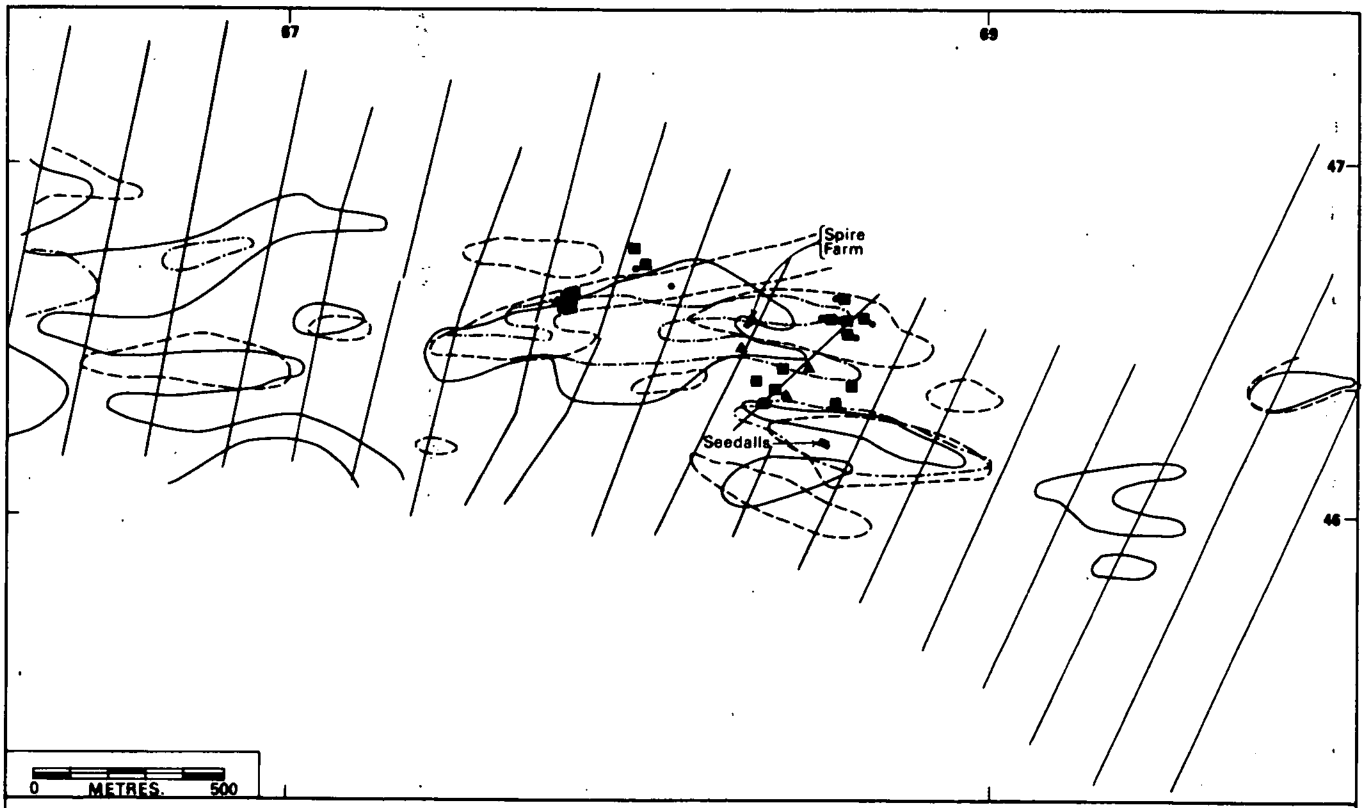


FIG. 67 SOIL AND BASAL TILL SAMPLING AT COW ARK

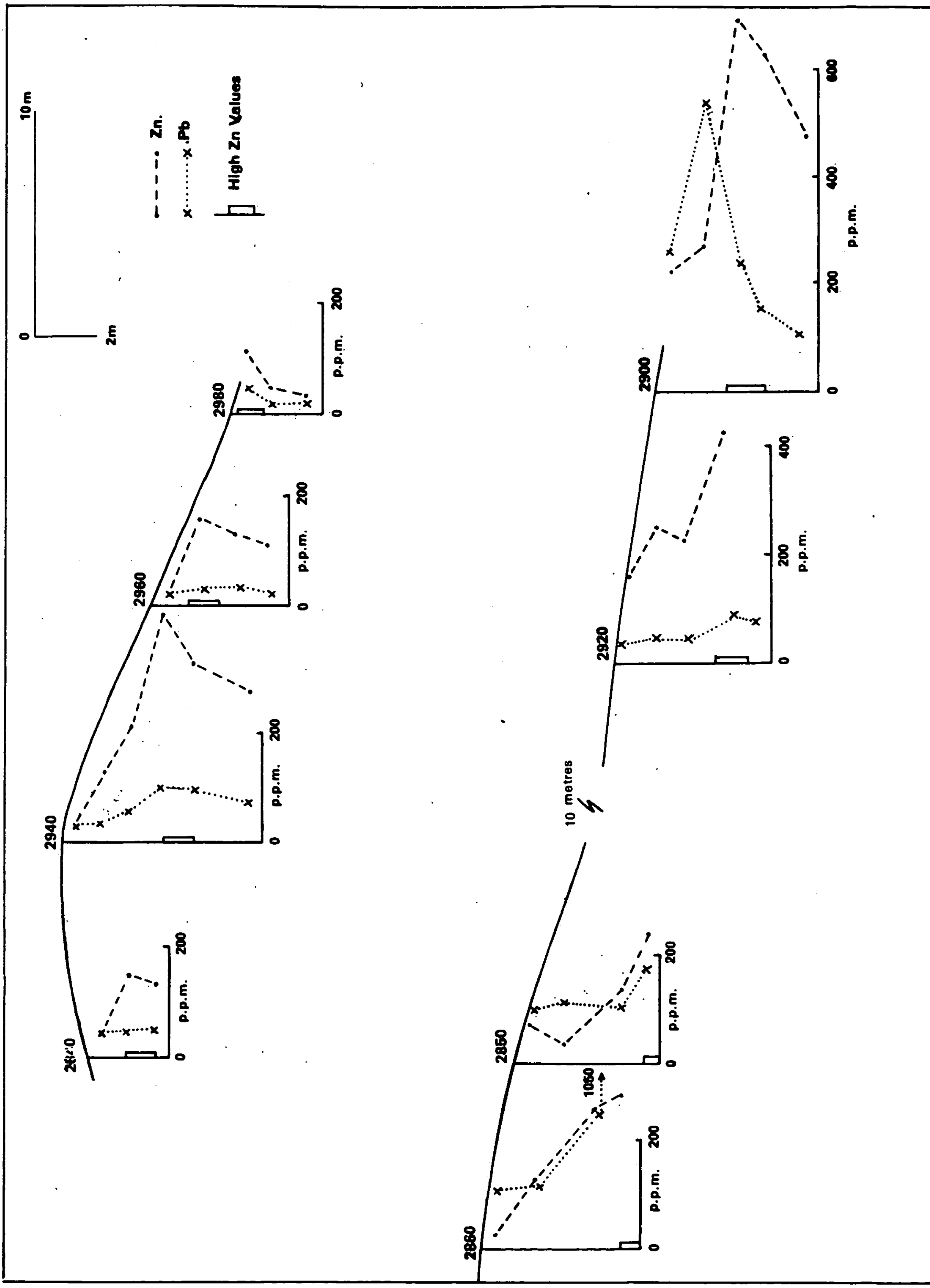


FIG. 68 DEEP TILL AUGER PROFILES FOR COW ARK

are recorded, with the exception of locations 2950, 2970 and 2980 where values were generally below background. The inference may be made that these holes were terminated above the till-rock interface. The auger holes sited between Seedalls and Spire farms generally show higher values for both Zn and Pb and frequently show increased values for both with depth.

Geophysics

An IP survey was conducted in the Cow Ark area, covering about 4 km^2. Traverse lines and location of the survey are shown in Figure 69. Time-domain IP using a dipole-dipole array was selected initially to locate any extension of the Crimpton Pit limestone by resistivity contrast with the overlying shales and also to seek associated chargeability values which might indicate disseminated mineralisation. The orientation of the traverses was dictated by the strike of the geochemical soil anomalies. Figure 70 is a map of resistivity values obtained with 50-m dipoles with a separation of 100 m ($n = 2$), while Figure 72 shows the resistivity for the $n = 4$ separation. Chargeabilities at these dipole separations are shown in Figures 71 and 73. Seven areas of interest have been distinguished (Figure 70) and are discussed below. Interpretations are based on comparison with model curves and are necessarily qualitative.

Area 1 (Figure 70) is a restricted but sharply defined feature with resistivity values up to 323 ohm metres. Crimpton Pit is contained within the feature, although the resistivity peaks lie some 100 m east of the pit and the feature is elongated to the east. Low chargeabilities coincide with the high resistivities. The general shape of the feature indicates high resistivity rocks dipping to the west. It is restricted to the north by a northerly-dipping feature, possibly a fault. A detailed 25-m dipole traverse (40W) indicates that the 'fault' anomaly has surface expression at 120N (Figure 69). On line 100W a similar feature is seen at 60N, just north of a feature marking high resistivity rocks at depth, while on line 100E the feature is at 150N, with a northern dip. Interpolation between these lines gives the feature an approximate E–W trend and it passes into the fault seen in the northern part of Crimpton Pit. Line 100W has a similar feature at 230S, although this is steeper and possibly dips very steeply to the south. The interpretation from the resistivity work is that the rock exposed in the pit overlies the most highly resistive material, which dips very steeply to the west or north-west and is cut off to the north by a northerly dipping fault with E–W trend, and possibly to the south by another fault. Chargeabilities were nowhere significant in area 1, being uniformly low at the background level of 8 milliseconds (ms). The Bowland Shales to the north of the fault in Crimpton Pit are marked by generally low resistivity values.

In area 2, near Spire Farm, there seem to be limestones with similar geophysical properties to those cropping out in Crimpton Pit but here lying at a deeper level. They are mapped as the Pendleside Limestone. At $n = 2$ a broad band of resistivity values of 150–200 ohm-metres encloses a restricted high of greater than 250 ohm-metres. Chargeabilities are in the range of 8–12 ms. At $n = 4$, two discrete anomalies form an arch-like feature on the pseudosection, caused by something near to the surface, although there appears to be less resistive material immediately overlying it. Just east of area 2 the Pendleside Limestone is shaly in facies and its outcrop gives lower resistivity values north of Seedalls farm. To the west of area 2 chargeabilities are affected by a metal water-pipe obliquely crossing the traverse lines.

In area 3, west of Bateson's farm, there are high resistivities at $n = 2$, up to 440 ohm-metres and low chargeabilities (< 12 ms) except across an artificial conductor. At $n = 4$ similar values are found. These mark the outcrop of massive limestones of the Clitheroe Limestone Complex. To the north, where the mapping suggests that they are faulted against Worston Shales, resistivities are lower. The steepness of the contact confirms the view that it is a fault.

High resistivity values are found near to the surface in area 4, on Marl Hill Moor. They have an asymmetry which is taken to indicate shallow dips to the north-east, and are associated with chargeability highs in excess of 15 ms. The area lies north-east of Crimpton Beck and the anomalies are probably caused by a high resistivity bed within, or just beneath, the Bowland Shales. Mapping shows that the rocks do dip north-eastwards across this part of Marl Hill Moor.

Farther east, across Marl Hill Moor and Browsholme Moor, the outcrop of the Pendle Grit is marked by high resistivity values in areas 5 and 6. Chargeabilities are also high in area 5 at both $n = 2$ and $n = 4$. The chargeability of sandstones is a function of their clay content and it seems likely that the Pendle Grit in area 5 has high chargeabilities because it contains more clay than usual. There is some evidence on lines 700 and 800N around 100W of deep-seated material with similar resistivity and chargeability values to those of Crimpton Pit. Area 6 differs from area 5 in that resistivities tend to be lower at $n = 4$, so that the Pendle Grit seems to be thinner here. There is also a lack of coincident chargeability highs which may indicate less clay in the Pendle Grit.

In area 7, south-west of Crimpton Pit, chargeability and resistivity anomalies are ascribed to faulting. They lie in the southern part of the area, on lines 100W and 200W, but show interference from artificial sources including a pipe. The fault can be traced as a weak anomaly on line 450W, where a zone of low resistivitities (less than 100 ohm-metres) is offset to the north at $n = 4$ and indicates a fault dipping steeply to the south, but elsewhere a grounded forestry fence gives widespread interference. One area of high chargeability (> 20 ms) is of possible interest. It occurs on the fault line on 200W to the north of Bateson's (Figure 69) and appears to be remote from the influence of both forestry fence and pipe, but no conclusions have been reached as to its cause.

A VLM-EM survey, using the Geonics EM 16 equipment used to define faulting at How Hill, was carried out at Cow Ark. The line of the fault to the south of Crimpton Pit, already defined by the IP survey, was tested but a strong anomaly due to the water-pipe masked other effects. Farther west, and to the north of Bateson's, there were no strong anomalies, but a weak conductivity contrast coincided with the stronger IP anomaly recorded on line 200W and probably indicates the westward continuation of the fault. In area 1, VLF traverses at 70W to 20E show a rapid shallowing eastwards of resistive rocks with more conductive rocks to the north and south, again indicating the restricted outcrop of the beds in Crimpton Pit. A sharp VLF anomaly at the northern end of the lines indicates the fault delimited by the IP survey. In area 5, VLF traverses outline the same outcrop pattern as indicated by the IP work.

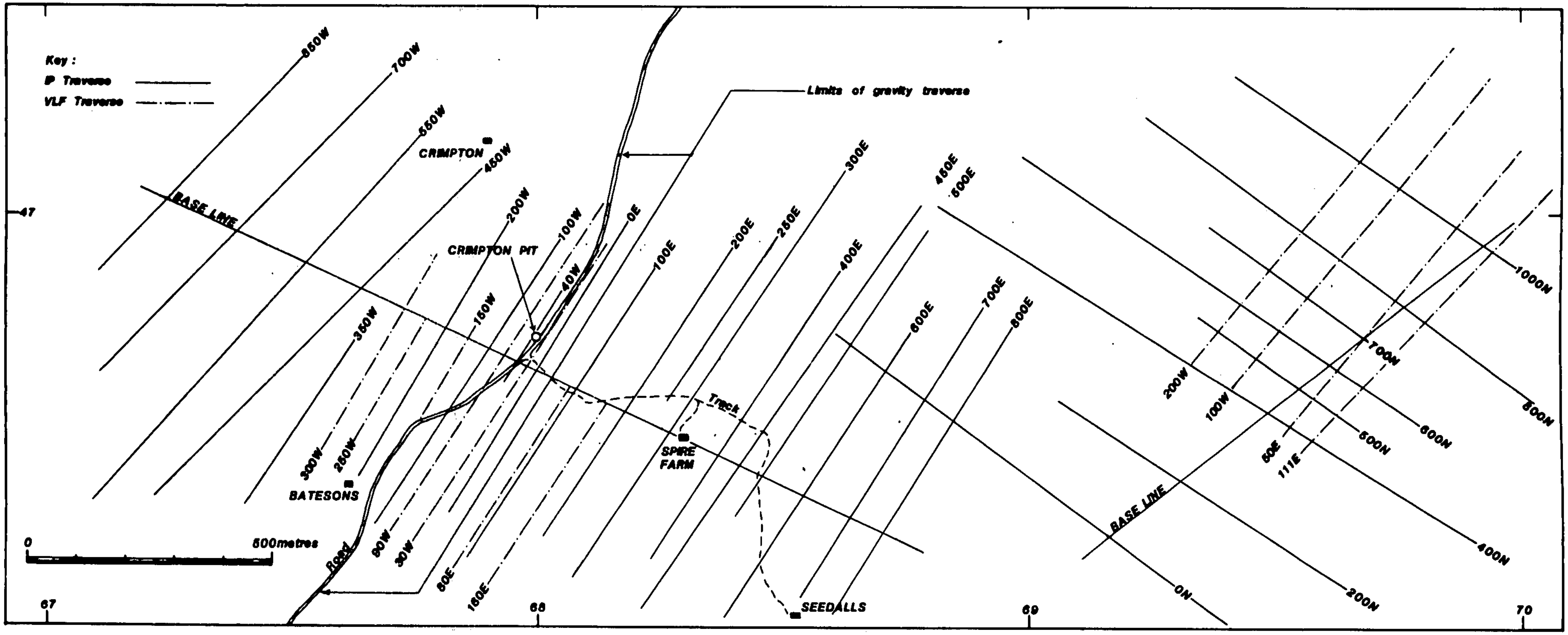


Fig. 69 Location of geophysical traverses at Cow Ark.

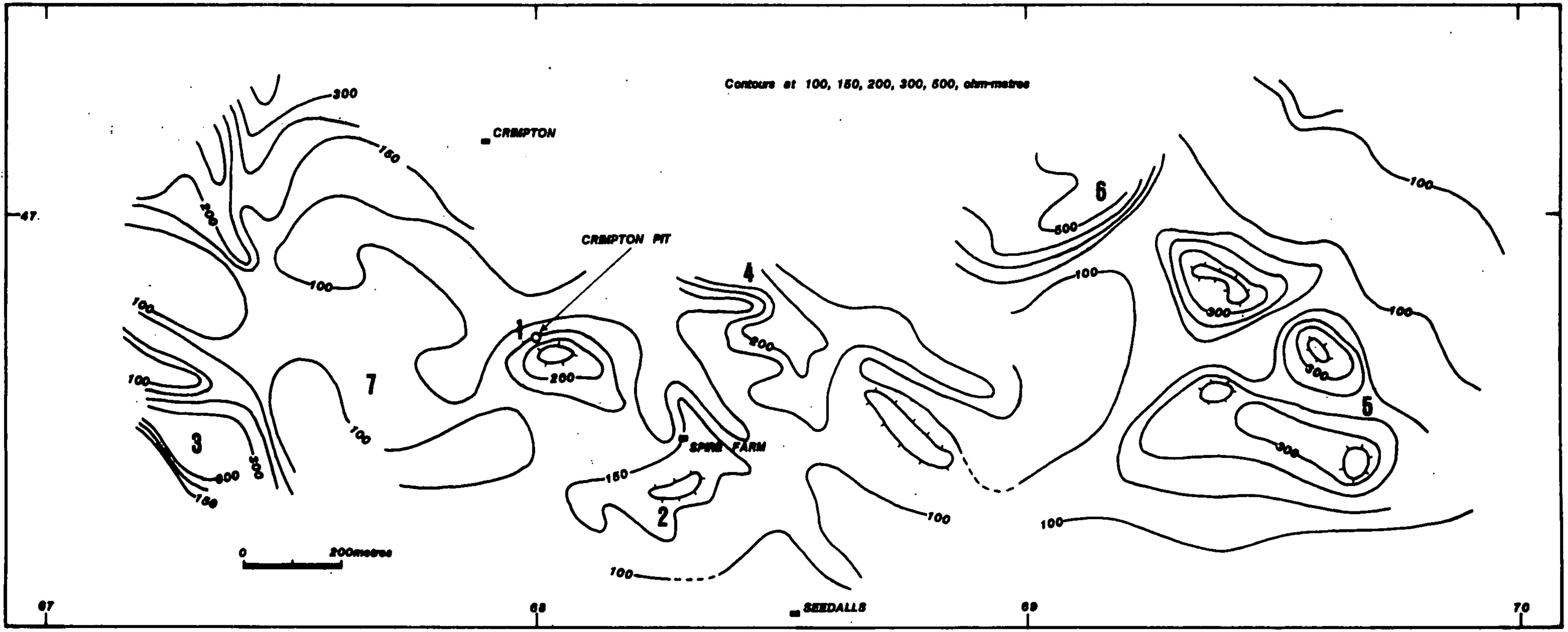


Fig. 70 Results of IP surveys at Cow Ark : Contours of apparent resistivity (ohm-metres) at n=2.

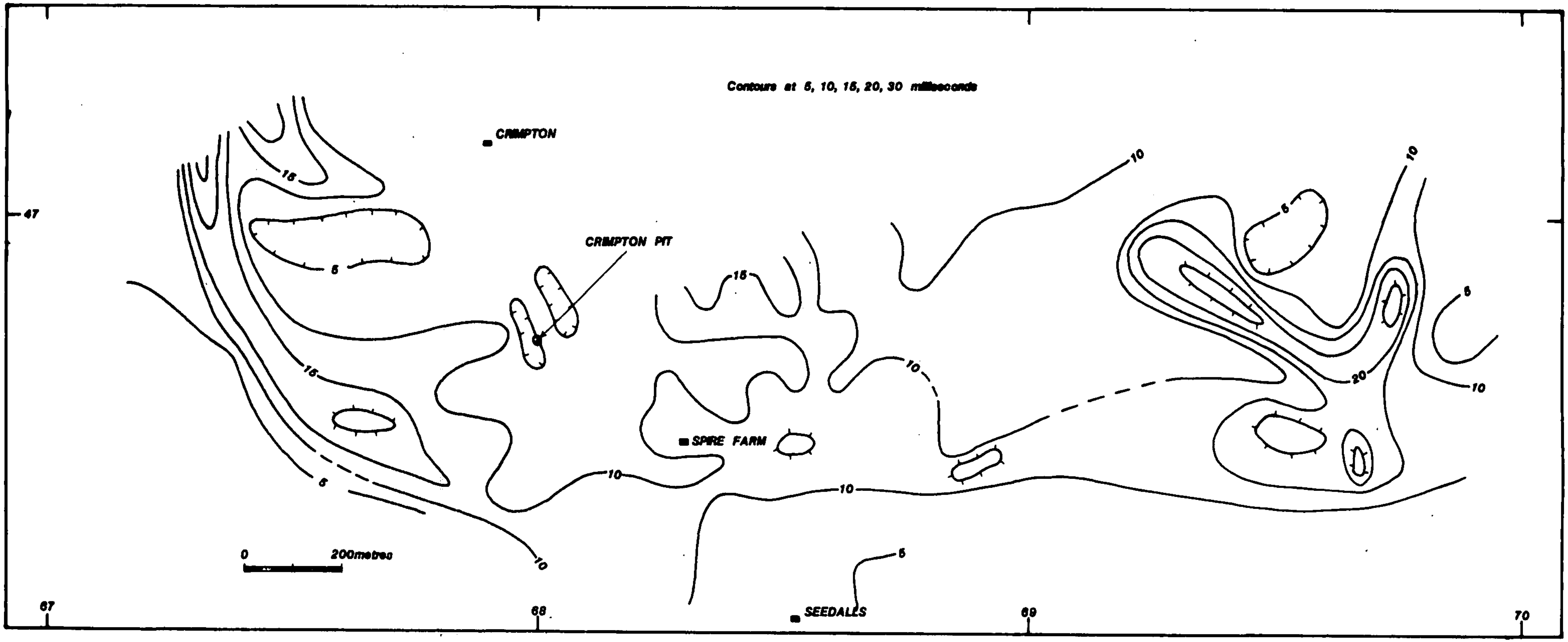


Fig. 71 Results of IP surveys at Cow Ark : Contours of chargeability (milliseconds) at n=2.

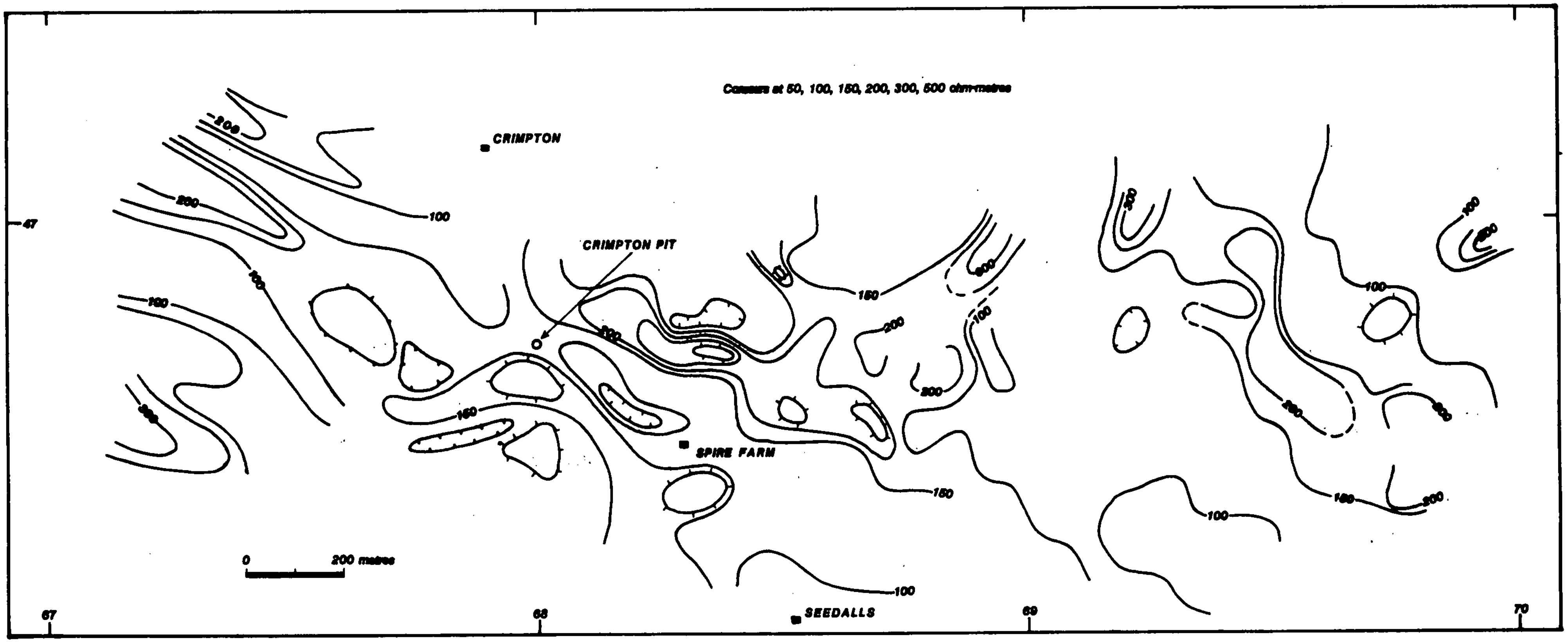


Fig. 72 Results of IP surveys at Cow Ark : Contours of apparent resistivity (ohm-metres) at n=4.

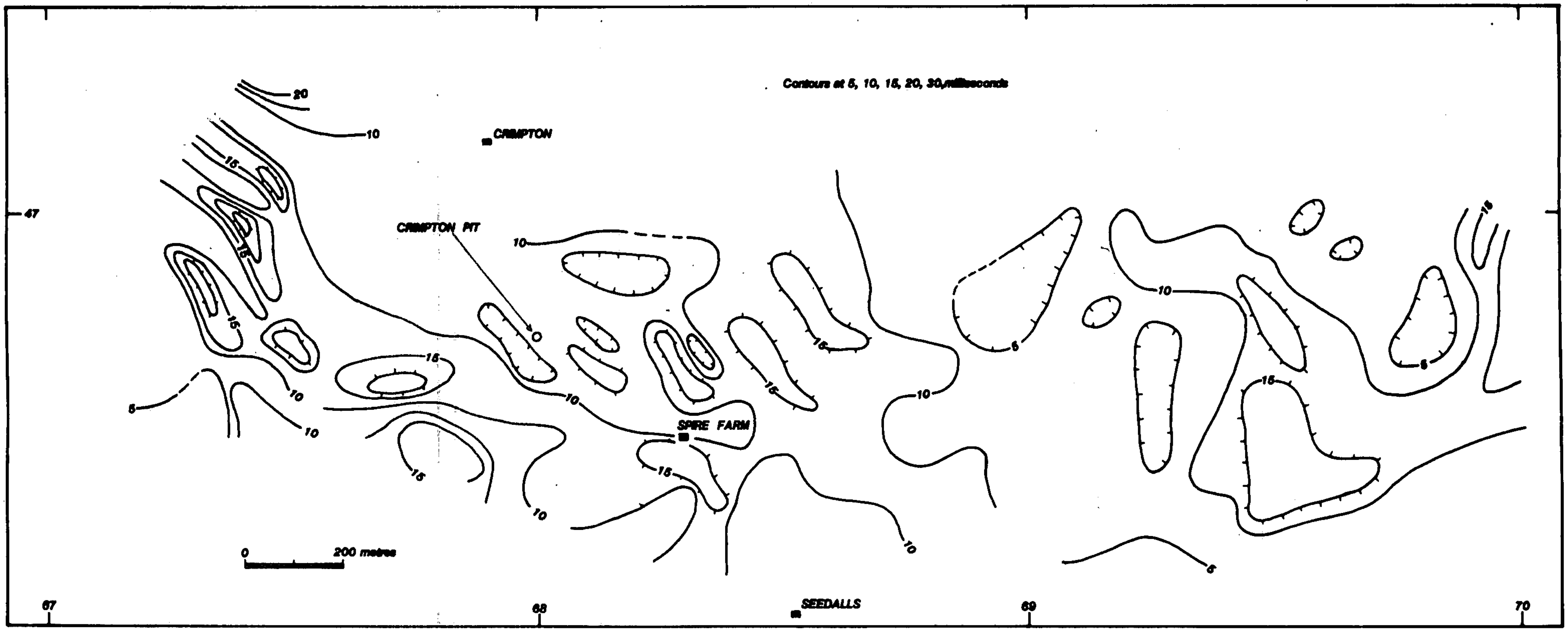


Fig. 73 Results of IP surveys at Cow Ark : Contours of chargeability (milliseconds) at n=4 .

Drilling

Drilling investigations on this prospect were in two phases with a total of ten boreholes sunk. The boreholes were drilled to provide information on mineralisation at depth. During the earlier phase three holes were drilled from sites close to the exposed mineralisation in the Crimpton Pit, while later phases of drilling were more widespread to check the distribution of mineralised horizons encountered in the previous phase of work and also to check the subsequently delineated geochemical and geophysical anomalies.

The first two holes were drilled to the east of the pit (Figure 59), one vertical and the other inclined at 45° to the west.

Borehole 2 was sunk parallel to the bedding of the strata and the log given in Figure 60 is therefore schematic. The third hole in this phase was sited just to the west of the pit exposure and was inclined at 60° to the east in order to intersect the limestone dipping 45°W at an estimated vertical depth of 3–4 m and pass through it nearly perpendicularly. This hole was terminated after 35 m, having successfully cored a thickness of some 15 m, equivalent to 14.5 m true thickness, through a mineralised limestone.

Holes 1 and 2 of the second phase of drilling were relatively shallow (31 and 40 m respectively) and sited on anomalous Zn–Pb values in augered samples to the north-west of Spire Farm (Figures 59, 67). These anomalous samples, from an interpretation of the available surface geological evidence, were considered to lie across the line of a fault. Both of them intersected a succession of dark mudstones with shales, in which the only sulphides present were tiny specks of pyrite. Although core recovery was good, there was no indication of faulting. Investigation of the core with the PIF analyser indicated only low Zn values. Total gamma profiles of these holes do not give a great deal of information but the relatively small increases in gamma count probably relate to minor lithological changes.

The pattern of holes 4–8 inclusive was designed both to test the bedrock beneath the anomalous basal till values and also to explore the possibility of the down dip extension of the mineralisation exposed in Crimpton Pit.

Vertical Borehole 4 was situated 50 m north-west of Crimpton Pit. Sites 5 and 6 were selected to investigate the lateral extent of the mineralisation in a south-westerly direction and also to confirm the position of a fault plane indicated by anomalous surface radon values. In Borehole 6 no core was recovered after a depth of 29 m, which is thought to be due to intersecting the fault. Borehole 7 was inclined at 75° towards 146° magnetic and situated 115 m north-west of borehole 4. The hole cored 222 m of strata, representing a vertical depth of 210 m. Borehole 8 was situated 80 m due north of hole No. 4 and was inclined at 60° with an azimuth of 180°.

Borehole No. 9 was drilled 130 m south-south-east of Spire Farm to a depth of 260 m at an inclination of 80° to the north and from which recovery of almost 100% was achieved. Borehole 10 was sited to attempt to intersect the major east-west fault at depth. Borehole No. 10 was drilled about 140 m south-east of Crimpton Pit at an inclined angle of 60° with an azimuth of 180°. Drilling was terminated at 257 m before reaching the inferred position of the east-west fault. Again, the recovery for this hole was nearly 100%.

Visible mineralisation in the boreholes

Indications of mineralisation were present in much of the examined core, though often in only very small amounts, occurring over very short vertical intervals. The mineralised sections together with their mineralogy are given along the right hand side of the borehole logs, Figures 60–66. This information is partly generalised due to the scale used in the diagrams. Also in these diagrams the use of several notations (PYR for example) shows a continuous presence of pyrite, while a single Zn (for example) notation would show only a limited length over which sphalerite is visible.

Pyrite This is by far the most common sulphide seen and is present over considerable lengths of core. It is generally distributed over zones of up to 20–30 m, with concentrations in shorter lengths of core, particularly within the mineralised zones at: 4–26 m (BH 3, 1975), 60–73 m (BH 4), 45–49 m (BH 5), 61–79 m (BH 7), 84–91 m (BH 8) and 197–207 m (BH 9). Pyrite is generally finely disseminated in specks (<0.05 mm) passing up into small grains (>1.0 mm) which may grade into less common pyrite-rich segregations and diffuse clots 1–2 cm across. Pyrite also forms tiny stringers and veinlets a fraction of a cm wide, which at times follow the bedding planes. Pyrite is associated with calcite veining, often forming a rim to the veins. Pyrite rims are also present around calcareous clasts within more argillaceous matrices. Only in a few cases is pyrite seen to be associated with fault zones, where it forms small euhedral crystals lining tiny drusy cavities. The most intense pyrite mineralisation is associated with brecciated and incipient brecciated limestones. Here nearly all of the interstitial area, often very argillaceous where still present, plus various amounts of the country rock are replaced by masses of small grains, stringers, irregularly shaped segregations and colloform pyrite. There were two distinct phases of mineralisation, indicated by cross-cutting relationships of the calcite veining. Pyrite is present in all types of lithology, but is most common in limestones, argillaceous limestones and the breccias.

Galena This is uncommon and is observed over short core lengths generally only a fraction of a metre long. It is commonly in the form of small scattered crystals, though tiny veinlets are also present. Between 69.10 and 70.60 m in BH 4 small veins and massive pockets of galena were seen, but the true amount of mineralisation was obscured by the poor recovery of core.

Sphalerite This mineral is not common in the cores, being present within narrow horizons less than 10 cm wide, where it generally forms large rounded red-yellow translucent crystals, either scattered throughout the core or concentrated in small clots of mineralisation. At some horizons sphalerite is associated with vuggy calcite veins and it also occurs as tiny veinlets a fraction of a cm wide. The greatest concentrations lie at 70–80 m in BH 4 and 198.00–199.50 m in BH 9.

Chalcopyrite This mineral is also very uncommon, being positively identified only as several tiny grains in the core. It is possible that some of the references to this mineral in the figures should be more correctly identified as cupriferous pyrite.

Sludge sampling of boreholes

Sludge samples from Boreholes 7 (Figure 63), 8 (Figure 64), 9 (Figure 65) and 10 (Figure 66) were sampled during drilling operations in order to determine the most suitable intervals on which core analyses should be undertaken; this material was analysed for Pb, Zn and Cu. In all of the boreholes copper values were low, with values remaining below 100 ppm. Sampling of borehole 7 was possible to a depth of 182 m, beyond which water circulation, and thus sludge, was lost. Figure 63 shows that between depths of 60 and 110 m, Zn values in sludges reached 1.75%, while Pb values reached 0.1%. In borehole 9 (Figure 65), sampled to a depth of 235 m, values for Pb and Zn were low to 192 m after which Pb values reached 0.32% and Zn values 2.4% over short intervals of sampling. Borehole 10 was sampled to 245 m (Figure 66). Pb values were generally low, with higher values (up to 0.22%) over a few short intervals. Zn values were found to be irregular with a number of short intervals where values reach 0.30–1.52%.

Analysis of sectioned core

Sections of core were cut and one half was analysed for Pb, Zn and Cu; the Cu values were so low that they are not discussed in the following account.

Borehole 3 gave the analysis values shown in Figure 60, where Zn is seen to reach a maximum of 11% over 1 m with high values over an interval of about 8 m. Below a depth of 11 m low values (100–500 ppm) were present, apart from a small peak of 0.5%. High values for Pb were found between 5 and 9 m, with a peak of 5.8%, while below this depth values ranged between 100 and 500 ppm. Although the high values range over some 8 m of core length, the true amount of mineralisation is difficult to assess due to poor recovery of core.

Borehole 4 was sampled at 43–50 m and 58–81 m, (Figure 61). Values were low for Zn in the top 60 m, after which a peak of 3.36% was present over a core thickness of 2 m. Pb values were very low apart from a single narrow peak of 21% at around 67 m depth at which depth there was poor core recovery.

Borehole 5 was sampled at 44–59 m and 76–80 m, the values obtained being shown in Figure 62. Values for Zn were low except between depths of 49–52 m where the average value was 0.36% Zn, with a peak of 0.7%. Pb values were very low.

Borehole 6 was sampled at 15–28 m, (Figure 61). Zn values are very low, while Pb values were below the threshold levels for this element.

Borehole 7 was sampled at 58–100 m, 145–155 m and 208–220 m, the values obtained being shown in Figure 63. There are two Zn peaks between 58 and 68 m with maximum values of 3.3% and 1.24% Zn. Below this depth small peaks are present with values of around 0.25%. Below 93 m values are low, apart from a value of 0.75% at 208 m. Pb values are low throughout the lengths of sampled core.

Borehole 8 was sampled at 50–94 m and the values obtained are shown in Figure 64. Values for both Zn and Pb are below the threshold levels, apart from around a depth of 90 m where a small peak of Zn is present with a maximum value of 1.1%.

Borehole 9 was sampled at 128–132 m and 192–259 m, the values obtained being shown in Figure 65. Zn shows a broad peak of high values (0.8–3.2%) between 197–205 m depth. Between 230 and 259 m there are irregular values giving rise to narrow peak values of 0.13–0.39%. There is a maximum value of 0.6% Pb at 205.5 m plus a number of narrow peaks at depths of 192–205.5 m and 227–246 m.

Borehole 10 was sampled over the intervals 75–110 m and 150–190 m, the values obtained being shown in Figure 66. The maximum Zn values lie between 171 and 173 m with a peak value of 1.8%. Smaller peaks of 0.3% and 0.26% Zn are also seen, but apart from these localised values the Zn levels fluctuate between 0.01 and 0.17%. Pb has a peak value of 0.35% at 96 m, while the remainder of the values vary irregularly up to 0.1%.

Conclusions

The Cow Ark area lies in the core of a NE-plunging anticline to the north of Browsholme Heights (Figure 58). A large fault throwing down to the north bounds the area on the south side. In the core of the fold, limestones of both the Clitheroe Limestone Complex and the Pendleside Limestone crop out, each overlain stratigraphically by relatively impermeable mudstone sequences. The boreholes show that there is considerable lateral variation in the succession (Figure 59), particularly at the horizon of reef limestones at the top of the Clitheroe Limestone Complex and in the overlying Worston Shales. This supports a general conclusion drawn from the recent mapping of the Settle district (Arthurton and others, *in preparation*) that contemporary folds and faults affected sedimentation in Craven during the Lower Carboniferous times. As a result the thin sequences tend to occur on the anticlines and the thick successions in the synclines. It is a feature of such circumstances that many stratigraphical traps develop within the succession, whose effects may be enhanced by faulting.

The geochemical surveys at Cow Ark show a number of weak anomalies trending roughly east-west, and correlating with the solid geology, particularly with the outcrops of limestone. The geophysical surveys showed a variety of anomalies, though small in extent, which again correlate well with the local geology. The Bowland Shales outcrops tend to be notably conductive, especially when wet.

The limited deep sampling auger survey showed that adjacent to Crimpton Pit there was an increase in the amount of sulphide with increasing depth. To check on the cause of these geophysical and geochemical anomalies and to follow at depth the mineralisation seen in Crimpton Pit, a detailed local drilling programme was carried out in several phases. This programme located a zone of sulphide mineralisation situated within the calcareous upper part of the Pendleside Limestone, lying below the impervious shales of the Bowland Shale Group. About 2220 m of core was drilled, much of it being sampled by sludges during the drilling operations. These sludges gave some indication that sulphides were present at certain horizons. Visible mineralisation was present in much of the core. Pyrite was by far the most common sulphide, Pb and Zn minerals not being particularly abundant. Analysis of 385 m of core was carried out for Cu, Pb and Zn. Significant Zn and Pb mineralisation was confined to a number of horizons between 2 and 9 m thick. The core analyses showed that mineralisation occurred at some horizons where it gave no visible indication of its presence.

It is concluded that the mineralisation at Cow Ark accumulated in the structural trap of the anticlinal core and that locally concentrations occur in minor stratigraphical traps. Almost always the host-rocks are the limestones and the cap-rocks are the mudstones.

DINKLING GREEN

This area lies about 12 km north-west of Clitheroe, along the southern boundary of the Bowland Forest. The elevation varies from 100 to 430 m OD, with the steep slopes of Burnslack Fell to the west. Mixed farming on the lower ground gives way to rough sheep grazing on the moors.

The geology of the area (Figure 74) has not been systematically mapped since the primary survey in 1871–1872, but some local revision was carried out for the present work. The facies variations of the Lower Carboniferous rocks are complex and not yet fully understood. Detailed faunal and sedimentological work still in progress (N. J. Riley, personal communication) suggests that the oldest rocks exposed are the reefs and associated bedded crinoidal limestones containing reef debris exposed in the River Hodder south of Whitewell. The reefs consist of pale grey fine-grained bio-calcarenite with areas of calcilutite and micrite infillings. The reefs attain a maximum thickness of 300 m on Long Knotts (Parkinson, 1935). Local dips are generally down the slopes of the lime-banks, but overall the reefs are inclined with the regional dip to the north-west. The Worston Shales overlie the reefs unconformably as exposed on Whitemore Knot [6399 4814], and contain many thin bands of turbiditic calcarenite. The Pendleside Limestone and Sandstone are both well-developed on the slopes below Burnslack Fell and are succeeded by a sequence of Bowland Shales and Pendle Grit compared with the Clitheroe section (Earp and others, 1961). A large tectonic fold trends north-eastwards along the Hodder valley, but, in addition, detailed sections show many smaller folds, some of which seem to be due to penecontemporaneous slumping during sedimentation.

The lower ground is largely covered by an overconsolidated till sheet varying from 3 to 10 m in thickness. The reefs and the high moors stand clear of the boulder clay but the hillsides are extensively covered in head.

Analyses of pan concentrates collected from streams in the area north and south of Dinkling Green [640 470] during the regional geochemical survey show high values for Ba and Zn. This information together with the presence of old calamine pit workings 900 m north-east of Dinkling Green justified collecting soil samples from the grid shown on Figure 74. Sampling was undertaken on a 350 × 150 m grid, extending 6 km north-north-east from Chipping, with the River Hodder forming the eastern boundary.

The analytical data from the soils were subjected to a simple statistical treatment to derive the anomalous values for Cu, Pb, Zn and Ba at the mean plus two standard deviation level ($\bar{x}$ + 2s). The values obtained from this treatment are given below and the geographical distribution of the anomalous samples indicated in Figure 74:

	Arithmetic mean ($\bar{x}$)	Standard deviation (s)	($\bar{x}$ + 2s)
Cu	25	13.7	52.4
Pb	57.56	20.93	99.42
Zn	174.6	110.2	395
Ba	528.5	144	816.5

As elsewhere in Craven, Cu values are generally low, falling well within background values and reaching a maximum of 130 ppm. The higher Cu values, as in other parts of the Craven Basin, occur towards the top of the Worston Shales.

Anomalous Pb and Zn values (>100 and >395 ppm respectively) are located on Mellor Knoll in the north, and around Long Knotts and New Laund Hill. The Long Knotts occurrence was worked on a small scale during the last century when smithsonite (calamine) was dug from an open working [645 476], and other small pits were sunk into the top of the reef farther south [643 472] along thin veins. There are also thin sphalerite and galena veins hereabouts. On New Laund Hill the values obtained for Pb and Zn in this location (330–1340 ppm Zn and 160–1650 ppm Pb) are much higher than the values near the old calamine pit (340 ppm Zn and 280 ppm Pb). There is no trace, however, of either old workings or visible mineralisation at this locality.

The origin of the high values for Pb and Zn in the soils overlying the reefs is not as yet understood but it is likely that these metals are co-precipitated with ferric oxide. It is, however, clear that the reefs generally give high Pb–Zn values and it may well be that the enhanced soil values are due to the trapping of metal-rich brines in the reefs below the cap rocks of the overlying shales.

ELMRIDGE

The Elmridge area lies at the western end of the Craven Basin, in the Chipping valley, approximately 12 km west of Clitheroe, at an altitude of 120–180 m. It is used for mixed farming and is readily accessible by minor roads.

The area is underlain by Lower Carboniferous rocks which emerge from beneath the Permo–Triassic of the Irish Sea basin just west of Elmridge. Details of the local sequence and structure are not well known. The area was last mapped in 1871 and the drift deposits are extensive (Figure 75). The succession comprises the Worston Shales, seen only in the cores of anticlines, the thinly bedded carbonates of the Pendleside Limestone, and the Pendleside Sandstone. The last is a series of turbiditic sandstones of variable thickness, well-developed to the north of Elmridge but thin or absent to the south and west. Finally the Bowland Shales complete the local sequence. There is considerable faulting present, particularly in a NW–SE direction, and the folding may be even more complex than is shown. Almost all the solid geology is obscured by a till-sheet generally 10–20 m thick.

Reconnaissance stream sediment and pan concentrate sampling in the River Loud and its tributaries revealed a number of samples of pan concentrates with anomalous values for Ba and Zn with occasional high values for Pb (Figure 3). High values were also recorded for Sn.

The largest concentration of anomalous pan samples occurs in the River Loud in the area of Little Elmridge [595 415] approximately 2.5 km south-west of Chipping. Mineralogical examination of three samples showed that the high values for Ba and Zn were attributable to massive barytes and yellow glassy sphalerite. High Pb values were thought in at least two samples to be due to the presence of cerussite. The Sn and Cu values are thought to be the result of contamination. The other minerals identified suggest derivation from mineralised veins.

As a follow-up study, soils were sampled over approximately 4 km^2 around Elmridge; the samples were collected at 100 m intervals along traverse lines about 300 m apart and were analysed for Cu, Pb and Zn. Values for each of these elements are low and the distribution of

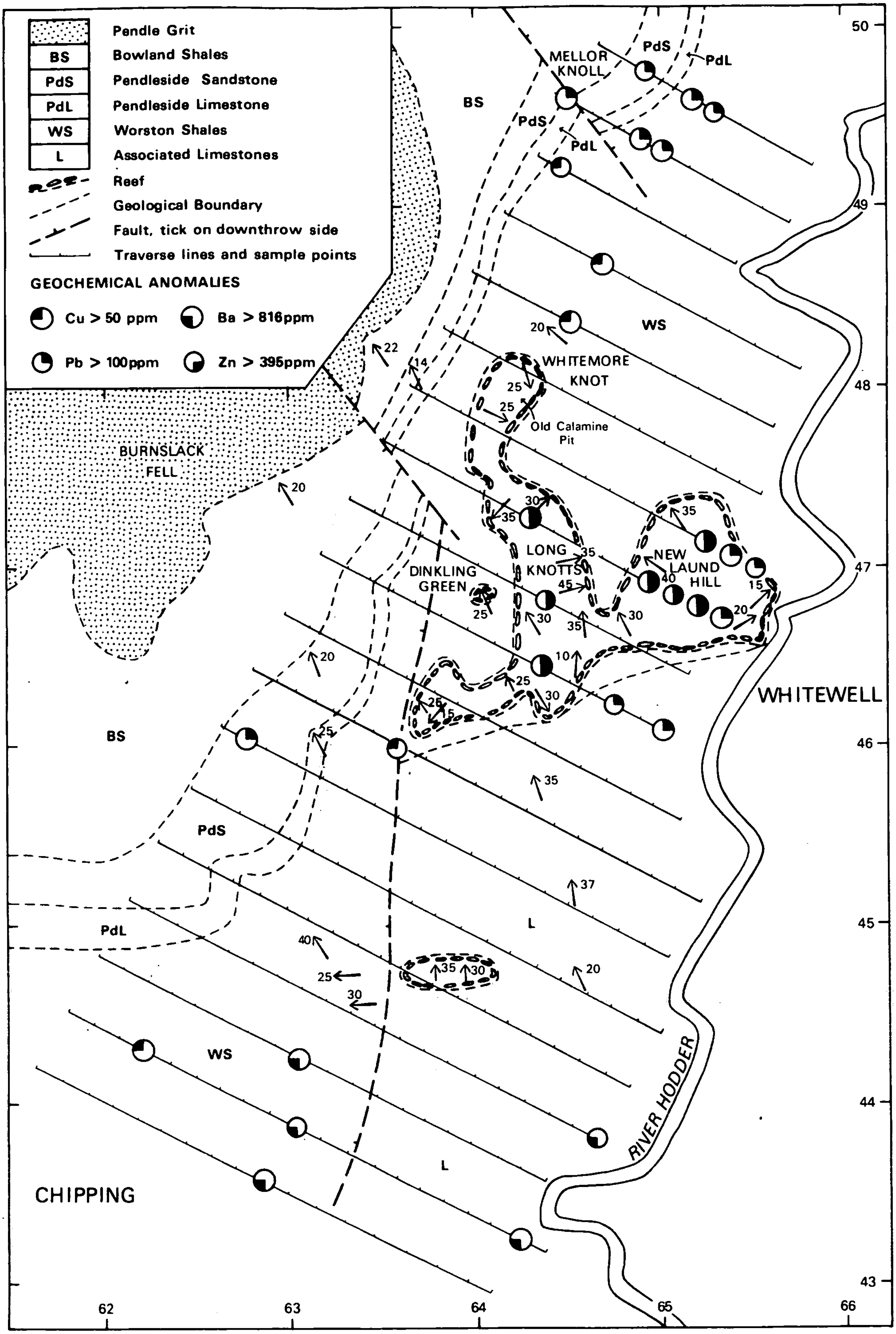


Fig. 74 Geology and geochemical surveys around Dinkling Green

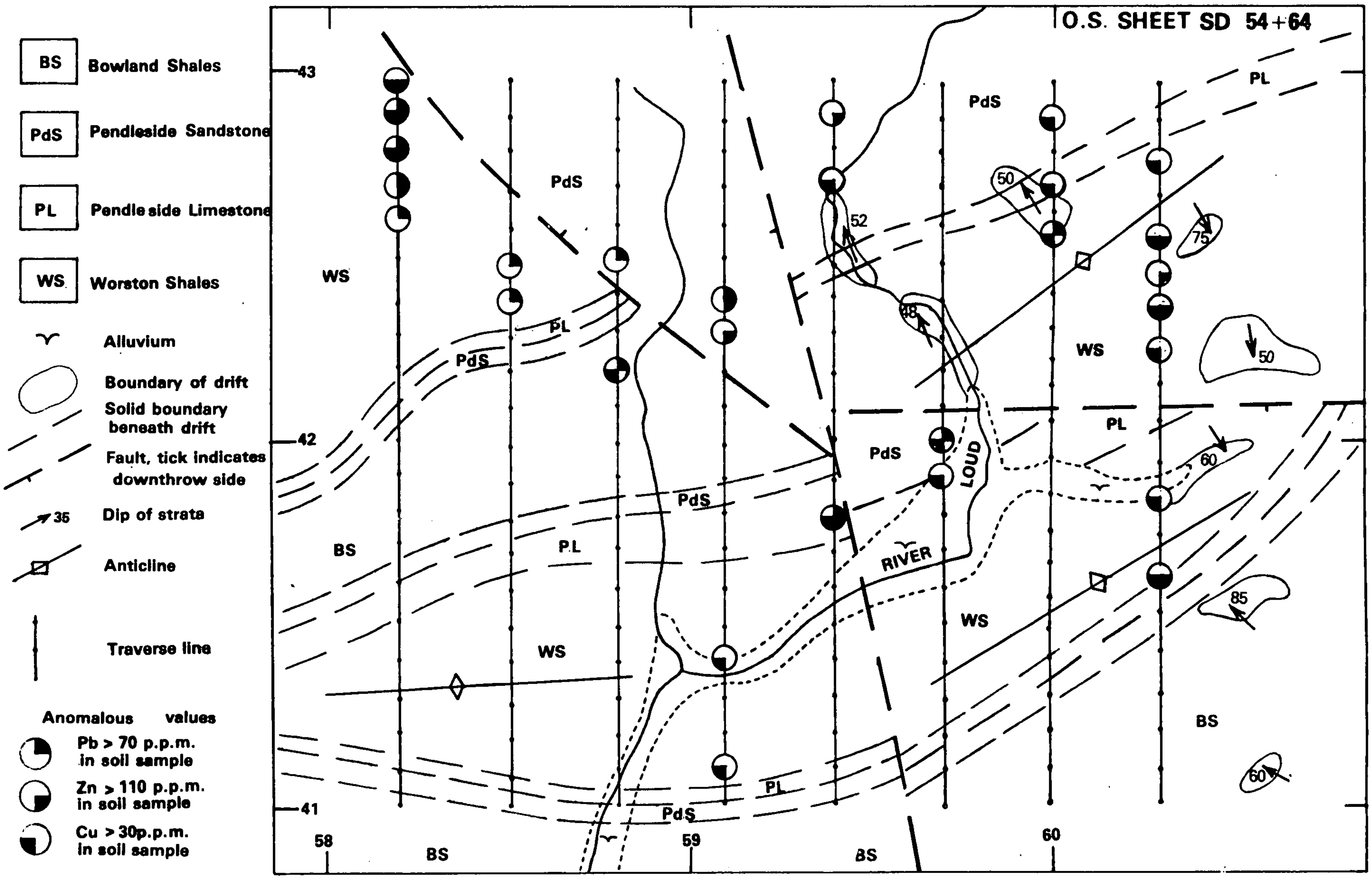


FIG. 75 GEOLOGY AND GEOCHEMICAL SURVEYS AT ELMBRIDGE

anomalous values taken at mean plus two standard deviations ($\bar{x}$ + 2s) does not show a well-defined pattern. The high values do, however, lie close to the probable faults and it is therefore considered likely that the distribution of anomalous values indicates minor sulphide enrichment along them.

The mineralisation is probably entirely Carboniferous in age. There are minerals in the Permo–Triassic rocks in parts of the Irish Sea basin, but these usually occur in structural traps. The lowest rocks in the local Permian sequence are open-textured sandstones which make it unlikely that metalliferous brines were ever trapped beneath the sub-Permian unconformity.

CONCLUSIONS

As a result of the combined geological–geophysical–geochemical reconnaissance surveys, the mineralisation of the Craven Basin has been assessed and a number of areas or sites for detailed work were selected.

The geological surveys provided further information on the known mineralisation within the basin and found previously unrecorded occurrences of sulphides, which prompted follow-up geochemical and geophysical surveys. It is concluded that further significant mineralisation which could give an incentive to exploration work is unlikely to be discovered by simply examining surface outcrops.

The reconnaissance geochemical drainage survey enabled several areas with anomalous levels of Cu, Pb and Zn to be identified, though background values throughout the basin are generally low compared with areas where subsequent exploration work has shown there to be significant mineralisation at shallow depths. Contamination from former mining is quite intense around the old workings and it was not possible in most cases to differentiate worked ground from possible extentions to the known mineralised area. Contamination by other sources was minor, and subsequent ground observations showed that it could be effectively defined by the Sn values. Over much of the area sampled there are thick or extensive superficial deposits, which have certainly affected the geochemical values obtained. These values have also been influenced by sampling parameters and the hydrology of the sediments compared with the geochemistry of the bedrock.

The airborne geophysical survey was carried out primarily in the north of the Craven Basin, along the southern edge of the Askrigg Block and astride the Craven Fault Zone. The survey was intended to ascertain if modern techniques could identify either new occurrences of vein type mineralisation on the Block or provide evidence of Irish-type mineralisation concealed at depth along the Craven Fault System. The results obtained showed no features of obvious economic significance, though the follow-up ground surveys identified some areas of interest. Several radiometrically anomalous reef limestones were also identified.

The electromagnetic data identify, though not completely, the more conductive strata (the Bowland Shales), and also indicate a number of more interesting shorter wavelength anomalies. Of these latter anomalies many were considered to be due to, for example, water pipes and were subsequently proved thus by ground surveys; the difficulty of positively identifying such artificial features from the airborne data makes this preliminary ground survey necessary. Elsewhere ground surveys identified shale-limestone or shale-sandstone contacts as the probable causes of airborne anomalies. Thus after preliminary follow-up of 25 airborne anomalies only five sites were still considered to be of interest, justifying more detailed geophysics at four sites and limited geochemical work at the fifth. In the absence of drilling or extensive geochemical work at any of these sites, the cause of the anomalies remains unidentified, though the existence of vein-type deposits is a possibility at some of them.

In addition to the airborne and related ground surveys, geophysical methods — principally IP — were employed extensively at several other sites in the Craven Basin. The chargeability anomalies observed at these sites are generally weak and are in most cases attributable to shale formations or shale–limestone contacts. The reef limestone areas, with their low background chargeability and high resistivity, lend themselves to the use of the IP method for detection of sulphides at depth, and the absence of anomalies is thus discouraging. However, the predominance of zinc mineralisation, difficult to detect geophysically, is not helpful. Furthermore, the rather restricted extent of the reef limestones, flanked by much more conductive shales, limits the possibilities for the use of large electrode arrays to investigate the reefs systematically at depth.

The experimental seismic lines were only of limited effectiveness, largely because of their short length, though poor reflections were also a problem. The traverses failed to show any positive information on the relationships between the Carboniferous and older strata. The work did provide some data on the nature of the South Craven Fault.

The present study of the Craven Basin has proved a new occurrence of significant sulphide mineralisation at Cow Ark, though it is clear that within the area investigated by drilling, this occurrence is not economic. A number of the other sites that were investigated in detail may have ore-grade mineralisation (in particular in the Settle–Malham area and in extensions of the Bycliffe Vein), but further work would be required to establish this. At many of these sites geophysical or geochemical anomalies were shown to be unrelated to mineralisation and at others the link could not be established. However, the work carried out, together with a comparison with the Carboniferous mineralisation of Eire, indicates that the Craven Basin is still of potential interest.

The area of greatest potential lies along the boundary of the Askrigg Block and Craven Basin, adjacent to the Craven Faults. However, in comparing Eire with this basin it is thought that the most suitable geological environments lie below the presently exposed structural and sedimentary levels towards the base of the Dinantian sequence. Since this base is unproved throughout the basin it is not possible to assess accurately how deeply the best sites lie along the northern margin, but perhaps 300–400 m is a realistic estimate. Within the basin the most promising areas for exploration continue to be associated with the flanks of anticlines, particularly adjacent to large faults. Gravity surveys could be of use in locating such structures. Other potential targets lie in areas that show prominent rapid lateral lithological changes. In Eire much of the mineralisation in the Carboniferous rocks lies close to the Old Red Sandstone. Therefore, deep exploration work should be continued in the Craven Basin area, particularly near the Craven Faults, in analogous geological environments.

REFERENCES

Anderson, F. W. 1928. The lower Carboniferous of the Skyreholme Anticline, Yorkshire. *Geol. Mag.*, Vol. 65, pp. 518–527.

Beales, F. W. and Jackson, S. A. 1966. Precipitation of lead-zinc ores in carbonate reservoirs as illustrated by the Pine Point ore field, Canada. *Trans. Inst. Min. Metall. Sect. B.*, Vol. 75, p. 272.

Black, W. W. 1958. The structure of the Burnsall-Cracoe District and its bearing on the origin of the Cracoe knoll-reefs. *Proc. Yorks. Geol. Soc.*, Vol. 31, pp. 391–414.

Bott, M. H. P. 1961. Geological interpretation of magnetic anomalies over the Alston Block. *J. Geol. Soc. London*, Vol. 97, pp. 481–495.

— 1967. Geophysical investigations of the northern Pennine basement rocks. *Proc. Yorks. Geol. Soc.*, Vol. 36, pp. 139–168.

Burley, A. J., Cornwell, J. D. and Tombs, J. M. C. 1978. Geophysical field techniques for mineral exploration. *Mineral Reconnaissance Programme, Rep. Inst. Geol. Sci.* No. 20.

Cannell, A. E. and Cannell, M. 1966. Ashnott Mine near Newton Bowland, Lancs. *Memoirs of the Northern Cavern and Mine Research Society*, pp. 46–48.

Dunham, K. C. 1952. Fluorspar. *Mem. Geol. Surv. Spec. Rep. Miner. Resources G.B.* Vol. 4 (4th edit.) (London: HMSO) 143 p.

— 1967. Mineralisation in relation to the pre-Carboniferous basement rocks, northern England. *Proc. Yorks. Geol. Soc.*, Vol. 36, pp. 195–201.

— 1974. Granite beneath the Pennines in North Yorkshire. *Proc. Yorks. Geol. Soc.*, Vol. 40, pp. 191–194.

— In preparation. Geology of the Northern Pennine orefield. Vol. 2. *Mem. Geol. Surv.*

— **Beer, K. E., Ellis, R. A., Gallagher, M. J., Nutt, M. J. C. and Webb, B. C.** 1978. United Kingdom. *In* **Bowie, S. H. U., Kvalheim, A. and Haslam, H. W.** (editors), Mineral deposits of Europe: Vol. 1, Northwest Europe. (London: IMM and Min. Soc.) pp. 263–317.

— **and Stubblefield, C. J.** 1945. The stratigraphy, structure and mineralisation of the Greenhow mining field, Yorkshire. *Q. Jl. Geol. Soc. London.* Vol. 100, pp. 209–268.

Dunnington, H. V. 1945. Contemporaneous slumping in the Embsay Limestone Series of the Skipton Anticline. *Proc. Yorks. Geol. Soc.*, Vol. 25, pp. 239–247.

Earp, J. R. and others. 1961. Geology of the country around Clitheroe and Nelson (Explanation of sheet 68). *Mem. Geol. Surv.*

Eddy, J. R. 1883. On the lead veins in the neighbourhood of Skipton. *Proc. Yorks. Geol. Polytech. Soc.*, Vol. 8, pp. 63–69.

Falcon, N. F. and Kent, P. E. 1960. Geological results of petroleum exploration in Britain, 1945–57. *Mem. Geol. Soc. London.* No. 2, 56 p.

Fraser, D. C. 1969. Contouring of VLF-EM data *Geophysics*, Vol. 34, pp. 958–967.

Geological Survey of Great Britain. 1965. Aeromagnetic map of Great Britain, 1:625 000, Sheet 2. (Southampton: Ordnance Survey).

Hudson, R. G. S. 1933. The scenery and geology of northwest Yorkshire. *In* The Geology oif the Yorkshire Dales. *Proc. Geol. Assoc.*, Vol. 44, pp. 227–269.

— 1937. The Lower Carboniferous of Carnforth. *Rep. Br. Assoc.* 1936 (Blackpool), pp.344–345.

— 1944. A pre-Namurian fault scarp at Malham. *Proc. Leeds Phil. Lit. Soc.*, Vol. 4, pp. 226–232.

Ingham, J. K. and Richards, R. B. 1974. Lower Palaeozoic rocks. *In* **Rayner, D. H. and Hemingway, S. E.** (editors), Geology and mineral resources of Yorkshire. *Yorks. Geol. Soc.*, pp. 29–44.

Institute of Geological Sciences. 1978. 1:250 000 Series Bouguer gravity anomaly map (Provisional edition). Liverpool Bay sheet, 53°N 04°W (London: Institute of Geological Sciences).

Miller, S. and Grayson, R. F. 1972. Origin and structure of the Lower Visean reef limestones near Clitheroe, Lancashire. *Proc. Yorks. Geol. Soc.*, Vol. 38, pp. 607–638.

Moseley, F. 1962. The structure of the south-western part of the Sykes Anticline, Bowland, West Yorkshire. *Proc. Yorks. Geol. Soc.*, Vol. 33, pp. 287–314.

Myers, J. O. and Wardell, J. 1967. The gravity anomalies of the Askrigg Block south of Wensleydale. *Proc. Yorks. Geol. Soc.*, Vol. 36, pp. 169–173.

Parkinson, D. 1935. The geology and topography of the limestone knolls in Bolland (Bowland), Lancs and Yorks. *Proc. Geol. Assoc.*, Vol. 46, pp. 97–120.

— 1936. The Carboniferous succession in the Slaidburn district, Yorkshire. *Q. Jl. Geol. Soc. London.* Vol. 92, pp. 294–321.

Raistrick, A. 1954. The calamine mines, Malham, Yorks. *Proc. Univ. Durham Phil. Soc.*, Vol. 11, pp. 125–130.

— 1973. Lead mining and the Mid-Pennines. *D. Bradford Barton Ltd.*, pp. 158–162.

Schultz, R. W. 1971. Mineral exploration practice in Ireland. *Trans. Inst. Min. Metall. Sect. B*, Vol. 80, pp. 238–258.

Wager, L. R. 1931. Jointing in the Great Scar Limestone of Craven and its relation to the tectonics of the area. *Q. Jl. Geol. Soc. London*, Vol. 87, pp. 392–424.

Whetton, J. T., Myers, J. O. and Watson, I. J. 1956. A gravity meter survey in the Craven district of north-west Yorkshire. *Proc. Yorks. Geol. Soc.*, Vol. 30, pp. 259–287.

Williams, C. E. and McArdle, P. 1978. Ireland. *In* **Bowie, S. H. U., Kvalheim, A. and Haslam, H. W.** (editors), *Mineral deposits of Europe: Vol. 1, Northwest Europe.* (London: IMM and Min. Soc.) p. 319–345.

Williamson, I. A. 1959. The Skeleron or Yorks and Lancaster lead mines. *Jl. of Past and Present Min. Stud. Assoc. Wigan and District Mining and Technical College.* No. 1, pp. 46–50.

Wilson, A. A. and Cornwell, J. D. 1982. The Institute of Geological Sciences borehole at Beckermonds Scar, north Yorkshire. *Proc. Yorks. Geol Soc.*, Vol. 44, pp. 59–88.

FIGURE 10

BAND-PASS FILTER

TIME(MS)	FREQUENCY(HZ)
4	27-30-100-120
370	27-30-100-120
500	22-25-80-100

BLANKING

LINE A SP 36-120

TRACE	TIME[MS]	DISTANCE[M]
24	100	740
22	160	300
1	380	700

VELOCITY CHARTS

THE VALUES LISTED BELOW ARE DERIVED FROM RMS VELOCITIES OBTAINED FROM THE MULTI-VELOCITY STACK [MVS] ANALYSES. VALUES ARE CALCULATED USING THE ASSUMPTIONS OF STRAIGHT PATH TRAVEL IN HORIZONTAL LAYERS WITH SNELL'S LAW APPLIED AT EACH INTERFACE. VELOCITIES ARE IN METRES PER SECOND AND INTERPOLATED BETWEEN DISPLAYED FUNCTIONS. TIMES ARE TWO WAY AND IN MILLISECONDS. DELTA-T VALUES ARE RELATED TO DISTANCES OF 700 METRES

LINE A SP 36

TIME [MS]	DELTA T	INTERVAL VELOCITY	R.M.S. VELOCITY	DEPTH [M]
1	228	3100	3100	1
100	137	3302	3300	164
230	70	4007	3700	425
360	41	4530	4000	720
420	32	5750	4250	892
500	24	5812	4500	1125
1000	7	7500	6000	3000

LINE A SP 50

TIME [MS]	DELTA T	INTERVAL VELOCITY	R.M.S. VELOCITY	DEPTH [M]
1	228	3100	3100	1
90	146	3251	3250	146
270	60	4000	3750	506
360	41	4750	4000	720
430	32	5228	4200	902
500	25	5985	4450	1112
1000	7	7550	6000	3000

LINE A SP 75

TIME [MS]	DELTA T	INTERVAL VELOCITY	R.M.S. VELOCITY	DEPTH [M]
1	228	3100	3100	1
100	116	3706	3700	184
240	59	4214	4000	480
300	42	5500	4300	644
400	28	5900	4700	939
580	17	5666	5000	1450
1000	7	7380	6000	3000

LINE A SP 87

TIME [MS]	DELTA T	INTERVAL VELOCITY	R.M.S. VELOCITY	DEPTH [M]
1	228	3100	3100	1
110	109	3755	3750	206
220	63	4250	4000	440
280	41	6333	4500	630
450	22	5823	5000	1125
550	15	7750	5500	1512
1000	7	6611	6000	3000

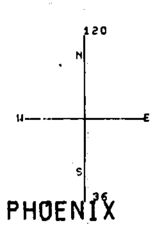
LINE A SP 100

TIME [MS]	DELTA T	INTERVAL VELOCITY	R.M.S. VELOCITY	DEPTH [M]
1	228	3100	3100	1
100	108	3908	3300	194
200	59	4700	4300	429
360	30	5200	4700	845
450	22	6200	5000	1125
530	16	7650	5400	1430
1000	7	6676	6000	3000

I.G.S.	LINE A SHOT POINTS 36-120

RECORDED BY I.G.S.
PROCESSED BY SEISMOGRAPH SERVICE (ENGLAND) LIMITED
PROSPECT CRAVEN
SPECIAL REMARKS
MIGRATED SECTION

SLOPING DATUM CORRECTED TO HORIZONTAL DATUM 250 METRES ABOVE M.S.L., USING ELEVATION VELOCITY 3100 METRES /SEC.

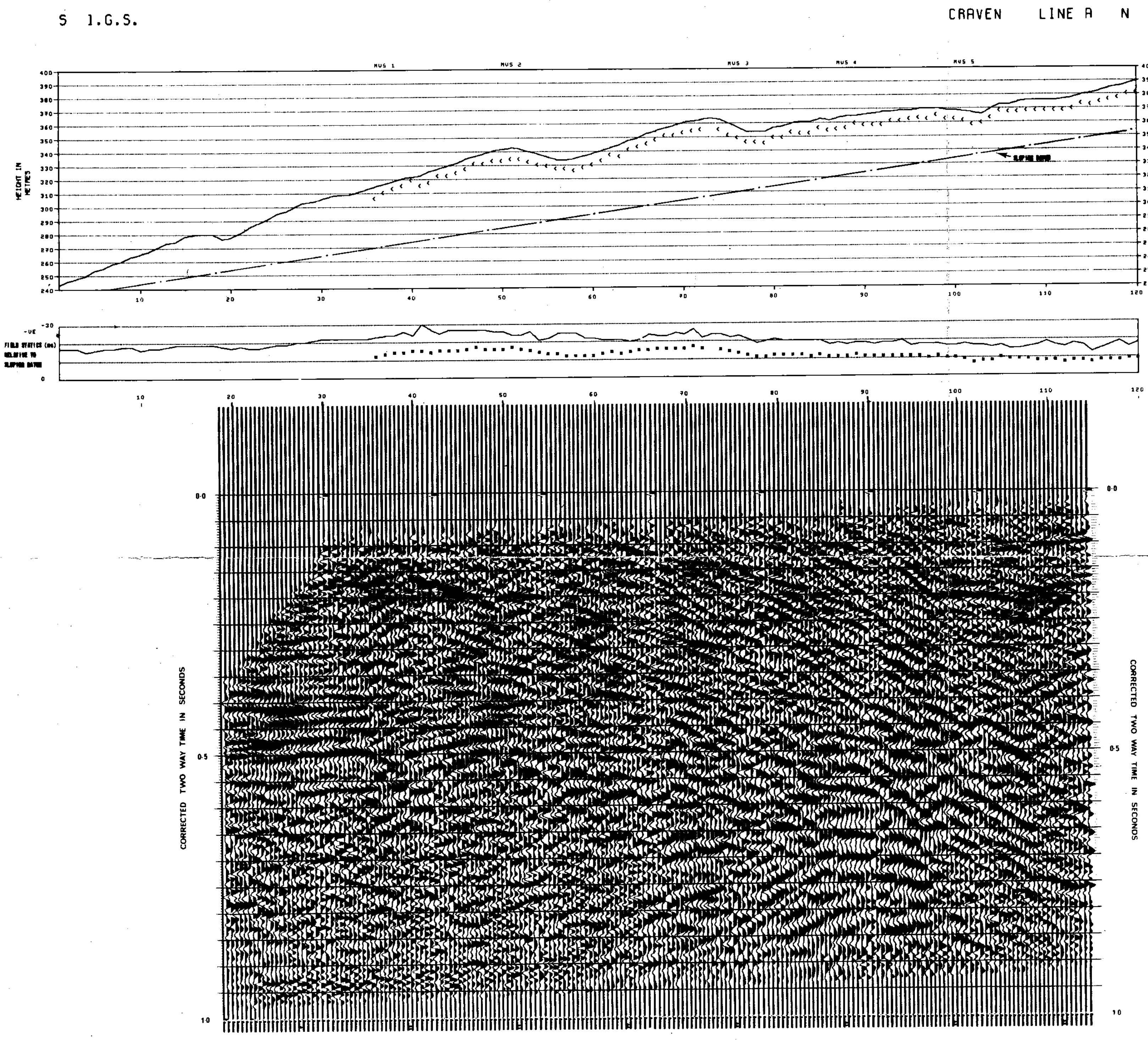


PROCESSED THROUGH PHOENIX

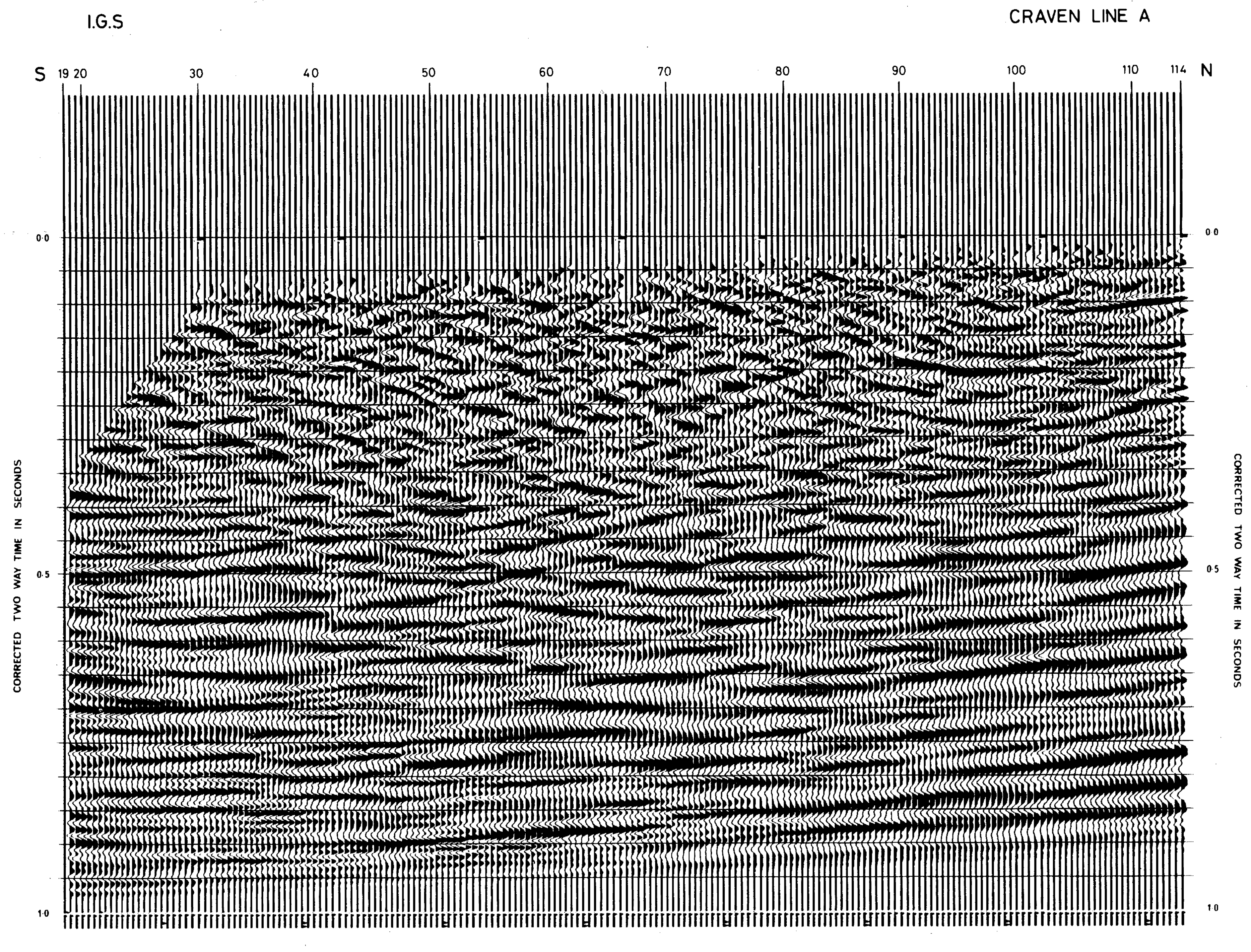
RECORDING PARAMETERS	RECORDING GEOMETRY
CABLE 0- 240 -700 GEOPHONE INTERVAL 20M SHOT INTERVAL 20M FILTER OUT DATE SHOT 11-22AUGUST 1975 DATA SOURCE SERCEL 338 24 T SAMPLING INTERVAL 1 MS RECORD LENGTH 1 SECOND	SHOT POINT PATTERN SINGLE HOLE GEOPHONE PATTREN 6 GEOPHONES PER STATION 4M APART IN LINE NOMINAL COVER 12 FOLD

SEQUENCE	PROCESSING PARAMETERS		
1 PREPARATION	BINARY GAIN RECOVERY AND EDIT		
2 FILTER	15-20-100-120 HZ		
3 DECONVOLUTION	OPERATOR 50MS WINDOW 100-500 MS		
4 CORRECTION	WITH AUTOMATIC STATICS WINDOW 100-500 MS		
5 STACK 12 FOLD			
6 BAND PASS FILTER	TIME VARIANT		
7 TV EQUALISATION	100MS WINDOW		
8 MIGRATION	120 TRACE SCAN		
DISPLAY	HORIZ 1:3700 VERT 12 INS TO 1 SEC	SECURITY NO. 05700/3867 MIG SEPTEMBER 1975	PROCESSED PHOENIX LONDON

a) LINE A, PROCESSING DATA

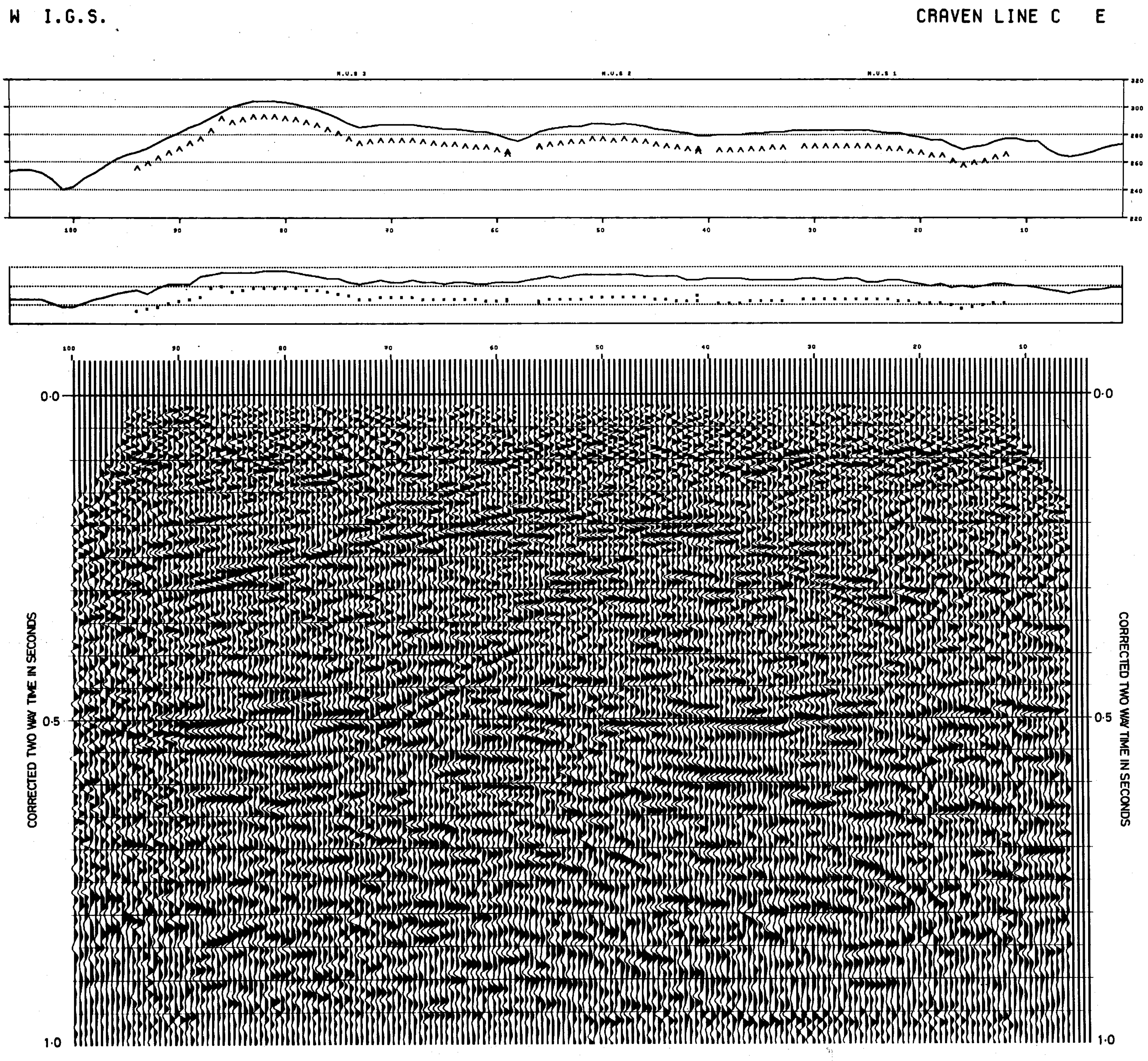


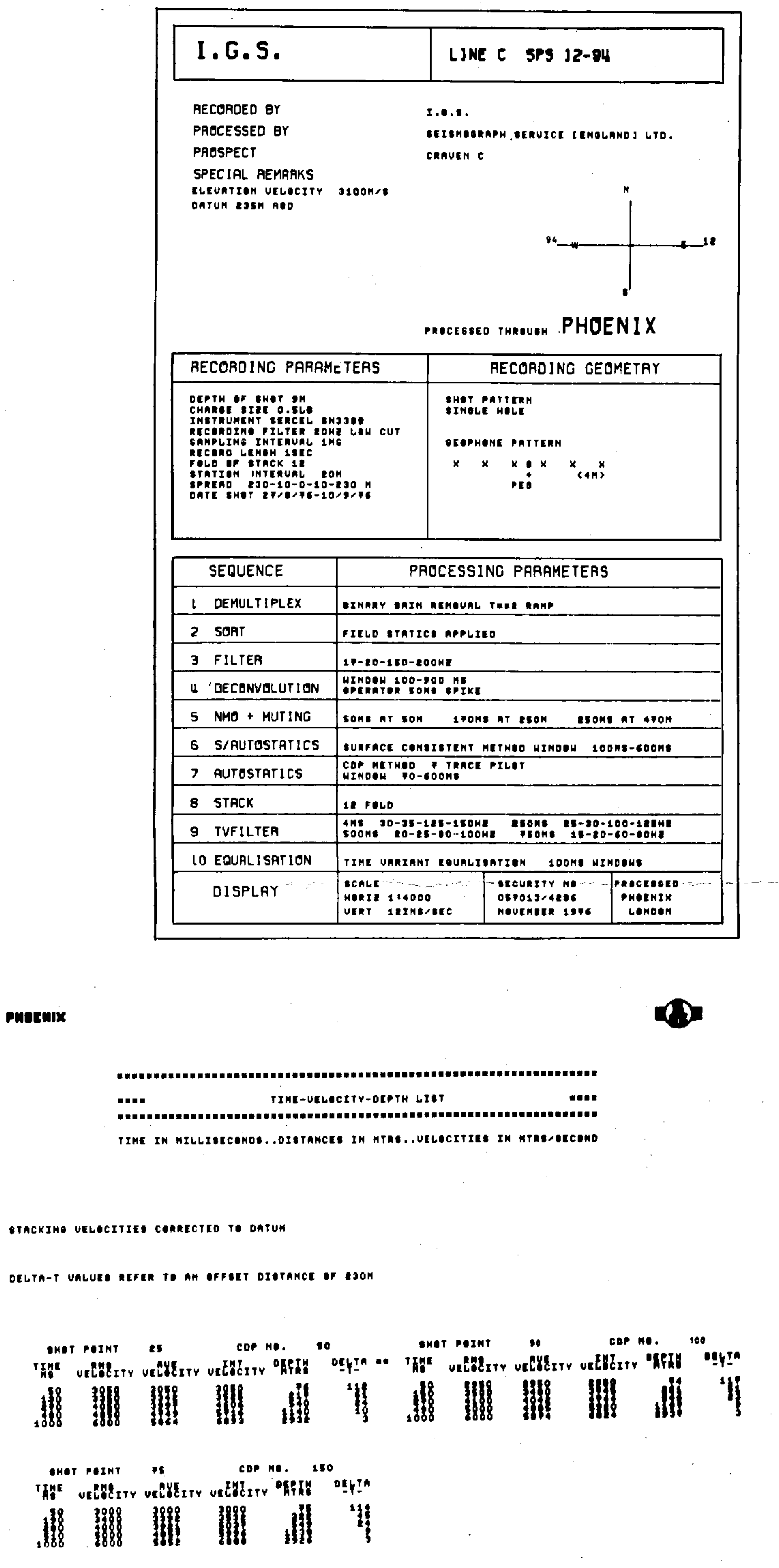
b) LINE A, TIME SECTION



WF/8R/83/66.

c) LINE A, MIGRATED TIME SECTION





I.G.S.	LINE C SPS 12-94

RECORDED BY I.G.S.
PROCESSED BY SEISMOGRAPH SERVICE (ENGLAND) LTD.
PROSPECT CRAVEN C
SPECIAL REMARKS
ELEVATION VELOCITY 3100M/S
DATUM 235M AOD

PROCESSED THROUGH PHOENIX

RECORDING PARAMETERS	RECORDING GEOMETRY
DEPTH OF SHOT 9M CHARGE SIZE 0.5LB INSTRUMENT SERCEL SN338B RECORDING FILTER 20HZ LOW CUT SAMPLING INTERVAL 1MS RECORD LENGH 1SEC FOLD OF STACK 12 STATION INTERVAL 20M SPREAD 230-10-0-10-230 M DATE SHOT 27/8/76-10/9/76	SHOT PATTERN SINGLE HOLE GEOPHONE PATTERN X X X S X X X + (4M) PEG

SEQUENCE	PROCESSING PARAMETERS		
1 DEMULTIPLEX	BINARY GAIN REMOVAL T**2 RAMP		
2 SORT	FIELD STATICS APPLIED		
3 FILTER	17-20-150-200HZ		
4 DECONVOLUTION	WINDOW 100-900 MS OPERATOR 50MS SPIKE		
5 NMO + MUTING	50MS AT 50M 170MS AT 250M 250MS AT 470M		
6 S/AUTOSTATICS	SURFACE CONSISTENT METHOD WINDOW 100MS-600MS		
7 AUTOSTATICS	CDP METHOD 7 TRACE PILOT WINDOW 70-600MS		
8 STACK	12 FOLD		
9 TVFILTER	4MS 30-35-125-150HZ 250MS 25-30-100-125HZ 500MS 20-25-80-100HZ 750MS 15-20-60-80HZ		
10 EQUALISATION	TIME VARIANT EQUALISATION 100MS WINDOWS		
DISPLAY	SCALE HORIZ 1:4000 VERT 12INS/SEC	SECURITY NO 057013/4286 NOVEMBER 1976	PROCESSED PHOENIX LONDON

PHOENIX

TIME-VELOCITY-DEPTH LIST

TIME IN MILLISECONDS..DISTANCES IN MTRS..VELOCITIES IN MTRS/SECOND

STACKING VELOCITIES CORRECTED TO DATUM

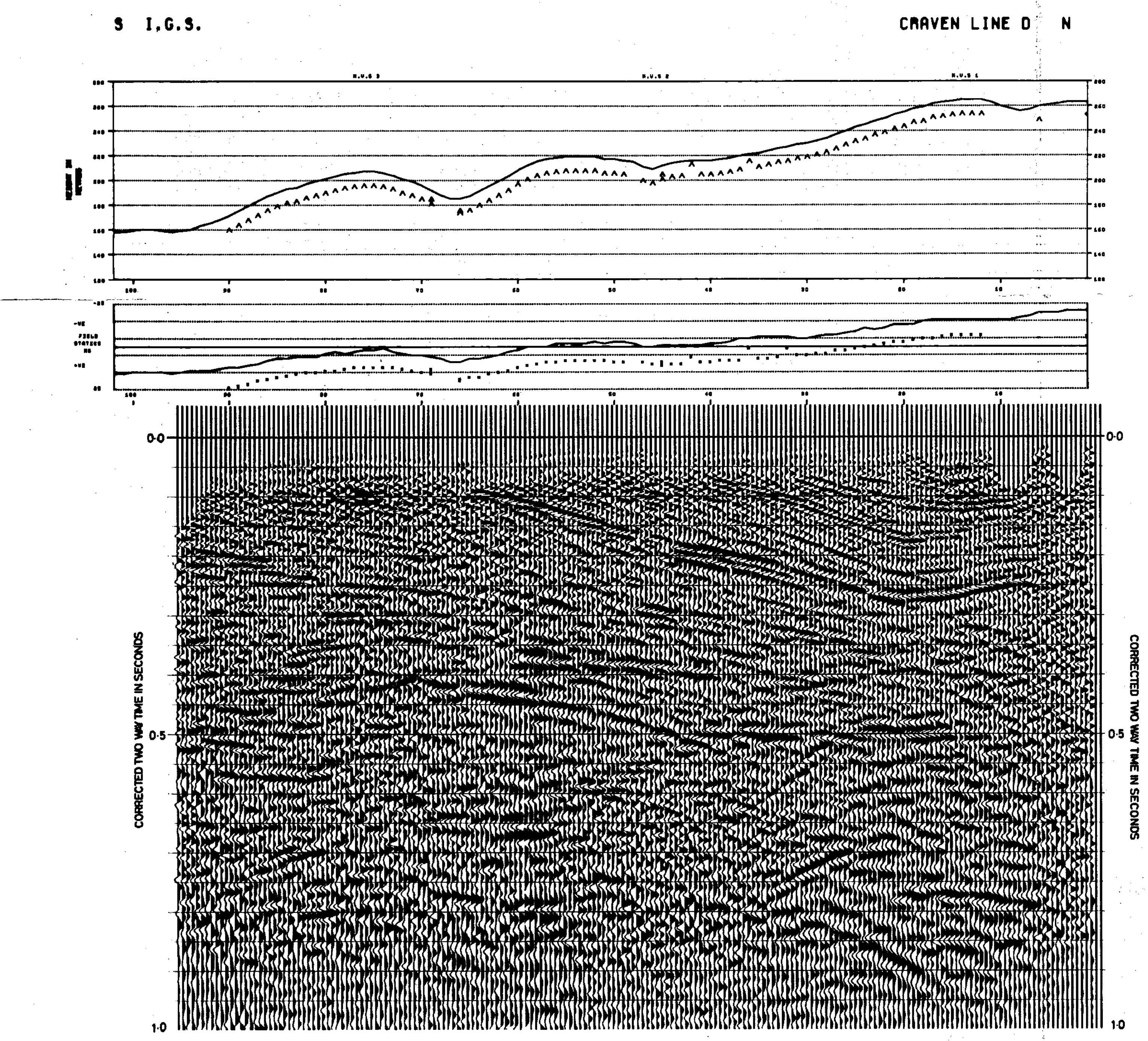
DELTA-T VALUES REFER TO AN OFFSET DISTANCE OF 230M

SHOT POINT 25 CDP NO. 50
TIME MS RMS VELOCITY AVE VELOCITY INT VELOCITY DEPTH MTRS DELTA -T-

SHOT POINT 50 CDP NO. 100
TIME MS RMS VELOCITY AVE VELOCITY INT VELOCITY DEPTH MTRS DELTA -T-

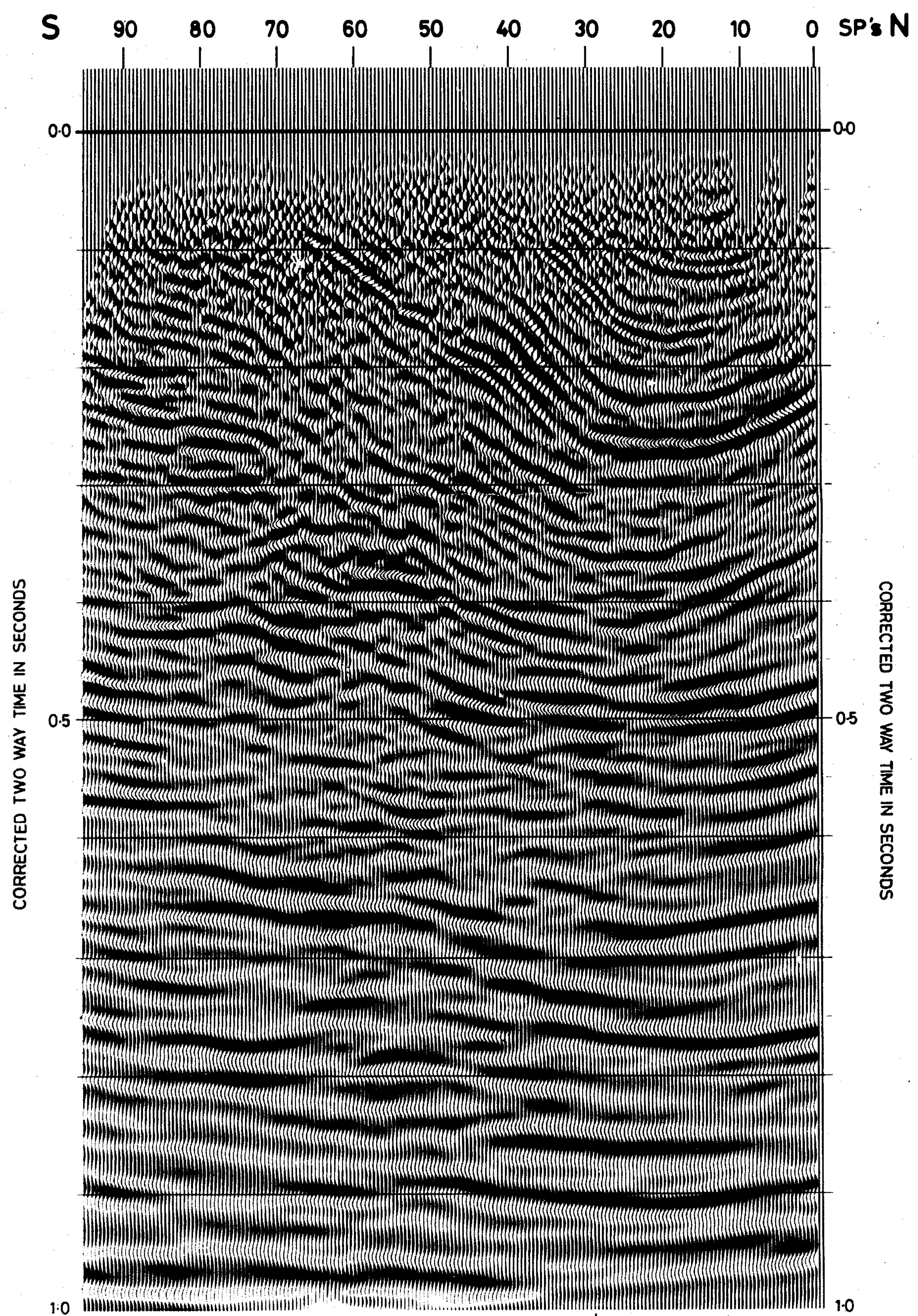
SHOT POINT 75 CDP NO. 150
TIME MS RMS VELOCITY AVE VELOCITY INT VELOCITY DEPTH MTRS DELTA -T-

a) LINE C, TIME SECTION AND PROCESSING DATA



b) LINE D, TIME SECTION

FIGURE 12



c) LINE D, MIGRATED TIME SECTION

WF/8R/83/66

Fig.3 CRAVEN BASIN: DRAINAGE SURVEY, ANOMALOUS STREAM SAMPLES AND AREAS OF FURTHER INVESTIGATION

WF/8R/83/66

FIGURE 11

a) LINE B, PROCESSING DATA

VELOCITY CHARTS

THE VALUES LISTED BELOW ARE DERIVED FROM RMS VELOCITIES OBTAINED FROM THE MULTI-VELOCITY STACK (MVS) ANALYSES. VALUES ARE CALCULATED USING THE ASSUMPTIONS OF STRAIGHT PATH TRAVEL IN HORIZONTAL LAYERS WITH SNELL'S LAW APPLIED AT EACH INTERFACE. VELOCITIES ARE IN METRES PER SECOND AND INTERPOLATED BETWEEN DISPLAY FUNCTIONS. TIMES ARE TWO WAY AND IN MILLISECONDS. DELTA-T VALUES ARE RELATED TO DISTANCES OF 700 METRES.

LINE B SP 30

TIME (MS)	DELTA T	INTERVAL VELOCITY	R.M.S VELOCITY	DEPTH (M)
4	226	3050	3050	6
60	166	3232	3220	96
175	89	3722	3550	310
250	62	4216	3750	468
450	23	6067	4780	1075
525	19	5620	4900	1286
1000	7	7215	6000	3000

LINE B SP 48

TIME (MS)	DELTA T	INTERVAL VELOCITY	R.M.S VELOCITY	DEPTH (M)
4	222	3100	3100	6
120	114	3487	3475	208
200	77	3912	3650	364
300	53	4025	3775	566
410	38	4240	3900	799
480	29	5614	4150	995
1000	7	7707	6000	3000

LINE B SP 66

TIME (MS)	DELTA T	INTERVAL VELOCITY	R.M.S VELOCITY	DEPTH (M)
4	229	3000	3000	6
110	140	3129	3125	171
200	94	3380	3240	323
290	69	3433	3300	478
380	48	4440	3570	678
450	33	6334	4000	900
1000	7	7636	6000	3000

LINE B SP 96

TIME (MS)	DELTA T	INTERVAL VELOCITY	R.M.S. VELOCITY	DEPTH (M)
4	233	2950	2950	5
100	154	3002	3000	150
200	99	3290	3145	314
260	72	4105	3385	440
310	56	4718	3600	557
530	28	4563	4000	1060
1000	7	8255	6000	3000

LINE B SP 120

TIME (MS)	DELTA T	INTERVAL VELOCITY	R.M.S. VELOCITY	DEPTH (M)
4	222	3100	3100	6
80	147	3310	3300	131
200	84	3591	3475	347
275	59	4300	3700	508
300	50	5920	3885	582
420	33	4707	4120	865
1000	7	7361	6000	3000

BLANKING

TRACE	TIME(MS)	DISTANCE(M)
	45	80
24	115	240
14	200	440
1	450	700

BAND-PASS FILTER

TIME(MS)	FREQUENCY(HZ)
4	27-30-100-120
370	27-30-100-120
500	22-25-80-100

I.G.S.	LINE B SHOT POINTS 1-152

RECORDED BY	I.G.S.
PROCESSED BY	SEISMOGRAPH SERVICE (ENGLAND) LIMITED
PROSPECT	CRAVEN

SPECIAL REMARKS

CORRECTION DATUM 235M ABOVE M.S.L.

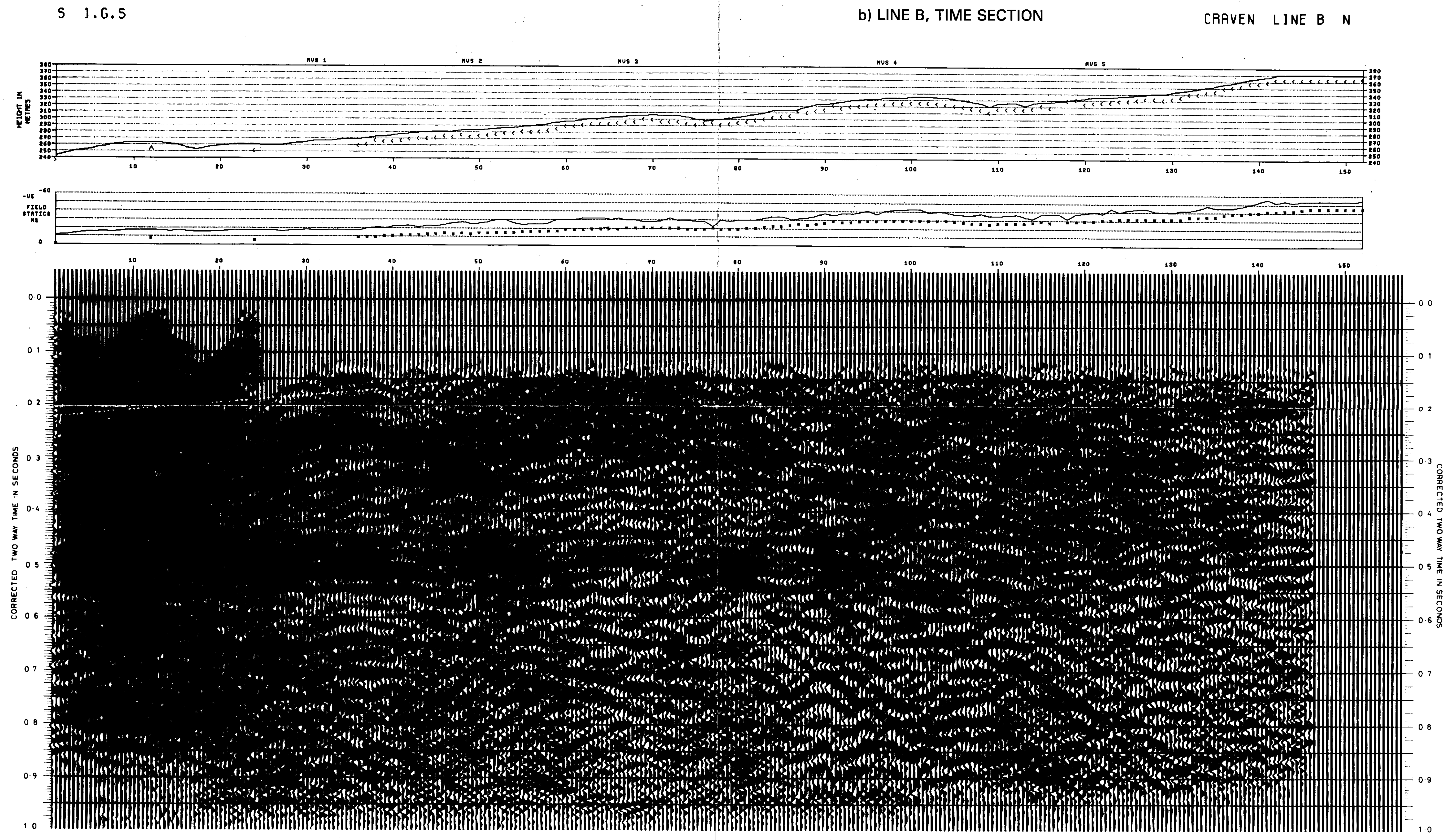
STACK WITH AUTOMATIC STATICS FILTERED

PROCESSED THROUGH PHOENIX

RECORDING PARAMETERS	RECORDING GEOMETRY
CABLE 0-240-700M GEOPHONE INTERVAL 20M FILTER 25-250 HZ DATE SHOT 12-26 SEPTEMBER 1975 DATA SOURCE SERCEL 338 24 T SAMPLING INTERVAL 1 MS RECORD LENGTH 1 SECOND	SHOT POINT PATTERN SINGLE HOLE GEOPHONE PATTERN 6 GEOPHONES PER STATION 4 METRES APART IN LINE NOMINAL COVER 12 FOLD

SEQUENCE	PROCESSING PARAMETERS		
1 PREPARATION	BINARY GAIN RECOVERY AND EDIT		
2 FILTER	15-20-100-120 HZ		
3 DECONVOLUTION	OPERATOR 50MS WINDOW NEAR 100-500 FAR 240-640MS		
4 CORRECTION	WITH AUTOMATIC STATICS WINDOW 200-600 MS		
5 STACK	12 FOLD		
6 BANDPASS FILTER	TIME VARIANT		
7 TV EQUALISATION	100MS WINDOW		
DISPLAY	HORIZ 1:3700 VERT 12INS TO 1 SEC	SECURITY NO 057009/3884FIL OCTOBER 1975	PROCESSED LONDON PHOENIX

b) LINE B, TIME SECTION



c) LINE B, MIGRATED TIME SECTION

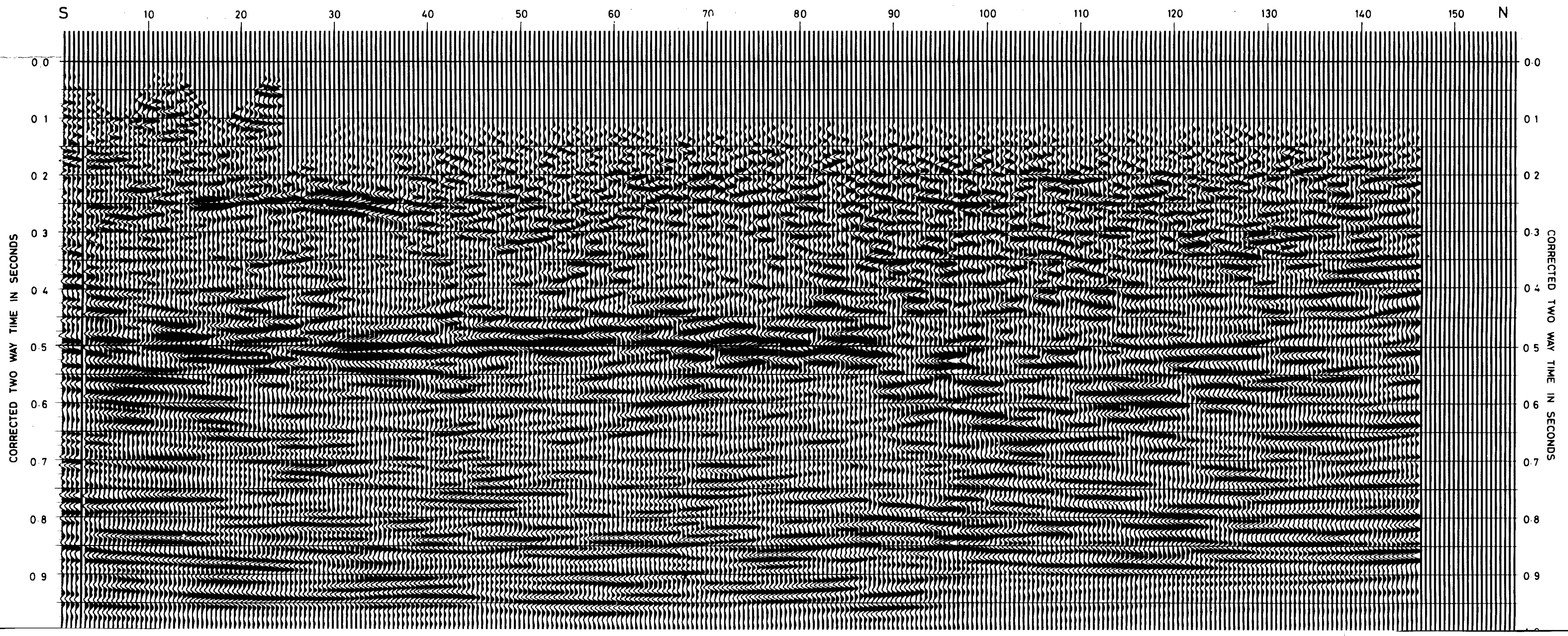
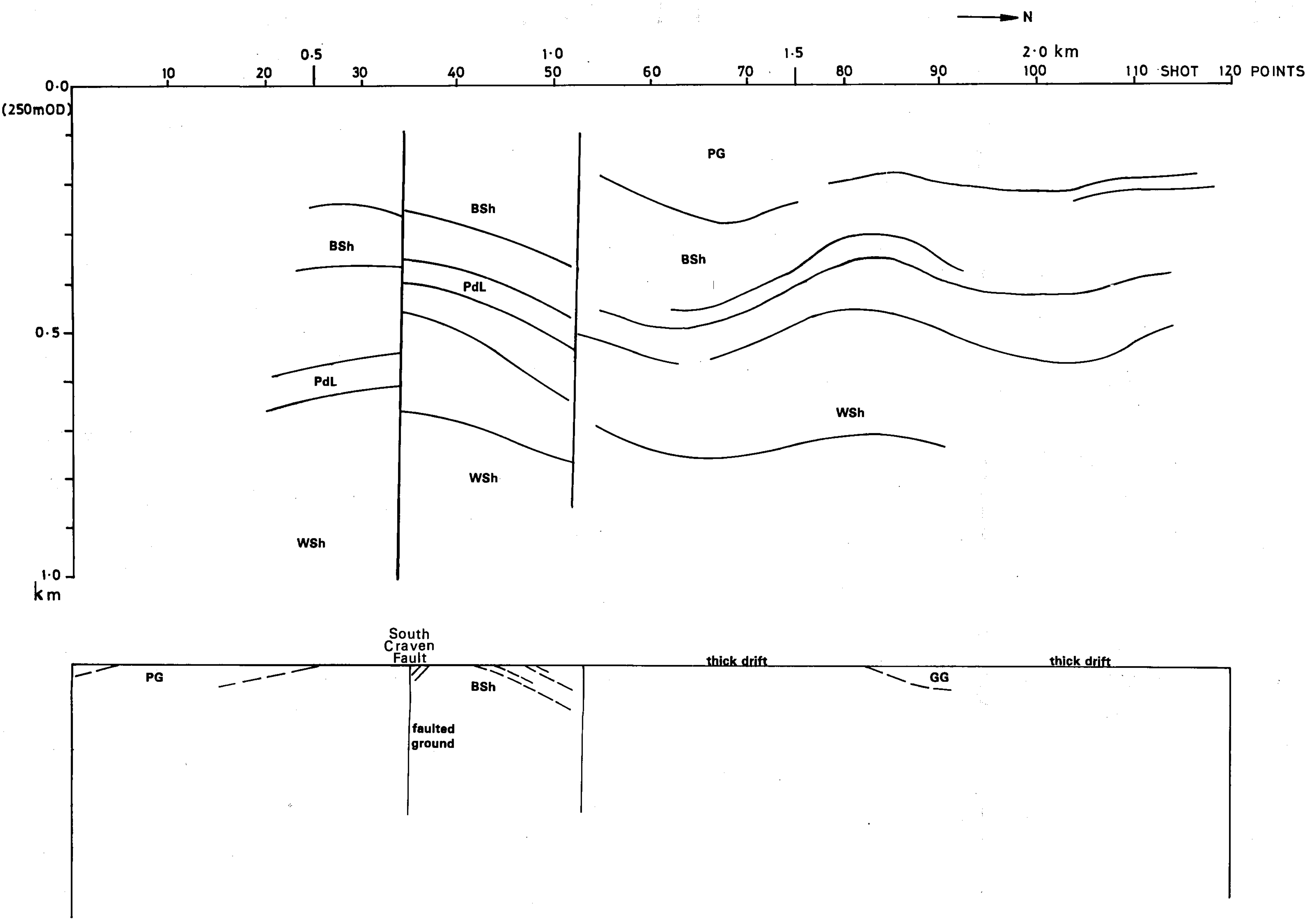
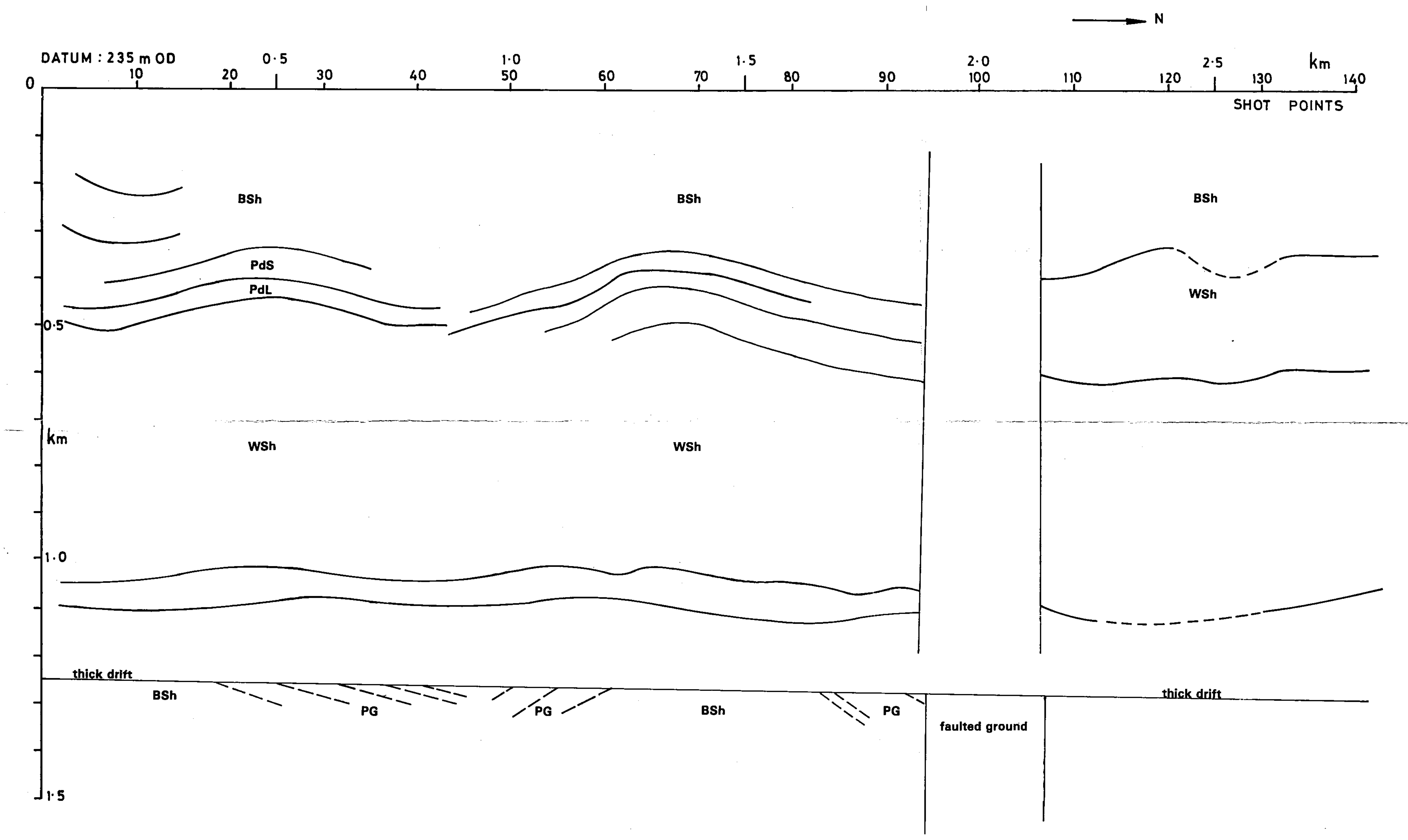


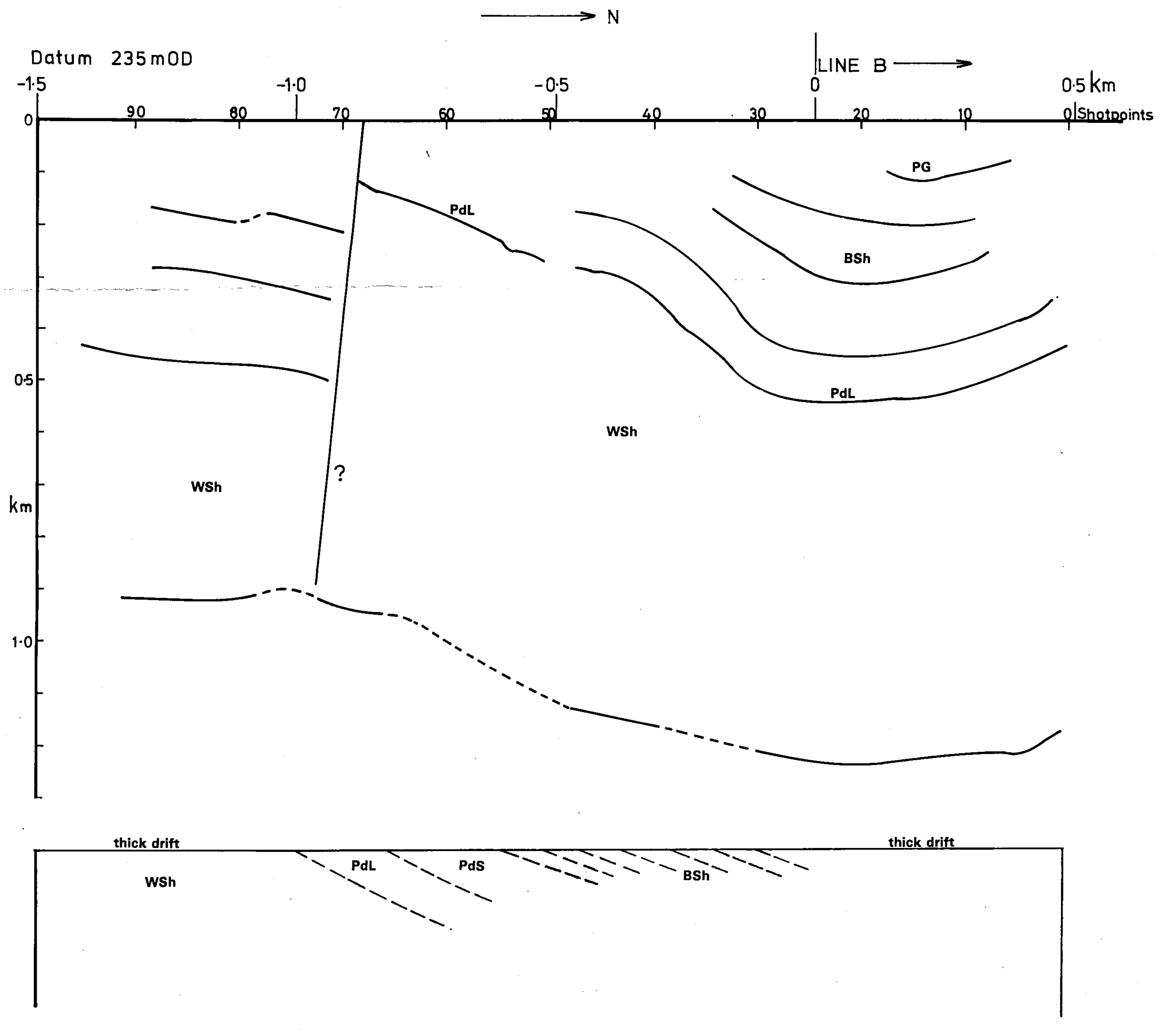
FIGURE 14



a) LINE A, REFLECTION DEPTH CONVERSION



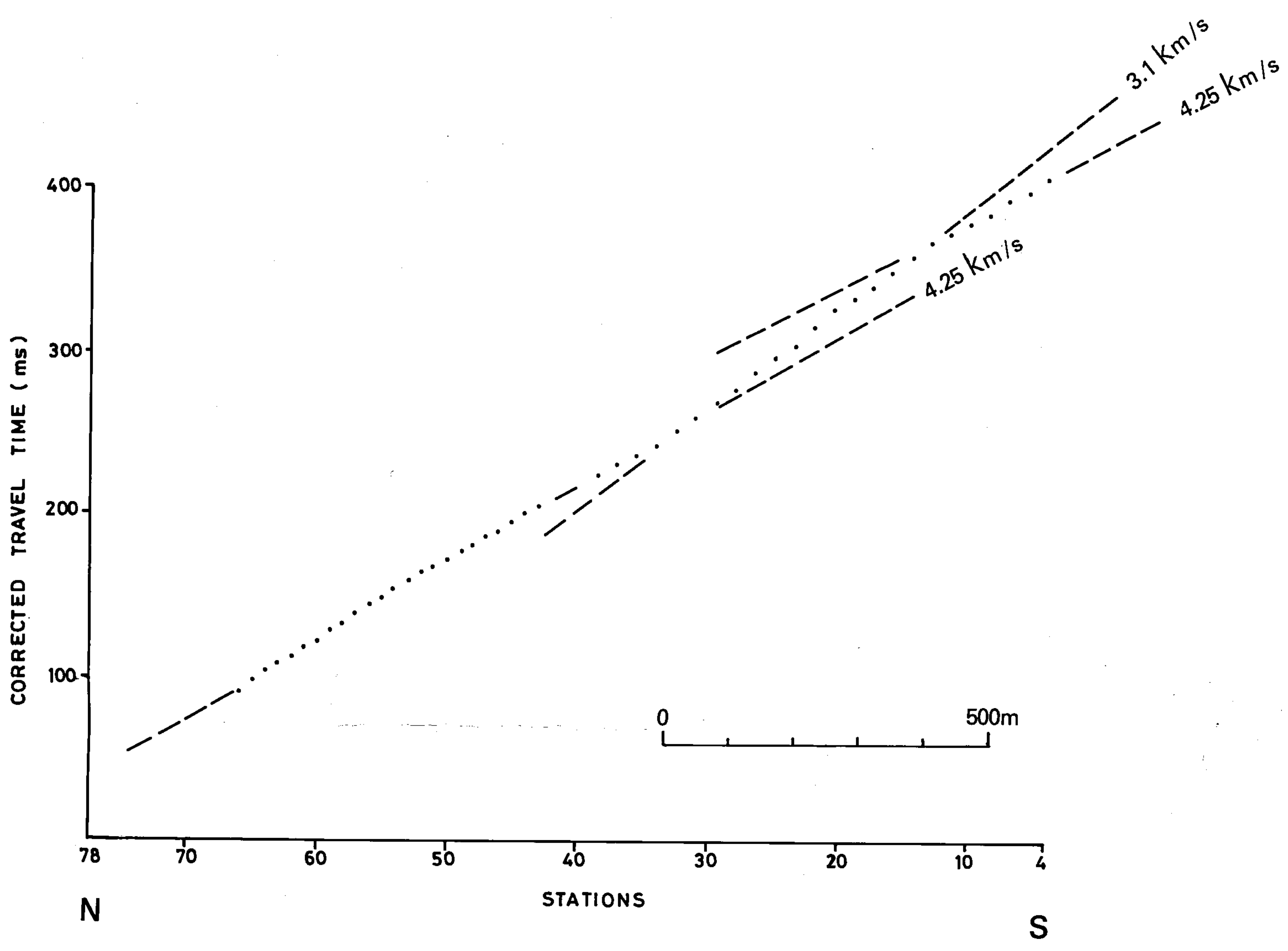
b) LINE B, REFLECTION DEPTH CONVERSION



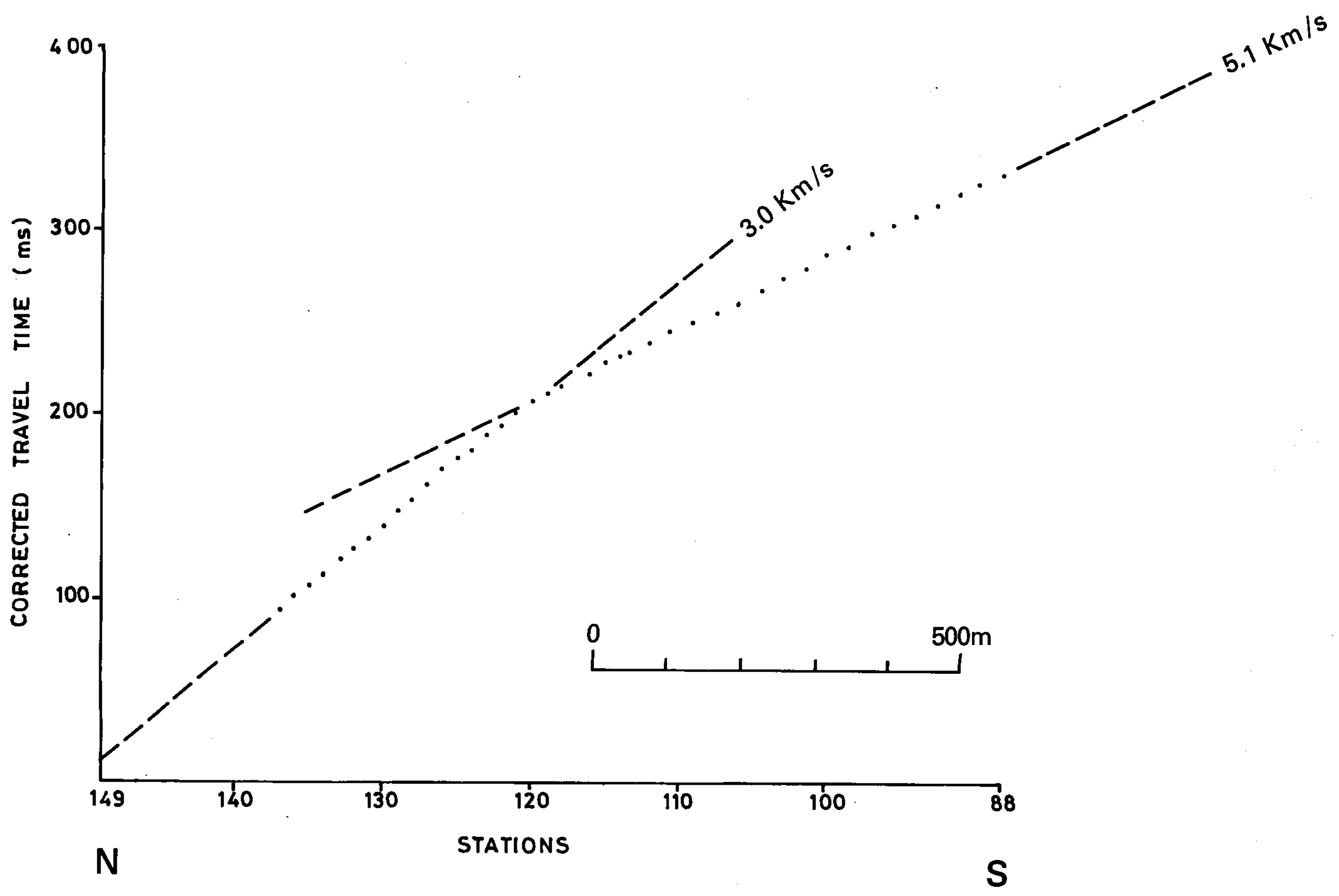
c) LINE D, REFLECTION DEPTH CONVERSION

WF/8R/83/66

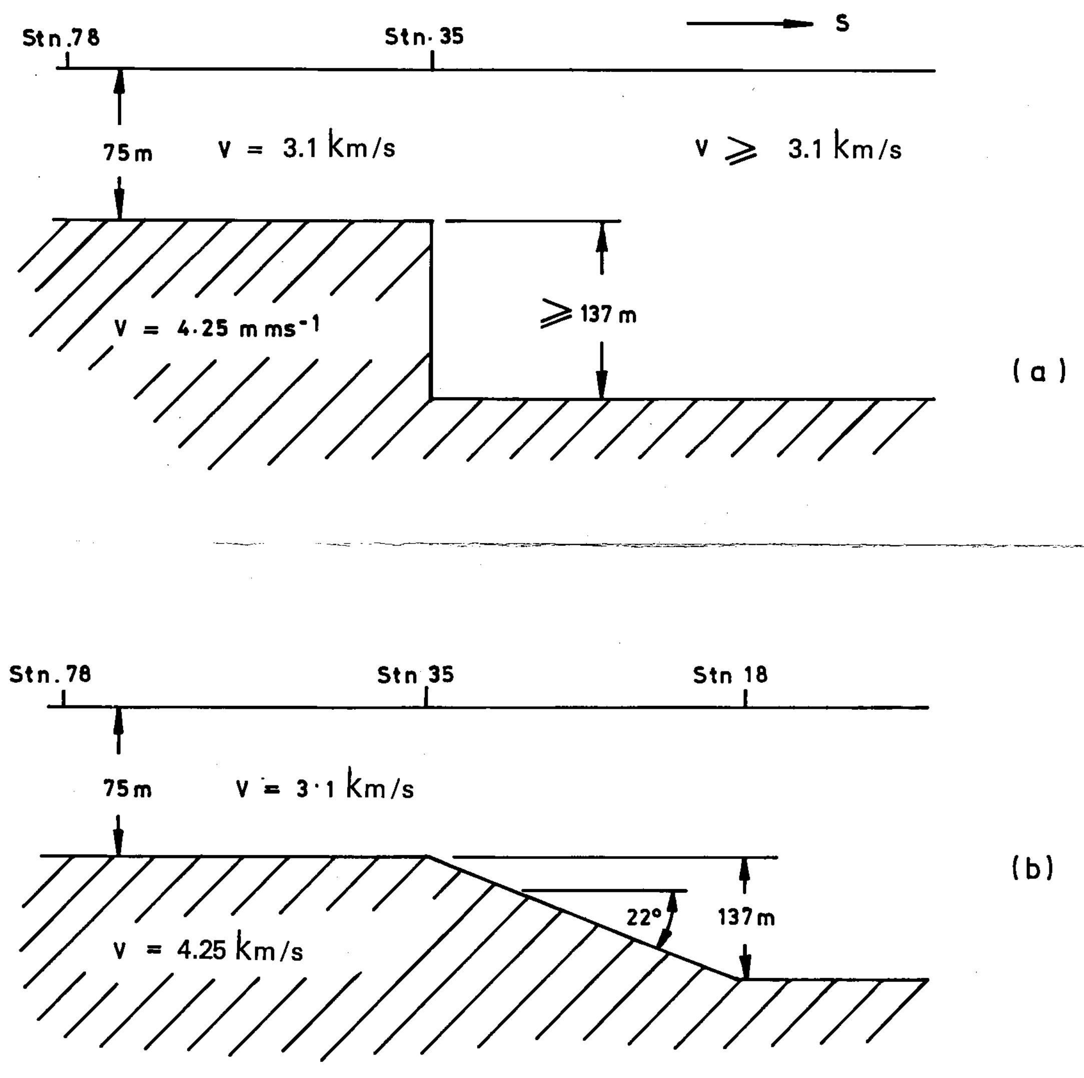
FIGURE 15



a) LINE A, REFRACTION DATA

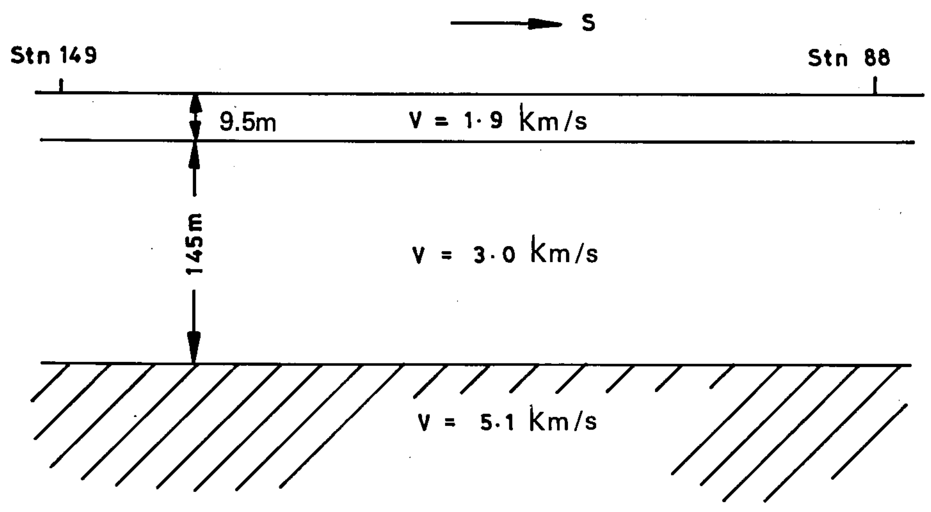


b) LINE B, REFRACTION DATA



NOT TO SCALE
BOTH MODELS REFERRED TO DATUM

c) INTERPRETATION MODELS FOR REFRACTION SEIMIC DATA OF LINE A

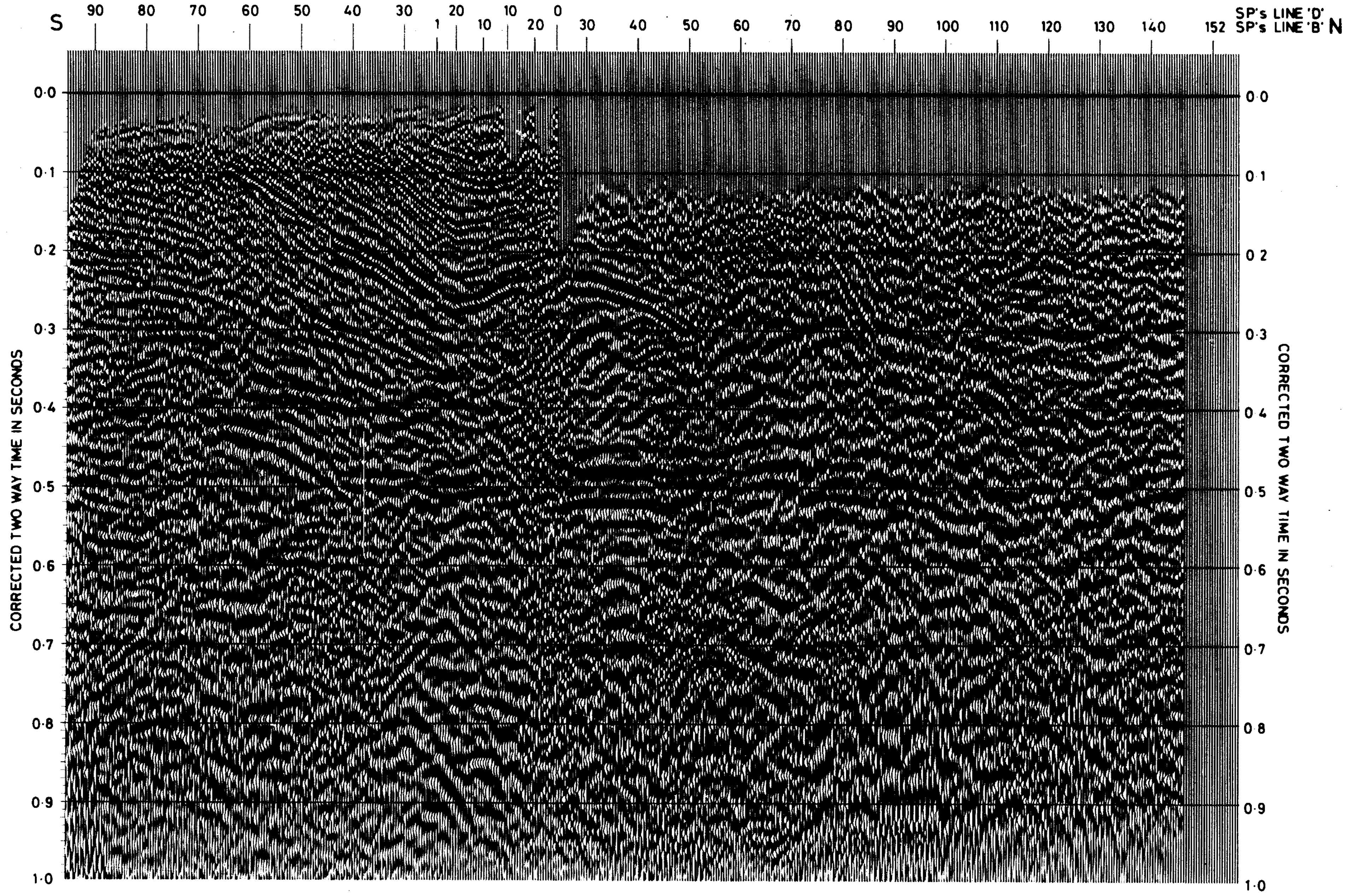


NOT TO SCALE
MODEL REFERRED TO DATUM

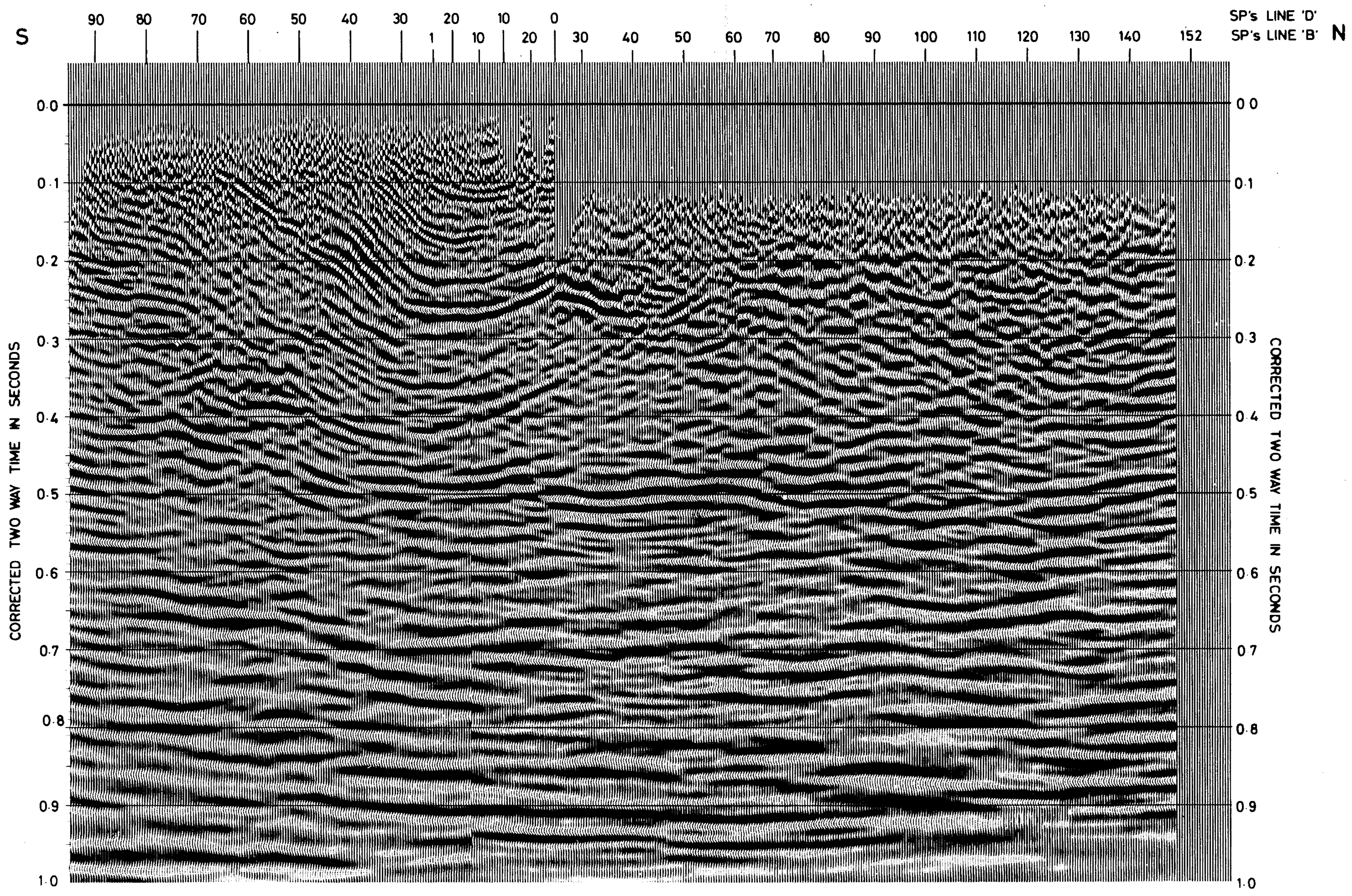
d) INTERPRETATION MODEL FOR REFRACTION SEISMIC DATA OF LINE B

WF/8R/83/66

FIGURE 13

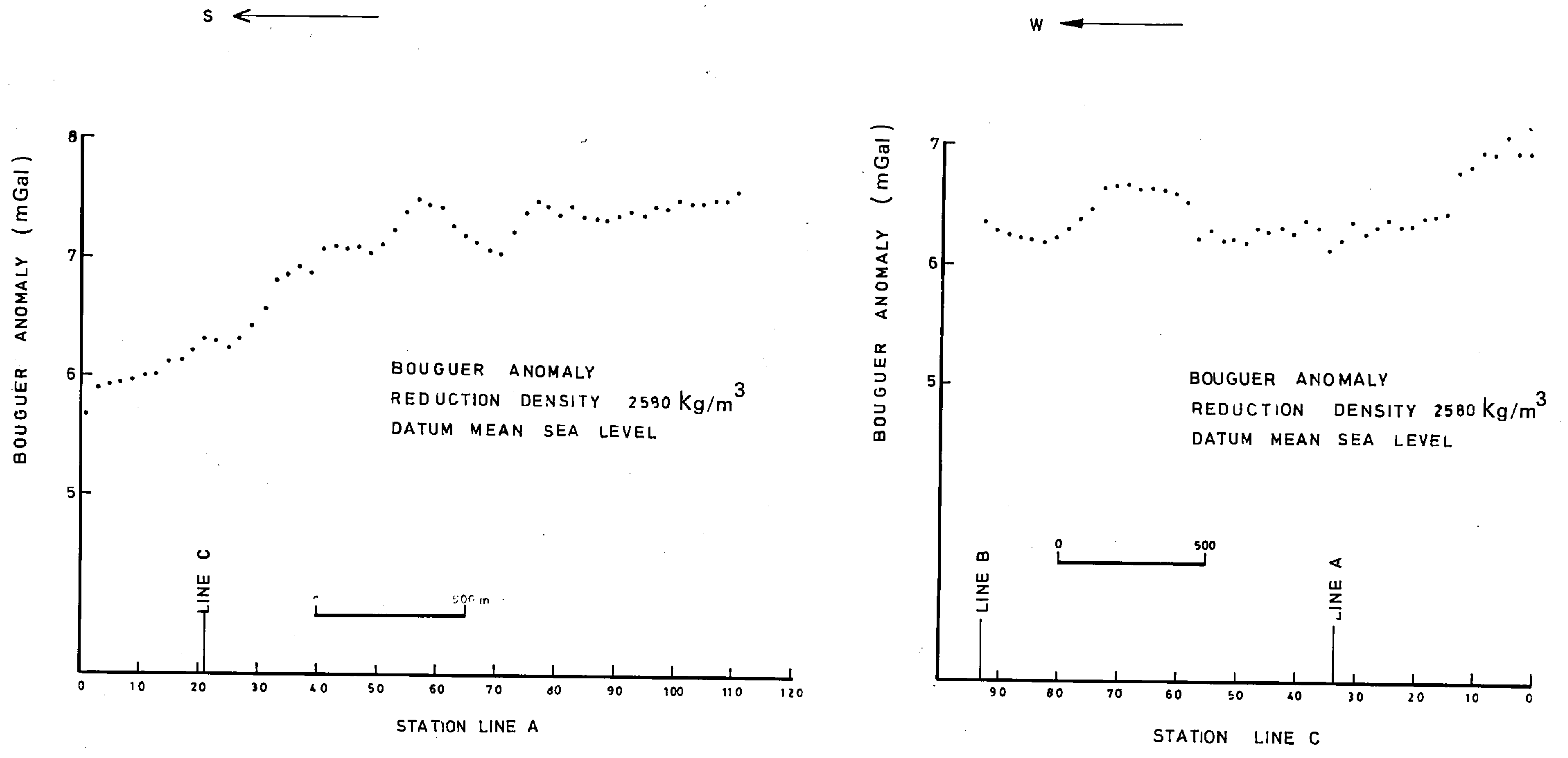


a) LINES B AND D, TIME SECTION



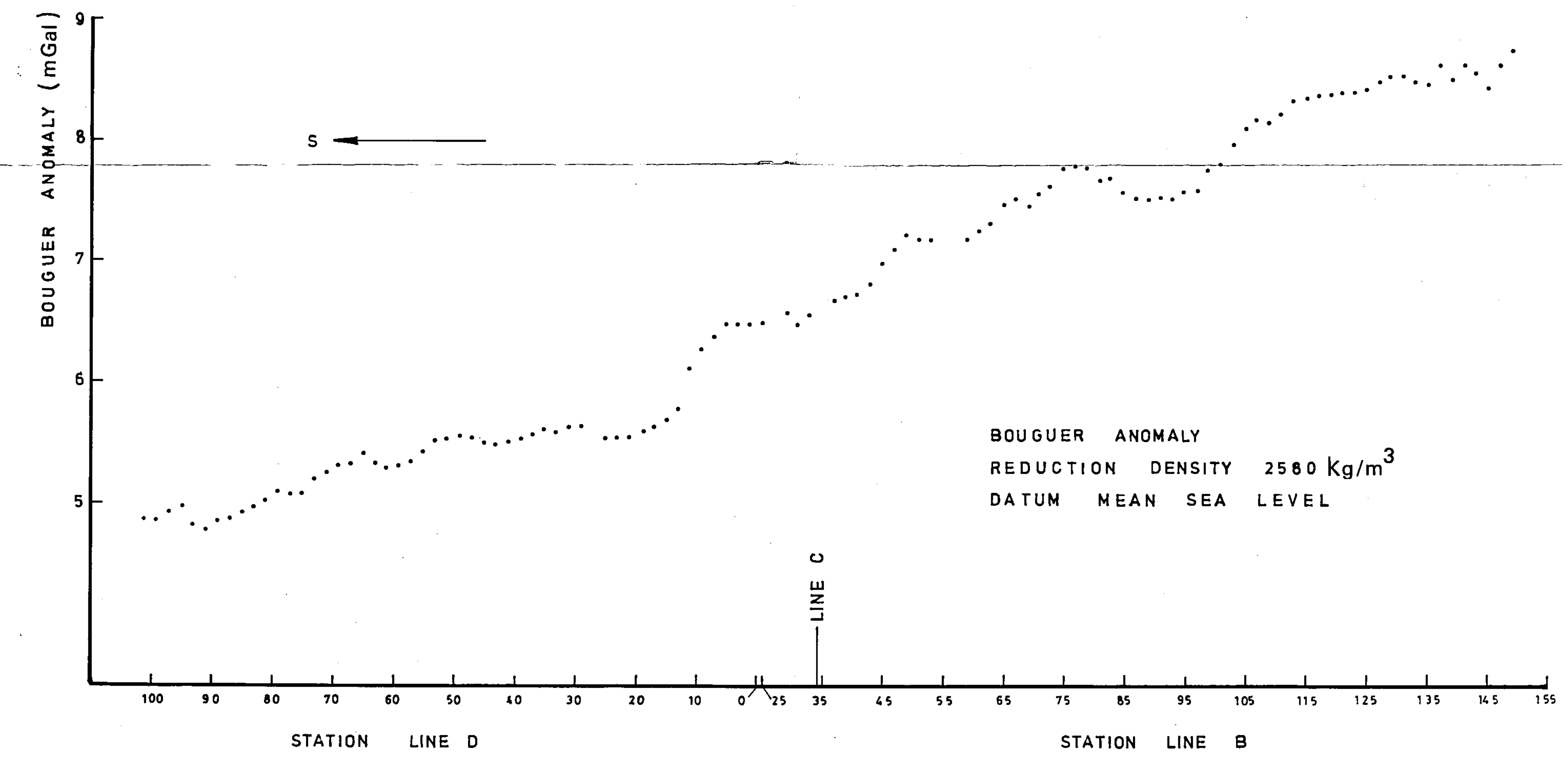
b) LINES B AND D, TIME SECTION

FIGURE 16



a) LINE A, BOUGUER ANOMALY PROFILE

b) LINE C, BOUGUER ANOMALY PROFILE



c) LINES B AND D, BOUGUER ANOMALY PROFILE

WF/8R/83/66