Natural Environment Research Council

Institute of Geological Sciences

Mineral Reconnaissance Programme Report

A report prepared for the Department of Industry

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Lead, zinc and copper mineralisation in basal Carboniferous rocks at Westwater, south Scotland

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Lead, zinc and copper mineralisation in basal Carboniferous sediments at Westwater, south Scotland

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CONTENTS

APPENDICES

I. Lithology, mineralogy and geochemical analysis of borehole cores from the Westwater district:
TABLES I to XIII represent BOREHOLES 1 to 13 respectively.

II. Statistical summaries of geochemical data on core samples analysed by X-ray fluorescence from boreholes 6 to 13.

III. Lithology, mineralogy and geochemical analysis of surface and trench rock samples from the Westwater district.

IV. Geochemical analysis lists for till samples from the Westwater district.

V. Statistical summaries of geochemical data on drainage samples from the area southwest of Langholm shown in Fig. 12 and on till and soil samples from the Westwater district.

ILLUSTRATIONS

Summary

A zone of lead, zinc and copper mineralisation is developed over a minimum of 4 km of strike of basal Carboniferous cementstone group sediments and immediately underlying Birrenswark Lavas at Westwater, near Langholm in south Scotland. Grades so far obtained from sparse rock exposures and from shallow boreholes are usually 0.1–0.3% of combined metals over 1-2 m of thickness, but a fissure vein of higher grade and a relatively thick zone of disseminated sulphides were also located. Galena, sphalerite, chalcopyrite and baryte occur mainly in thin dolomite veins but disseminations of galena are also present in sandstone units. The mineralisation is of low temperature type and was emplaced along northeasterly trending normal faults and cross faults regarded as late Carboniferous in age.

Mineralisation has been controlled by faulting, regional facies variation and local lithological variation as well as by stratigraphic position. These controls are applicable in further exploration of Lower Carboniferous rocks in both south and central Scotland. The heavy mineral fraction of stream sediment is the optimum sampling type in reconnaissance exploration of areas of calcareous rocks such as the Lower Carboniferous of south Scotland and basal till sampling is the most effective method of follow-up exploration in those areas where glacial deposits are widespread and often thick.

INTRODUCTION

Compared with sediments of similar age in Ireland and the English Pennines, the Lower Carboniferous of Scotland contains few metalliferous mineral deposits of consequence (Dunham et al., in press). The most important were baryte veins such as Gasswater (Scott, 1967) and the ancient lead-silver mine of Hilderstone (Wilson and Flett, 1921) in central Scotland. The marine limestones of the Pennines (Dunham, 1948) and the Waulsortian reefs of Ireland (Lees, 1961) are not represented in the lowest strata of the Scottish Carboniferous sequences (Lumsden and Wilson, 1977), in which the lowermost carbonate rocks are thin dolomitic beds of the cementstone group. In central Scotland the cementstones locally overlie red sandstones of Upper Old Red Sandstone facies, but in southern Scotland their deposition was preceded by the eruption of basalts (Lumsden et al., 1967).

Exploration interest in the region was prompted by broad similarities in stratigraphy and structure with the Lower Carboniferous of east-central Ireland where a major lead-zinc deposit is known to occur at Navan (Morrissey, Davis and Steed, 1971). A small lead trial (Wilson and Flett, 1921) is sited at the cementstones-lavas junction in Mine Sike (Fig. 4), but another lead trial believed to be near Crawthwaite (Wilson and Flett, 1921) was not relocated in the present survey and an exploration adit for copper in the Birrenswark lavas at Torbeckhill (Fig. 12) appears to have been unsuccessful. A geochemical drainage survey of the post-Silurian unconformity between Hawick and Dumfries showed anomalous lead and zinc values in stream sediment from Pokeskine Syke, 1500 m WSW of Westwater, and galena was observed in outcrop in the stream bed (Haslam, 1972).

The first results of this exploration are the location of minor lead, zinc and copper mineralisation in Lower Carboniferous rocks along 4 km of strike in the Westwater district southwest of Langholm (Fig. 1).

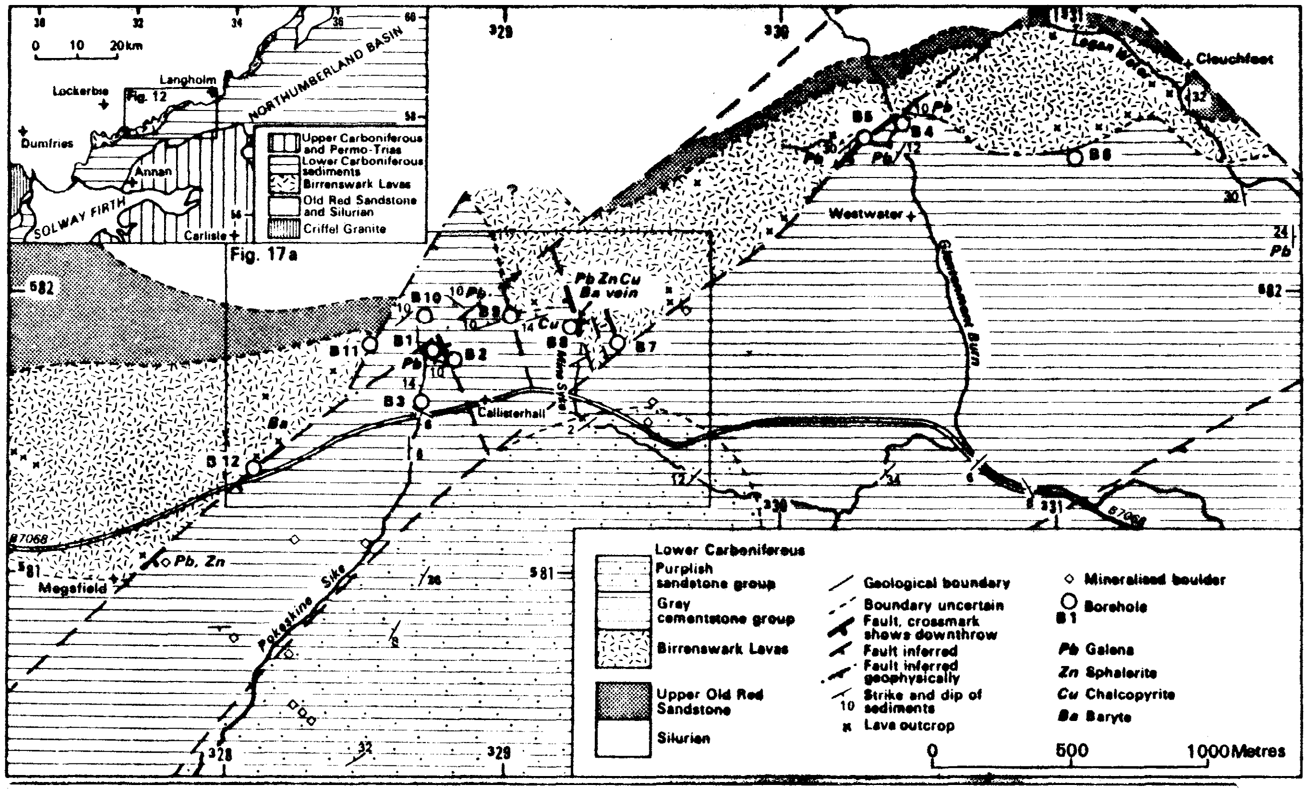

Fig. 1. Geology and mineralisation of the Westwater district in south Scotland based on this investigation. For location see Fig. 12.

General geology

The mineralised Lower Carboniferous rocks of the area southwest of Langholm form part of the northwestern margin of the Northumberland basin. They comprise the Birrenswark Lavas, mapped as the lowermost Carboniferous formation in the region (Lumsden et al., 1967), and the immediately overlying Lower Carboniferous sediments. These sediments are characterised by the presence of dolomitic beds known as cementstones. The Northumberland Carboniferous basin is considered to have been initiated by eruption of the alkali olivine basalt lavas of Birrenswark on to the fluviatile sediments of the Upper Old Red Sandstone Scottish Borders basin (Leeder, 1974a) lying at the southeastern margin of the Southern Uplands massif.

To the south and east of Langholm about 2 km of Lower Carboniferous sediments were deposited, followed by nearly 1.5 km of Millstone Grit and Coal Measures (Lumsden et al., 1967). Southwest of Langholm, the stratigraphy of the Carboniferous succession is not known in detail, in part because of heavy drift cover, and extrapolation from the adjoining area to the east is made difficult by the facies variation and faulting that is known to occur (see Fig. 12). In particular, a thick deltaic sandstone (Whita Sandstone) resting on the Birrenswark Lavas at Langholm (Lumsden et al., 1967) is absent from the mineralised district near Westwater to the southwest, but reappears further west as the Annandale Sandstone (Nairn, 1956). Around Westwater, the Birrenswark Lavas are overlain by cementstones and associated sediments for at least 4 km of the regional strike. Thus a restricted zone of carbonate rocks developed penecontemporaneously with deltaic sequences which have been interpreted as the products of river systems flowing southeastwards into a marine gulf (Leeder 1974a, Fig. 4c).

Fig. 12 is based on the original geological survey of the area west of Langholm (Peach et al., 1883) in which many of the faults now known to occur in the adjoining eastern area were not recognised. South and east of Langholm, numerous northeasterly trending faults have been mapped and ascribed to late Carboniferous movements prior to deposition of the New Red Sandstone. Downthrow is predominantly to the southeast by some tens to a few hundreds of metres, a small number of cross-faults are present, and small-scale folding is common mainly in association with the major faults. The faulting has been ascribed to reactivation of Caledonian structures underlying the Northumberland basin induced either by Armorican orogenesis further south (Lumsden et al., 1967) or to rifting prior to the opening of the Rockall trough (Russell, 1976).

In the area of Carboniferous rocks southwest of Langholm, thick and stratigraphically complex tills obscure all but sporadic stream outcrops. The earliest glaciation is evidenced by deposits of a stiff, clay rich red till possibly derived from the New Red Sandstone rocks to the south and west. A second period of glaciation deposited a less extensive grey, sandy-clay till derived from Silurian greywackes and shales north of the Carboniferous outcrop. Morainic gravel ridges and mounds occur in the main valleys where there has been considerable reworking of all glacial deposits. Although the presence of granite boulders in the area implies glacial transport of tens of kilometres from the nearest known Caledonian granitic bodies in southwest Scotland there is convincing evidence of local derivation of at least the finer fraction of the basal till.

Present investigation

Following a brief period of geochemical orientation in 1974 during which several new occurrences of outcropping mineralisation were discovered, surface mapping, geochemical surveys and geophysical surveys were carried out in 1975 and a small programme of subsurface exploration completed early in the next year. Reconnaissance exploration was based on examination of sparse outcrops, drainage geochemistry and an evaluation of available airborne magnetic data. Follow-up investigations included pitting to bedrock as well as geochemical sampling of glacial deposits and soil, geophysical investigations in a selected area, and topographic surveys on which to base borehole sites. Finally 13 boreholes were sunk to depths of 20 m to 60 m to sample exposed mineralisation at depth and to test the principal anomalies resulting from the geochemical and geophysical surveys.

GEOLOGY

The geological sequence in the Westwater district of south Scotland can be summarised as follows:

	Thickness, m
Pleistocene	1–10
Lower Carboniferous (Dinantian)	
Purplish-coloured sandstone group	100+
Cementstone group	c100
Birrenswark Lavas	90
Upper Old Red Sandstone	c 50
Silurian (Wenlock)	500+

The Silurian rocks are principally steeply-dipping greywackes and intercalated shales of the Southern Uplands block. Quartz and carbonate veins occur quite commonly along late fractures and in places carry small amounts of pyrite, chalcopyrite and galena (see Fig. 12). The greywackes are overlain unconformably by red sandstones and mudstones originally mapped as Upper Old Red Sandstones but recent reappraisal suggests that these sediments may represent a reddened facies of the Lower Carboniferous (Lumsden and Wilson, 1977). The only exposure of "Upper Old Red Sandstone" rocks in the area is in the Logan Water at Cleuchfoot (Fig. 1) but red sandstones and mudstones intersected in borehole 5 (Appendix I, Table V) may represent an upfaulted slice of this facies.

Brief descriptions of the mineralised Lower Carboniferous rocks follow, based on the detailed observations on the available exposures given in Appendix III and the borehole logs in Appendix I, together with an account of the new evidence of faulting obtained in this investigation.

Birrenswark lavas

Except where broken by faulting, the outcrop of the Birrenswark Lavas runs east-north-east across the Westwater district, forming a low ridge northwards of the basal Carboniferous sediments. When partly exposed in a pipeline trench near Megsfield (Fig. 1), at least four flows of moderately altered basalt were distinguishable by the presence of slaggy, broken tops, siltstone intercalations and variations in vesicle distribution. In this section the lavas approach the maximum recorded thickness of 90 m (Leeder, 1974a). Mudstone and cementstone intercalations can also occur and thin tuffaceous sediments overlie the lavas in some areas (Fig. 2). The observed scarcity of pyroclastics is characteristic of other areas of Dinantian alkali basalt magmatism in Scotland (MacDonald, 1975).

Lower Carboniferous sediments

The basal Carboniferous sediments of the Westwater district form a highly discontinuous cyclic sequence typified by thin cementstone beds (average thickness about 30 cm). Junctions with the underlying Birrenswark Lavas where unfaulted are conformable or nearly so.

The mineralised cementstone group comprises irregularly-dipping grey to brown beds of sandstone, siltstone, mudstone and cementstone (see Figs. 3-4 and borehole logs in Appendix I). There is no systematic lithological variation in the basal part of this sequence over the 3 to 4 km of strike-length investigated by drilling (see Fig. 2 and Table 1).

Overlying or downfaulted against the cementstone group near Westwater is an unmineralised group of purplish-coloured sandstones, siltstones and clays

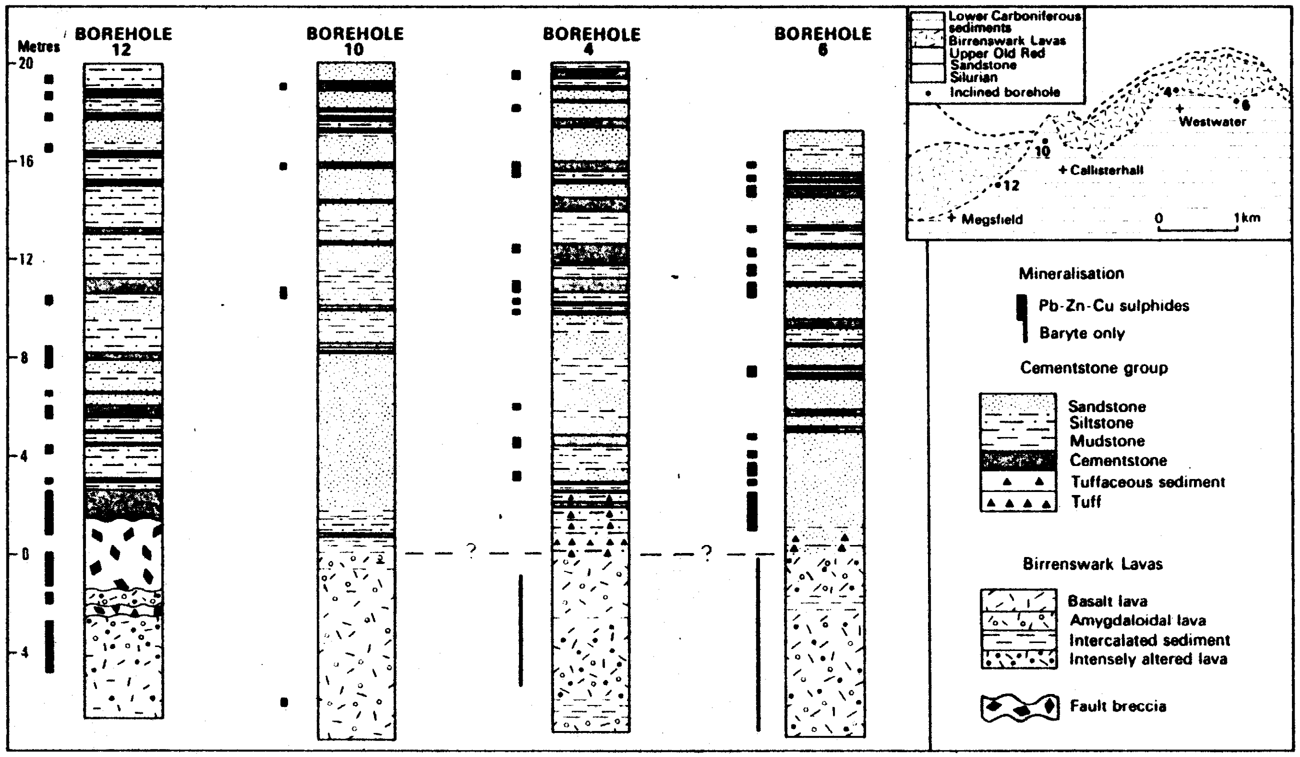

Fig. 2. Comparative sections through mineralised basal Carboniferous rocks in the Westwater district.

Table 1

Lithological abundances of basal Carboniferous sediments near Westwater

Borehole No (see Fig. 1)	Sandstone	Siltstone	Mudstone	Cementstone	Total of measured intersections, m
12	41	14	19	26	41
10	57	6	17	20	37
4	30	16	26	28	29
6	66	4	12	18	22
Averages	48	10	19	23	

with root beds which have been called the Fell Sandstone (Nairn, 1956). This sandstone group appears to directly overlie the Birrenswark Lavas southwest of the area of Fig. 1. Because of lack of exposure, however, the stratigraphy of the Lower Carboniferous sediments near Westwater is indeterminate. Furthermore, fossils are scarce and non-diagnostic so that the precise age of the sediments is uncertain although they have previously been referred to the Tournaisian (Leeder, 1974b).

Faulting

New mapping and borehole information, supplemented by geophysical evidence, indicates that junctions between the Birrenswark Lavas and cementstone group sediments in the Lower Carboniferous near Westwater are largely fault controlled. The fault pattern is one of northeasterly trending normal faults downthrowing to the southeast and subsidiary cross faults.

The northernmost of the two main northeasterlies shown in Fig. 1 was intersected in a pipeline trench near Megsfield and in a nearby borehole (no. 12 in Fig. 2; Appendix I, Table XII) where sediments are clearly downfaulted against the lavas. The inferred extension of this fault northeastwards accounts for the break in outcrop of the Birrenswark Lavas north of Callisterhall. A second northeasterly is exposed in streams north of Westwater farm where it occurs at or near the lava-sediment contact. Its extension to the southwest is based on topographic evidence, in particular the presence of a linear section in the valley of Pokeskine Sike which may mark a faulted contact between sediments of the cementstone group and the sandstone group believed to overlie them. Crossfaults shown in Figs. 1, 3 and 4 have been deduced from tectonic repetition of lava-sediment contacts observed in shallow boreholes. The incidence and style of faulting in the Westwater district would therefore appear to be very different from the picture provided by the original geological map (see Fig. 12) and probably accounts, in part at least, for the very variable dips observed in cementstone group sediments at outcrop. To the east of Westwater, cementstones are downthrown against the Silurian in Wauchope Water (Peach et al., 1883; Nairn, 1956) and the NW-trending displacement in Logan Water (Fig. 12) is possibly a crossfault between the Wauchope Water fault and the Westwater northeasterlies.

The pattern of faulting now apparent in the Westwater district is closely similar to that observed some 10 km to the northeast along strike where a maximum throw of 30 m has been estimated for the Hermitage fault, one of the main northeasterlies affecting Lower Carboniferous rocks in the area (Lumsden et al., 1967). Displacement on the main Westwater faults appears to be of the same order of magnitude and almost certainly took place in response to the same phase of movements. This phase has been shown to post-date the full Carboniferous sequence of the Langholm-Canonbie area but to be earlier than formation of (?) Permo-Trias New Red Sandstone "red beds" (Lumsden et al., 1967).

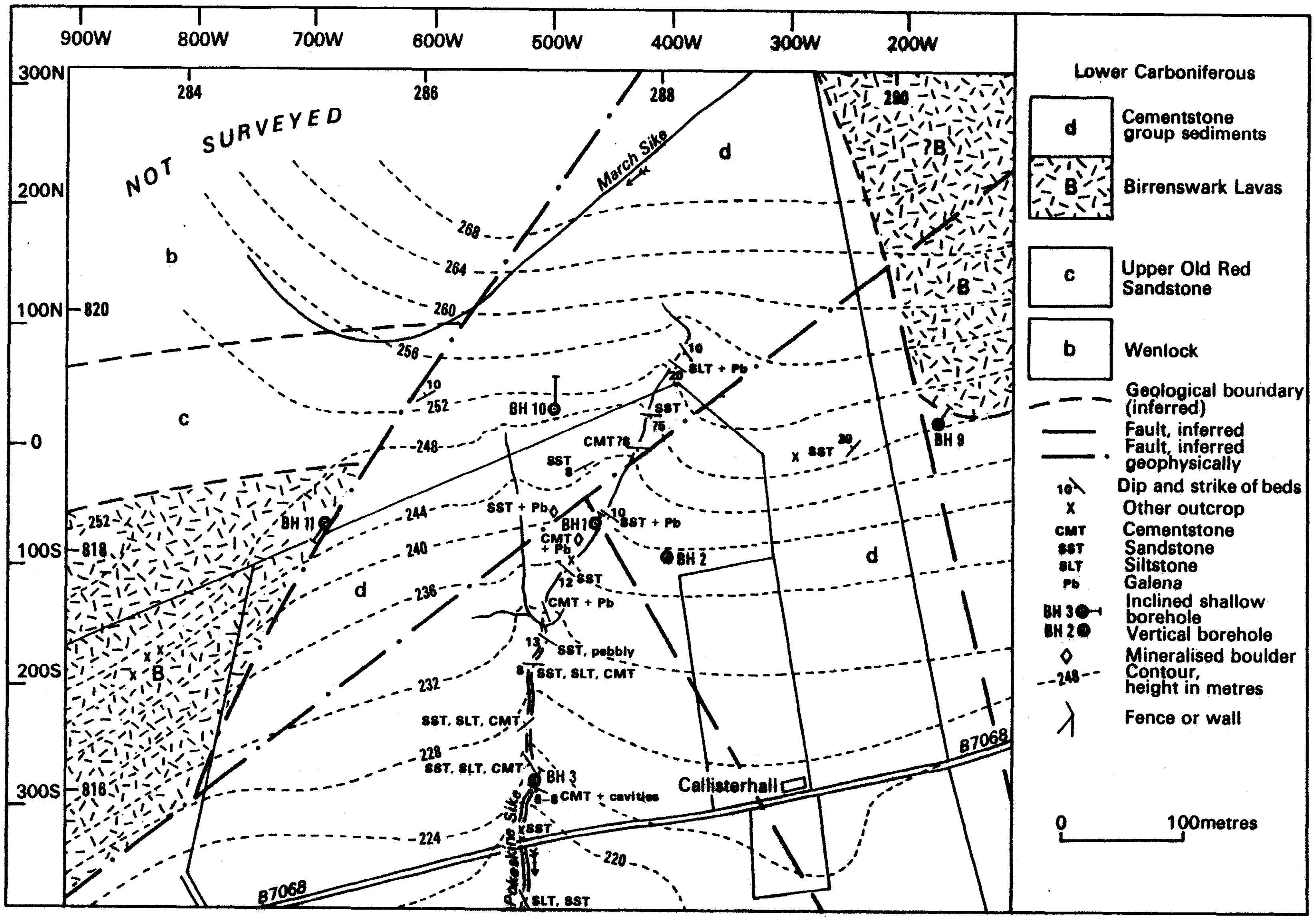

Fig. 3. Detailed topography and geology of the area around upper Pokeskine Sike, near Westwater.

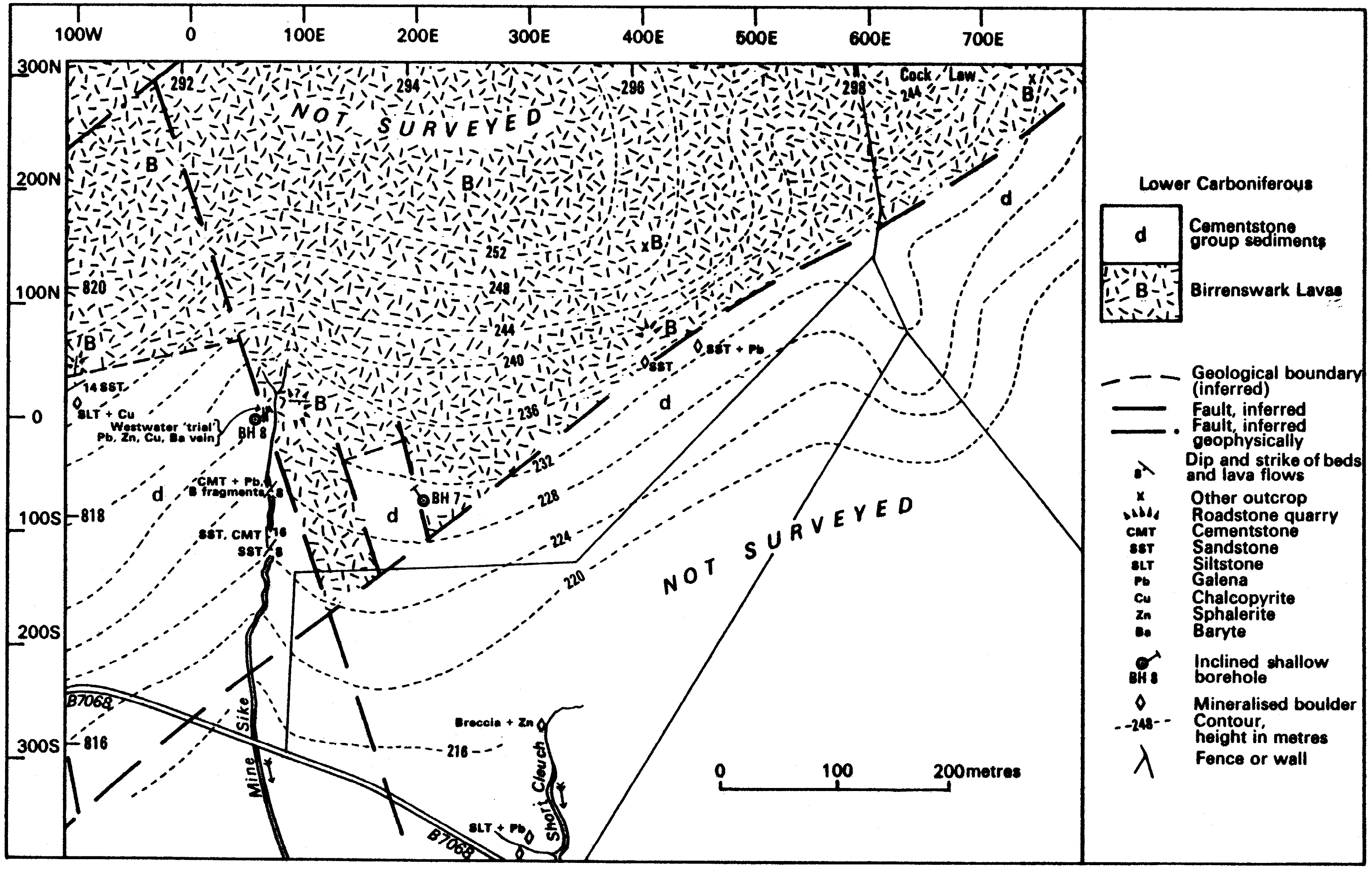

Fig. 4. Detailed topography and geology of the area around Mine Sike, near Westwater.

GEOPHYSICS

Geophysical survey

Total magnetic field and induced polarisation/resistivity surveys were carried out both to assist with revision of the existing geological map and to indicate any concentrations of sulphide mineralisation. In the first aim, reasonable success was achieved and a revised geological map, based on interpretation of the geophysical results, has been produced. The search for sulphide concentrations indicated that economic mineralisation was not present, although local minor induced polarisation anomalies were measured. Boreholes drilled to investigate areas of interest indicated by these surveys and related geochemical and geological studies, were geophysically logged.

Magnetic field survey

Geological mapping in the area is greatly hindered by scarcity of exposure. The magnetic field survey was designed to assist revision of the pre-existing geological map by delineating the suboutcrop of the magnetic basalts of the Birrenswark Lavas.

The total magnetic field was measured with a proton magnetometer over the area shown on Fig. 5. Readings were at 10 m intervals along traverses 50-200 m apart. The contoured map is presented as Fig. 6.

Induced polarisation and resistivity survey

To investigate the extent of the mineralisation found near Pokeskine Sike, and to indicate suitable borehole sites, an induced polarisation (I.P.) survey was made over the area indicated on Fig. 5. As a part of this survey, resistivity measurements were made, which it was hoped would aid the revision of the geological map.

The surveys were made with the expanding colinear dipole-dipole array, in the time domain, with chargeability measured over the interval from 240 to 1140 ms after termination of a 2s square polarising pulse. A dipole length of 30 m and dipole centre to centre separations from 60 to 180 m were used.

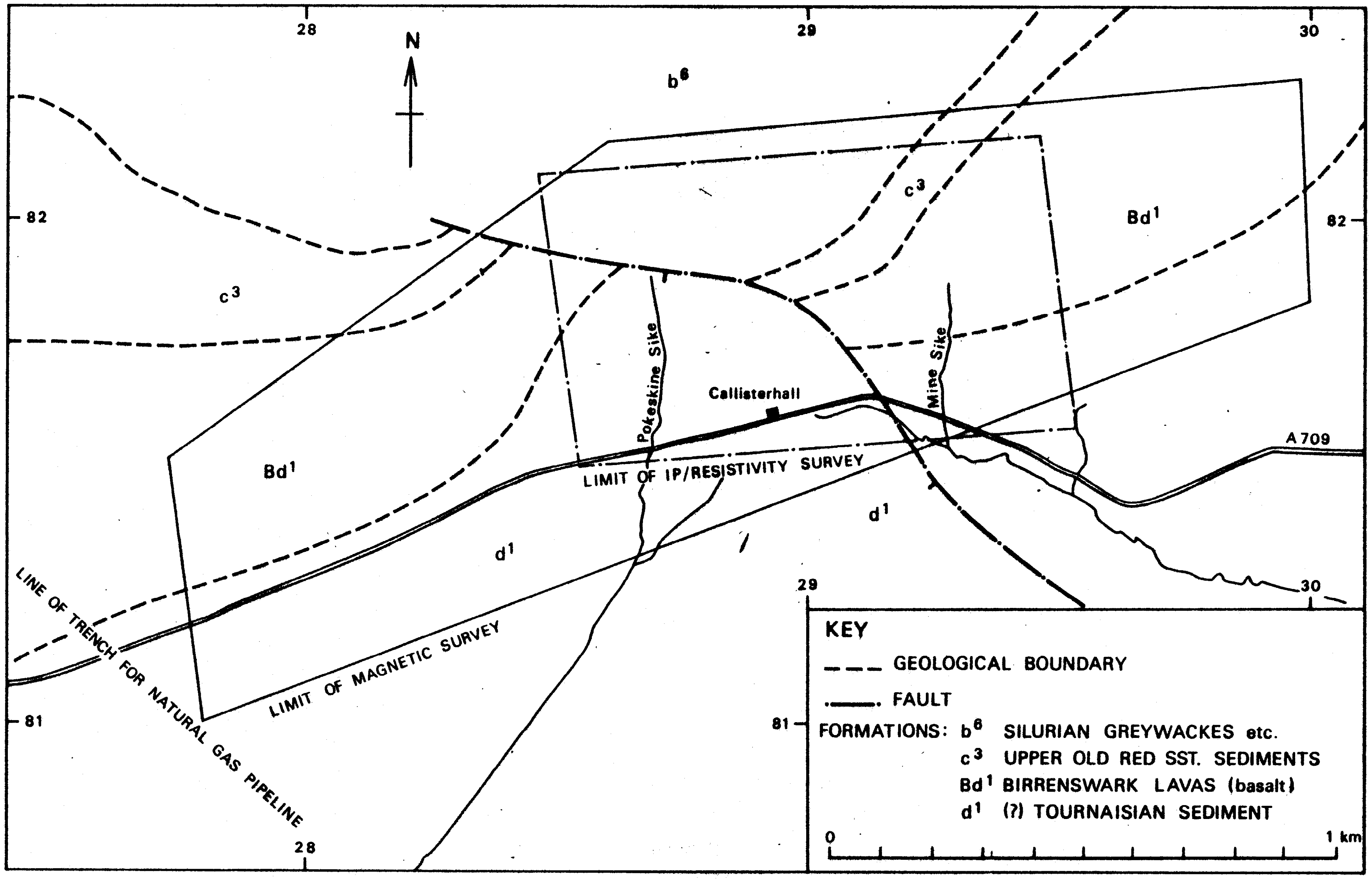

Fig. 5. Geology of the Callisterhall area, near Langholm (after Peach et al., 1885) showing areas of geophysical surveys.

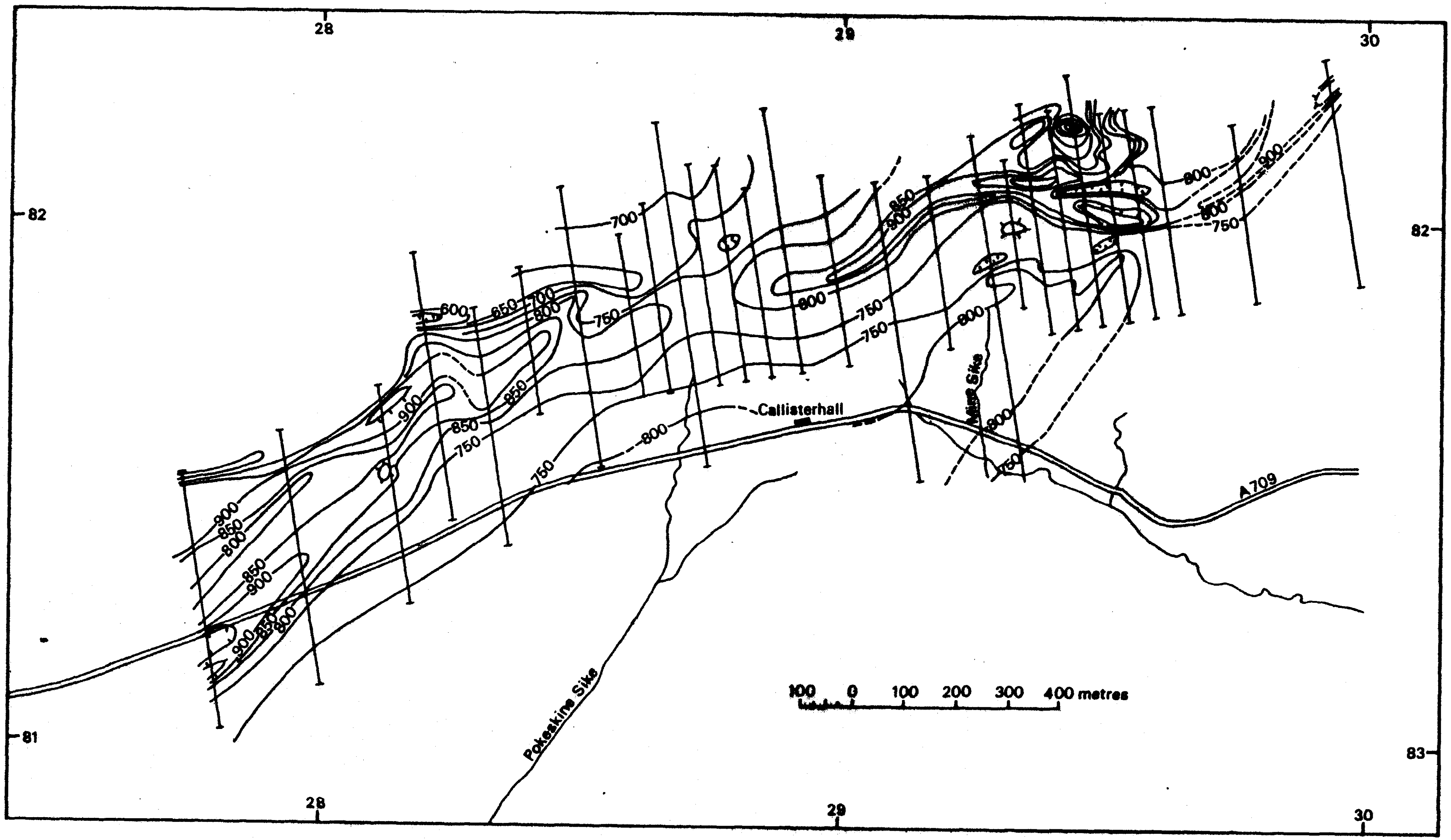

Fig. 6. Contour map of total magnetic field, Callisterhall area, relative to a datum of 48000 nT.

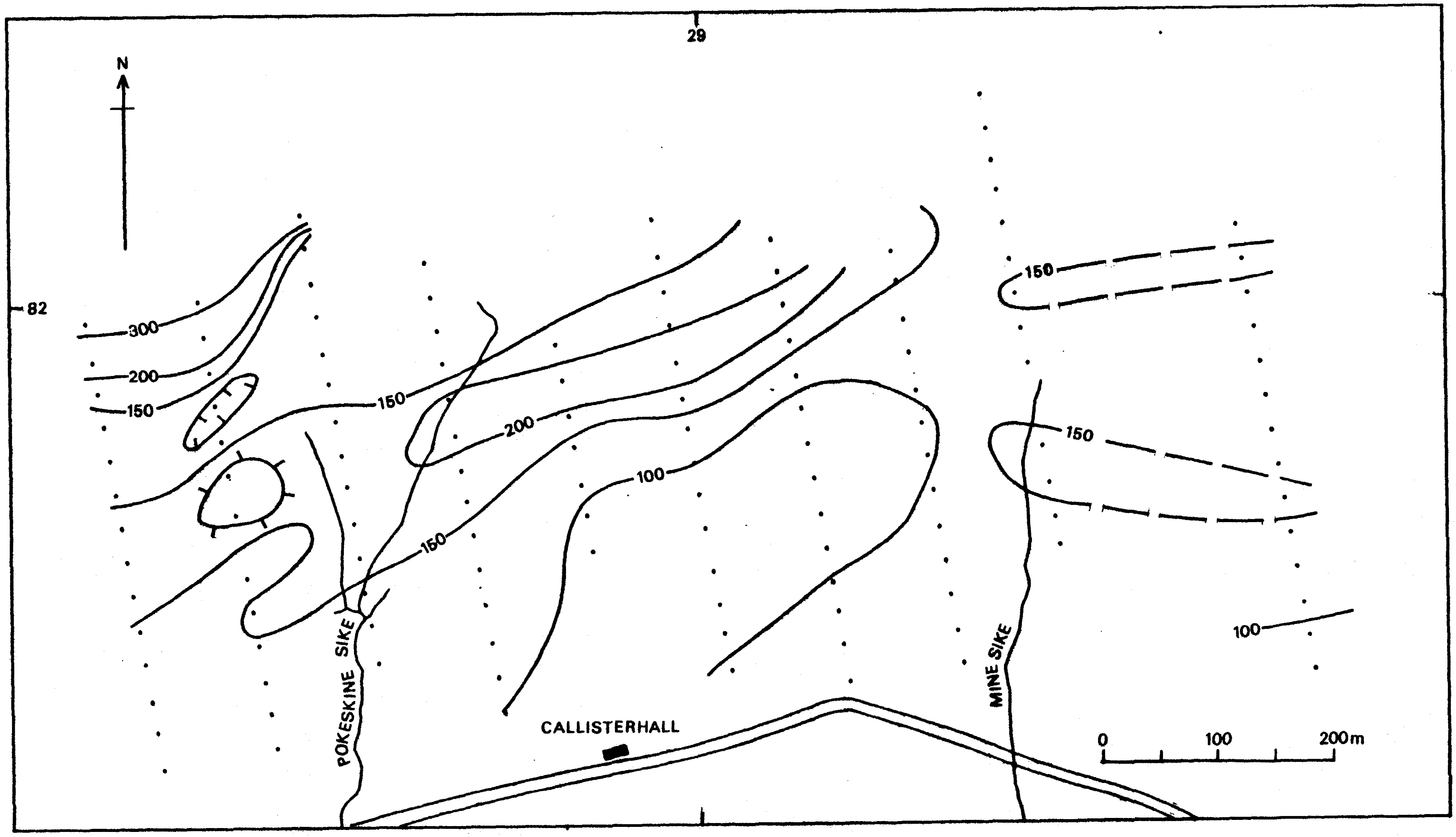

Fig. 7. Contour map of apparent resistivity in ohm metres, Callisterhall area, dipole-dipole array, with dipole centre-to-centre separation 60 metres.

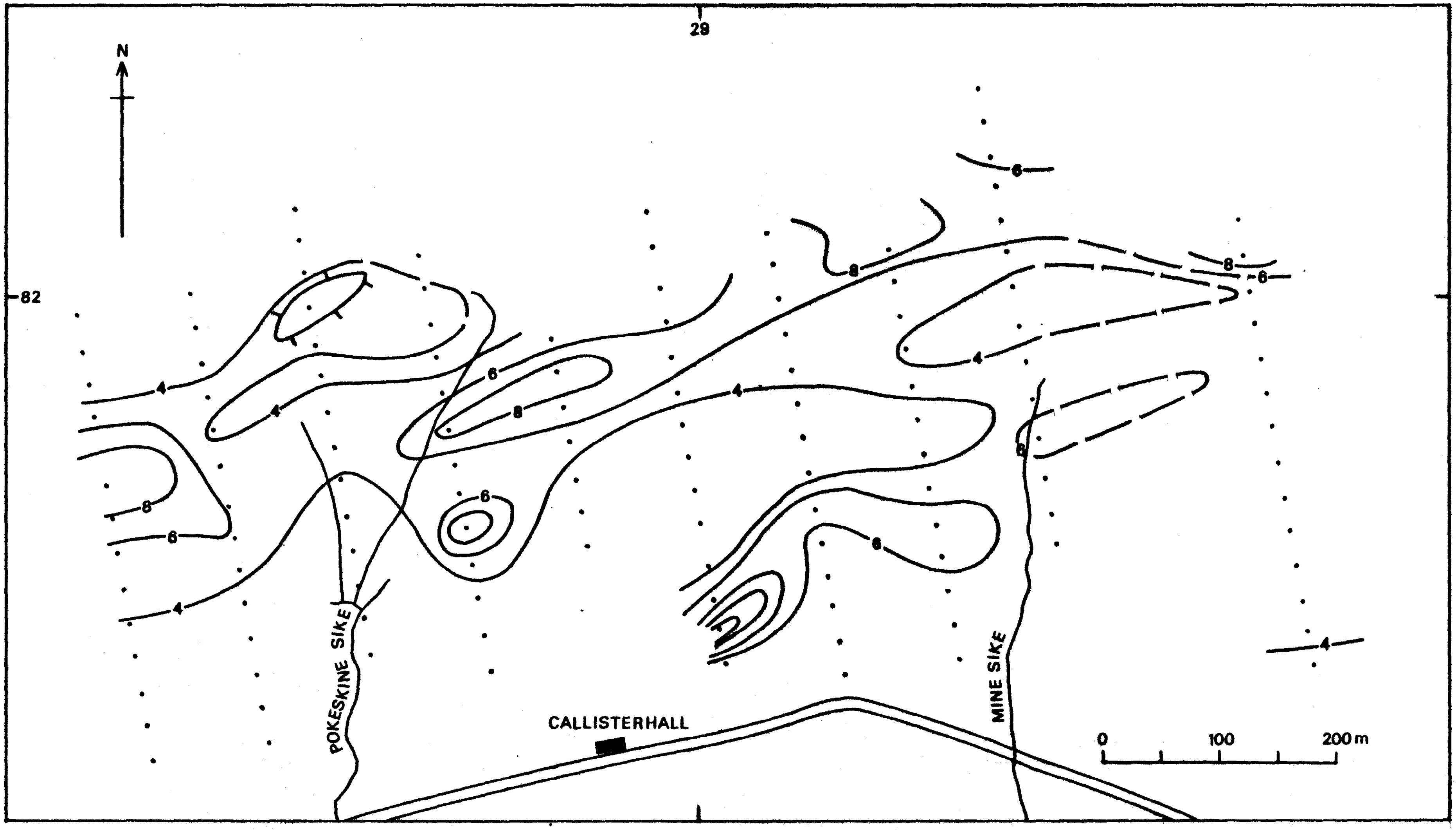

Fig. 8. Contour map of chargeability in milliseconds, Callisterhall area, dipole-dipole array, with dipole centre-to-centre separation 60 metres.

Figs. 7 and 8 show respectively the apparent resistivity and chargeability at 60 m separation.

Results and interpretation

Fig. 9 shows the modified geological map deduced from an interpretation of the geophysical results obtained. To the east and west, zones of perturbed magnetic field accompanied by resistivities typically in the range 120 to 150 ohm m are indicative of suboutcropping lavas. In the central part, gentler magnetic gradients and somewhat lower resistivities indicate that the lavas are buried. This is in broad agreement with the map of Peach et al. (1885). In detail, however, several differences can be seen, which will now be discussed working from west to east, and which could lead to a significantly different interpretation particularly with regard to the pattern of faulting.

In the southwestern corner, the boundary of the lavas has been adjusted to run further south than was deduced by Peach et al. (1885). This boundary can be clearly seen from the magnetic contours and is borne out by exposure in the pipeline trench. The likely northern limit of this western lava block is indicated by a steep magnetic gradient, and by an increase in resistivity to over 300 ohm m. Geological evidence indicates that the rocks to the north are Upper Old Red Sandstone sandstones and Silurian greywackes. They seem to be bounded to the east by a fault, indicated by a relatively steep resistivity gradient and a narrow band of low resistivity. The pattern of the magnetic field contours in this region also suggests a fault.

In the central region, for reasons given above, the lava is thought to be buried. However, the thickness of sediments covering them is not thought to be great, varying from a few metres at the edges to perhaps 30-40 m in the centre. Resistivities in this zone, although less than those over lava, are slightly higher at the surface than those normally encountered over the Lower Carboniferous sediments. At depth, values increase to those typical of lavas.

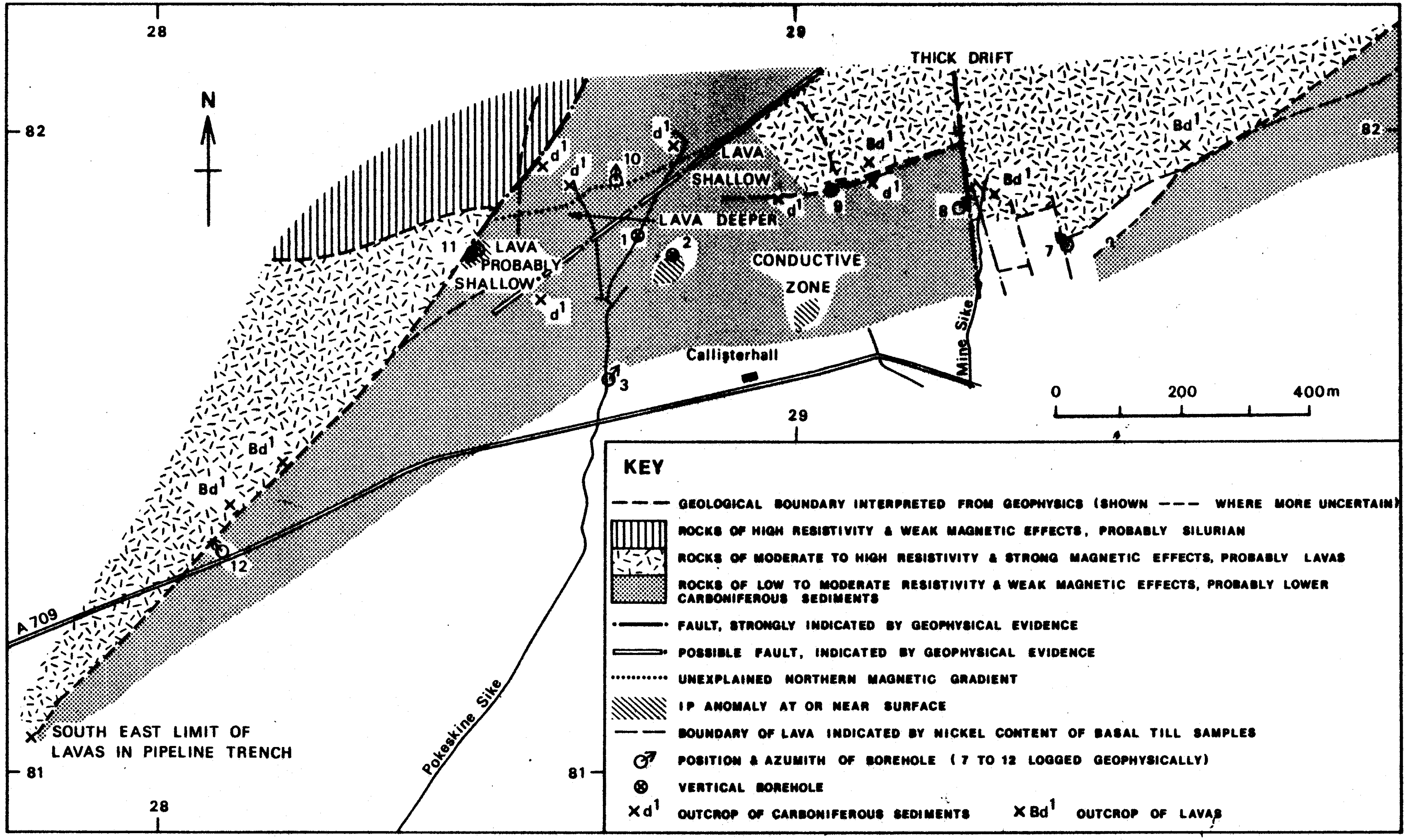

Fig. 9. Interpretation of geophysical evidence.

An approximately linear magnetic gradient can be followed across this zone. Its significance is not known, but it could represent a northern limit to the buried lavas, or a fault downthrowing them to the north. A line of lower resistivities which could result from a fault coincide in part with this gradient and with a band of low chargeability values. To the north of this possible fault lie rocks of medium resistivity (c. 120-160 ohm m) and rather higher chargeability. The magnetic field is almost completely flat, which suggests lava is absent or quite deeply buried.

Moving east, a zone of perturbed magnetic field and resistivities of the order of 150-250 ohm m inidcate suboutcropping or thinly covered lavas. The northern margin of this zone is the possible fault mentioned above, while its southern boundary is marked by magnetic and resistivity gradients. To its south lies a zone of low resistivities (50-100 ohm m) probably due to the presence of more conductive sediments, or of conductive overburden.

Along the line of Mine Sike, a significant discontinuity occurs. This is particularly clear from the magnetic profiles and provides further evidence for the fault which has been recognised from geological evidence. To the east, of this fault, pronounced perturbations in the magnetic field are typical of approximately flat-lying basalts, probably representing variations in thickness and magnetic properties between individual flows. The southern margin of the lavas is again marked by resistivity and magnetic gradients, but these are locally poorly defined and parts of the boundary are tentative.

Considering now the IP results, a correspondence can be seen between shallow and suboutcropping lava, and generally higher IP background values, between 5 and 8 ms. Chargeabilities over the sediments are generally in the range 2-4 ms. However the maximum IP anomalies occur as local features within the sediments and have values up to 25 ms. These were interpreted as far as possible from the pseudosections, to provide suitable sites for boreholes.

Recommended borehole sites with notes on the interpretation of IP anomalies

1. NY 2850 8180 (drilled as BH 11): The sparse indications are of a broad source at depth, with some contribution nearer surface. A hole inclined steeply northward should encounter the source of the IP anomaly at about 40 m.

2. NY 2880 8178 (drilled as BH 2): A prominent anomaly with a steep northerly dip indicated. A vertical hole should encounter the source of the anomaly at 20-30 m.

3. NY 2902 8172 (not drilled): This is approximately where the source of the IP anomaly outcrops, so a vertical hole should not need to be more than 20 m.

4. NY 2889 8195 (not drilled): A minor anomaly, which could be investigated by a vertical hole if any corresponding geochemical anomaly is indicated.

Geyphysical borehole logs

Induced polarisation and resistivity logs were run in boreholes 7 to 12, measurements being made at discrete intervals of between 0.5 and 3 m. The measurements were made in the time domain, over the interval 2400 to 3140 ms after switchoff of a 4s primary pulse, using the pole-dipole array with C_2-P_1 and P_1-P_2 electrode separation of 0.3 m. Results are presented in Figs. 10 and 11, with outline lithological logs.

Some generalisations can be made from a comparison of the two geophysical logs and the lithology. In particular, the resistivities observed agree generally with those measured at the surface for a given formation. Local variations are more pronounced, of course, particularly in the Carboniferous sediments, where local high values often correspond to certain siltstone horizons. As indicated by surface measurements, the lavas to the east of Mine Sike are less resistive than those to the west. All IP 'highs' coincide with occurrences of metallic minerals in moderate abundance in the core, most often as veinlets, but in one or two cases in disseminated form.

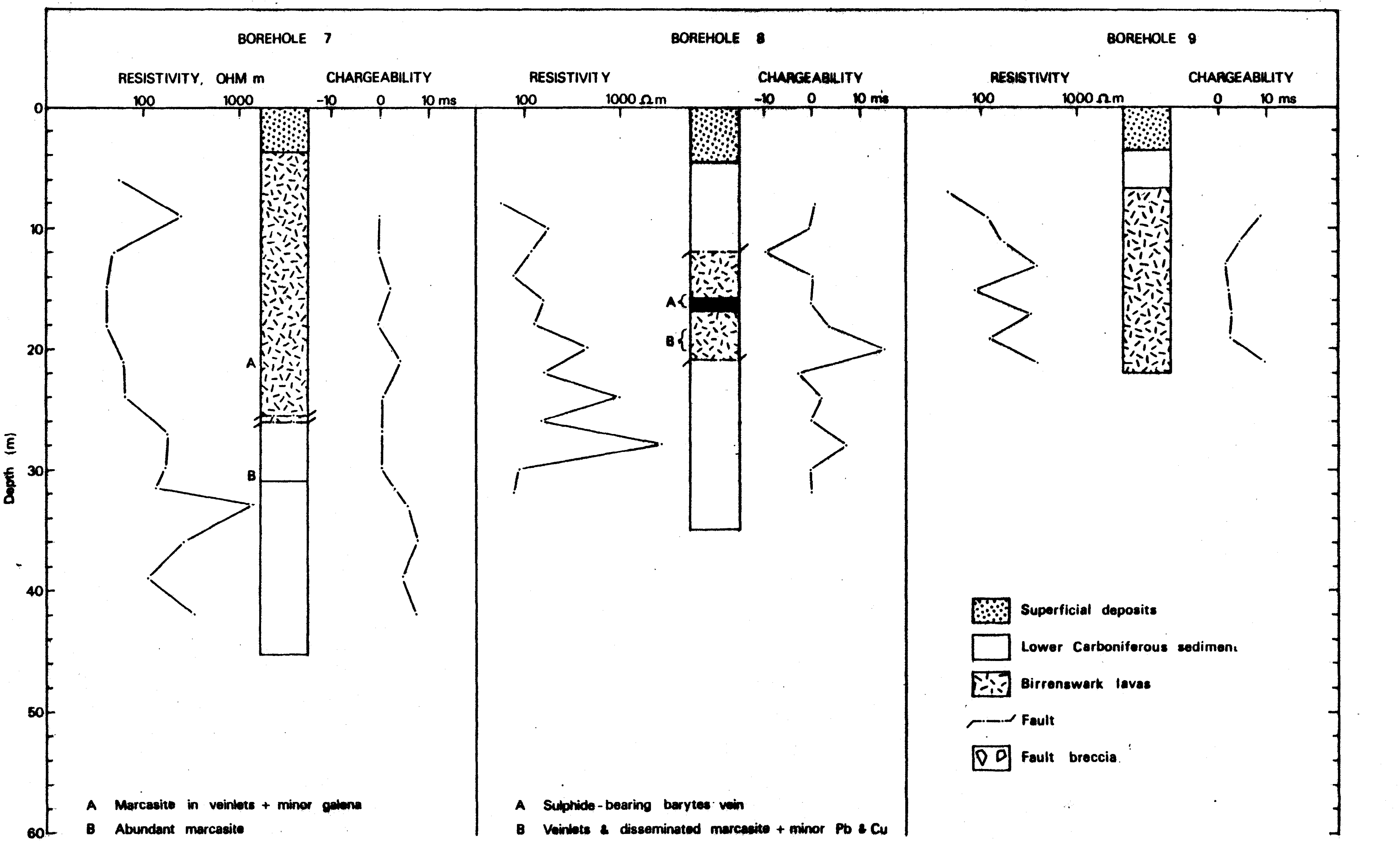

Fig. 10. Geophysical logs of boreholes 7, 8 and 9.

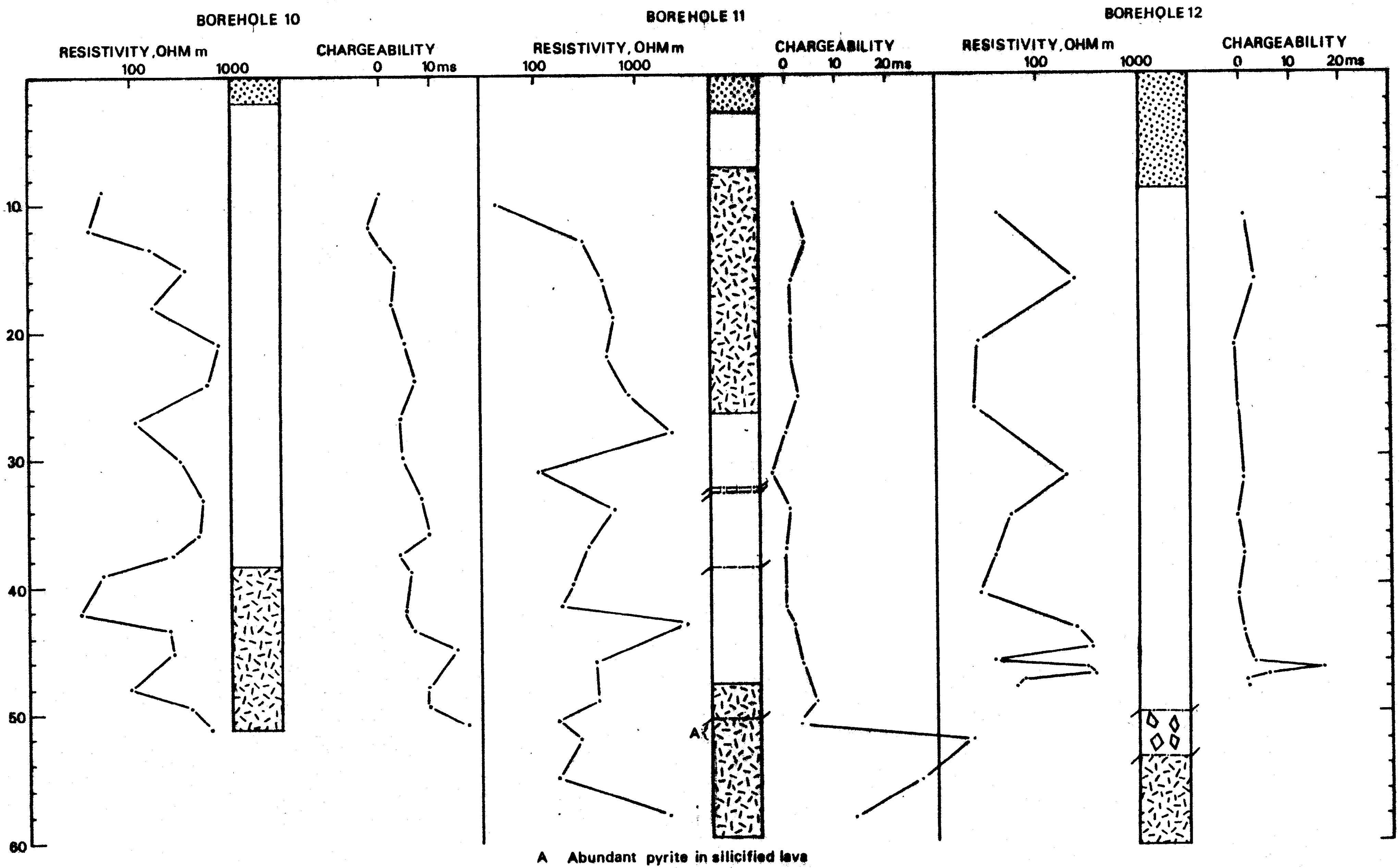

Fig. 11. Geophysical logs of boreholes 10, 11 and 12.

The IP Log of borehole 11, which was drilled to intersect an IP anomaly, has a relatively large IP 'high' (maximum chargeability of over 30 ms) at 50-60 m depth, corresponding to a zone of enrichment in the lavas. This is in agreement with the surface survey, which indicated a broad deep zone of high chargeability. However, the top 8 m of the hole, which could not be logged because of casing, showed pyrite and marcasite in the basal till and the uppermost bedrock horizon, and this would probably affect the surface measurements.

The best sulphide intersection, at 52 to 55 m in borehole 12 was not logged due to collapse of the hole at about 50 m, while in borehole 8 at Mine Sike, a pronounced chargeability high was offset by 3 m from the vein, corresponding instead with a zone of veinlets and disseminated sulphides.

GEOCHEMISTRY

Geochemical orientation for drainage sampling

Orientation studies designed to optimise size fraction and sampling interval were initiated in the Langholm area during 1974-75. The geochemical contrast of three sample types was investigated:

1. Heavy mineral concentrates, obtained by panning 2-3 kg of wet sediments screened through a 1 mm sieve, and yielding 25 g of concentrate on average.
2. Stream sediment (-150 µm) collected in the manner described by Plant (1971).
3. Suspended fines, consisting of silt plus clay grade material, sampled in the way described by Leake and Smith (1974).

To test the response of the three sample types to the different styles of base metal mineralisation known in the area west of Langholm, sampling was conducted at intervals downstream and near to sources of mineralisation in Pokeskine Sike, Green Burn and Mine Sike. These streams erode, respectively, coarse sandstone containing disseminated galena and cementstone with minor sphalerite and galena, a faulted contact of Carboniferous sediments against Birrenswark Lavas with galena in calcareous sediments, and a fissure vein with coarse galena-sphalerite-baryte-minor chalcopyrite in lava.

All concentrates were sub-sampled to 12 g and crushed with Elvacite 2013 resin in a tungsten carbide Tema Mill to minus 300 mesh. After pressing samples under a load of 15 tons, analysis of the discs was performed for the elements Ba, Sn, Pb, Zn, Cu, Ni, Fe, Mn, on a Phillips 1220C automatic X-ray spectrometer as described by Leake and Aucott (1972). The remaining 12-14 g of sample was retained for later mineralogical examination.

In close proximity to mineralisation at Pokeskine Sike, sediment and concentrate are both highly anomalous, but Pb and Zn levels in sediment fall to almost background concentration only 200 m downstream whereas the concentrate remains highly effective (see Table I, Appendix V). The fines sample fails completely to detect a Pb anomaly near to or downstream of the source, but 70 m upstream where the channel intersects a broad zone of metal enriched organic soil and till, the fines sample is enhanced in Pb and Zn relative to the sediment. The concentrate value is again higher by several orders of magnitude.

A few metres downstream of the old mine workings at Mine Sike, Ba, Zn and Cu levels are highly anomalous in concentrate, moderately anomalous in the fines and only slightly anomalous in sediment (see Table II, Appendix V). An upstream Pb anomaly is detected by the concentrate alone whereas downstream dispersion of all metals is significant over only a short distance (< 300 m). This may be attributable to a road-stream intersection impeding the natural process of clastic dispersion.

Minor mineralisation in Green Burn was effectively detected by concentrates in all samples collected within a distance of 150 m downstream of a lava-sediment interface (see Table III, Appendix V). Highly anomalous Pb, Ba, Cu and Fe values are accounted for by readily identifiable pyromorphite, traces of galena, baryte, cupriferous pyrite and large amounts of hematite. Stream sediments also register small but identifiable anomalies decaying rapidly with distance from source. No fines samples were collected at this locality.

The size distribution of ore minerals and other principal heavy mineral phases of specific gravity > 3.3 g/ml was compared in two large panning concentrate samples of -2 mm material collected a few metres downstream of outcropping mineralisation of Pokeskine Sike and Green Burn. For the total sample the grain size distribution was obtained by sieving and weight percentages of magnetic and non magnetic heavy fractions estimated from grain counts and corrected for density variations (see Appendix V, Table IV).

Several important differences are noted between the two sites. In the sample derived predominantly from mineralised sandstone with subsidiary cementstone the maximum abundance of sphalerite occurs in the middle size range (-0.50 mm to +0.25 mm) whereas galena tends to concentrate in the coarser fractions (+1.0 mm and -1.0 to +0.5 mm). These circumstances are reversed in the sample derived from the lava-sediment junction where smaller abundances of sphalerite are concentrated in the coarser sizes (1-2 mm) and pyromorphite in the finer sizes (+0.5 - 0.125 mm).

Abundant heavy mineral phases, particularly hematite may cause significant dilution of base metal anomalies. For this reason and because hematite relative to ore minerals is invariably concentrated in the +1.0 mm fraction, the routine collection of panning concentrates was based on the sampling of -1.0 mm stream sediment.

<u>Background variation in drainage sampling</u>

The efficiency of geochemical anomaly recognition is a function not only of the maximum concentrations recorded in the vicinity of mineralisation but also of the background metal content of samples derived from unmineralised lithologies. Estimates of background concentrations are based upon the collection of 27 concentrate-sediment pairs from streams draining apparently unmineralised Carboniferous sediments and lavas. Because of the small population, statistical parameters in Appendix V, Table V are intended to provide only a guide to the differences between the two sample types.

Arithmetic means and standard deviations for those elements primarily dispersed in relatively insoluble clastic grains are considerably higher in the concentrate, eg. Ba, Fe, Pb, and the degree of correlation correspondingly low between the two sample types (Appendix V, Table V). The background variations of Zn and Ni are similar for concentrate and sediment producing a strong but probably fortuitous correlation. Cu has a low regional background and is hardly detectable in the finer fractions of stream sediment. Only Mn has a significantly higher mean concentration in the sediments, implying a high degree of solubility and the well known enhancement in finer grain sizes due to coprecipitation and adsorption.

Summary statistics (Appendix V, Table VI) of 25 concentrate-sediment pairs from drainage affected by mineralisation, including samples described in the last section, demonstrate that mean values for concentrates are at least an order of magnitude higher in Ba, Pb and Zn, than values in sediments. Correlations are predictably high in both sample types for all elements associated with the mineralisation except Ba which exhibits no concentration at smaller particle sizes, and Mn which reflects a higher mobility and fixation in sediments. It is concluded from the results presented here that stream sediments adequately detect base metal mineralisation only when collected near to a discrete source and with much reduced sensitivity when compared with heavy mineral concentrates.

Chemical weathering rates of bedrock and detrital sulphides are observed to be low at altitudes of less than 230 m and under moderately alkaline surface water conditions (mean pH of 740 stream waters in the Langholm area is 7.7). Galena, baryte and to a lesser degree, sphalerite and chalcopyrite tend to occur in coarse grain sizes which persist in the stream sediment with only limited attrition and dissolution. However the overriding factor precluding the satisfactory use of stream sediments in this environment is the excessive dilution of anomalous material by vast quantities of clay grade glacial sediments.

A satisfactory compromise in optimising sample interval was found by collecting concentrates on average every 400-500 m along stream channels and by increasing the sampling frequency over geologically more promising areas or where local topographic and hydrologic conditions might result in shorter and poorly defined dispersion trains.

Contamination in drainage sediments

The correct identification of anomalies due to metallic contamination is an essential prerequisite to successful geochemical exploration. A broad spectrum of contaminating materials has been detected in stream channels originating from agricultural and forestry activities, a disused artillery range, intensive game shooting and a relatively dense road network. Appendix V, Table VII summarises the results of sample pairs collected from 14 contaminated sites. Tin mineralisation in this area is neither anticipated nor observed and the tin content of common rock forming minerals is consistently very low, thereby facilitating the use of tin as a contamination monitor. A threshold of 13 ppm Sn in concentrates is considered to be a reliable level above which contamination is implicitly assumed. Associated anomalies in other metals, particularly Pb and to a lesser extent Cu, are invariably related to contaminants although, rarely, detrital ore minerals and contamination are concomitant: for example in Bigholms Burn (3161 8245) galena occurs with slaggy metallic contamination in a concentrate. Stream sediments from the same sites contain either negligible or just detectable ($>$10 ppm) Sn values and do not reveal associated false Pb and Cu anomalies.

Regional distribution of lead in drainage

Fig. 12 illustrates the distribution of Pb in heavy mineral concentrates derived from drainage in the area west of Langholm. The data presented (315 samples

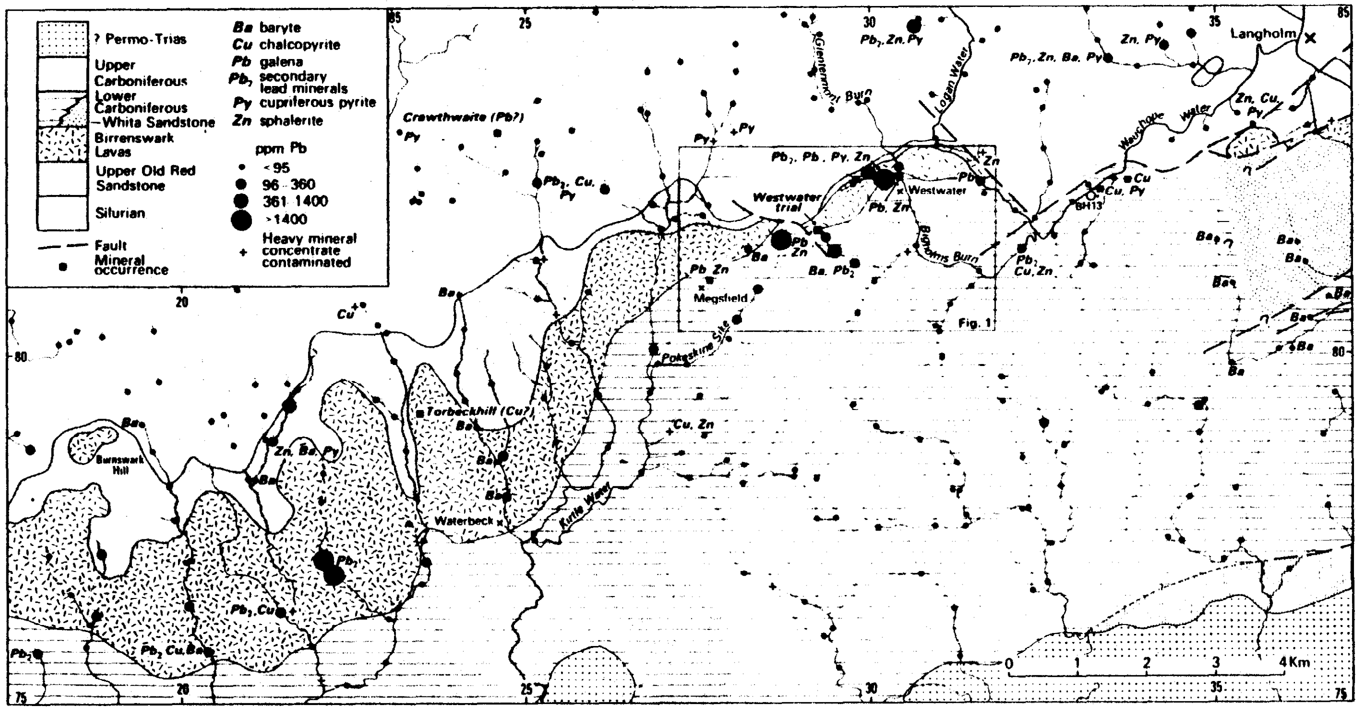

Fig. 12. Distribution of lead in heavy mineral concentrates from drainage west of Langholm.

over an area of 175 km^2) is an extract from the regional reconnaissance map of the Scottish Border region (in preparation). Class intervals defined by 'natural-breaks' in the cumulative frequency curve of the logarithmically transformed data are indicated by solid circles of increasing diameter. Coincident anomalies in other metals, where supported by mineral identification, are indicated by chemical symbols.

The statistical distribution of the data is complex and non-homogeneous due to a mixture of populations related to (1) mineralisation, (2) differences in background composition of the various bedrock lithologies, and (3) the presence of contamination. The effect of (3) has been largely removed by excluding all samples containing greater than 13 ppm Sn, excepting those in which the presence of detrital ore minerals has been established. There is a major discontinuity in the cumulative frequency curve at 95 ppm and Pb levels exceeding this value can be related to the presence of ore minerals in the concentrate. Anomalies related to contamination are distinguished by open circles.

As described under orientation, major lead anomalies occur principally in basal Carboniferous sediments at or near their junction with the Birrenswark Lavas between Callisterhall and Westwater. Along strike and approximately 8 km to the southwest a value of 3060 ppm Pb is recorded from Stoneybeck [2209 7706] where close interval follow-up sampling has located a concealed source of pyromorphite beneath till, some 400-500 m upstream of the original anomaly. Elsewhere, anomalies of lower magnitude (100-400 ppm) are explained by the presence of anhedral waxy-grey minerals of the plumbogummite-beudantite group in samples derived from a diversity of bedrock lithologies. Resampling has in all cases confirmed the anomalies but attempts to identify mineralisation have not succeeded due to paucity of outcrop and the probable low tenor of mineralisation. Several anomalous catchments in Silurian rocks

(Back Burn, 3347 8421; Arresgill Sike, 3068 8473; Dalbate 2520 8256) are tentatively ascribed to streams flowing along weakly mineralised faults or crush zones. Other elements (Cu, Zn, Ba) show enhancement in these areas and are attributed to the presence of optically identifiable cupriferous pyrite and rare chalcopyrite, sphalerite and baryte. Because of the relatively low magnitude of anomalies, their impersistent nature and unfavourable geological environment, detailed follow-up was restricted to rapid examination of float and available outcrop.

Further minor Pb anomalies appear to be due to secondary ore minerals, spatially related to the lava-sediment junction between Waterbeck and Ecclefechan and also to weakly mineralised calcareous sediments of Carboniferous age erratically distributed between Setthorns and Langholm.

Soil geochemistry

The dispersion of Pb and Zn was examined in soils lying above the projected strike extension of a galena-bearing sandstone unit exposed in the bed of Pokeskine Sike (see Fig. 14). Thin, grey-brown podzolic, and peaty gley soils are derived from the clay-rich, water-saturated tills. Impersistent, poorly formed B-horizons are apparent from the eluviation of iron and its irregular concentration in the top 40-50 cm of soil.

Close interval (10-20 m) profile sampling in three orientation soil pits revealed uniformly anomalous Pb and Zn values in the -150 µm fraction with the maximum Pb value (560 ppm) recorded in the deepest sample of the pit, 1-2 m downslope of the inferred mineralised suboutcrop. Till depths in the immediate vicinity are relatively shallow (1-2.5 m), facilitating the groundwater redistribution of till-derived heavy metals throughout the profile.

The 'buffering' effect on soil geochemistry of the very high proportion of clay present in the till, is well illustrated by examination of the size distribution of metals at a site 125 m east of Mine Sike (2940 8184). Levels

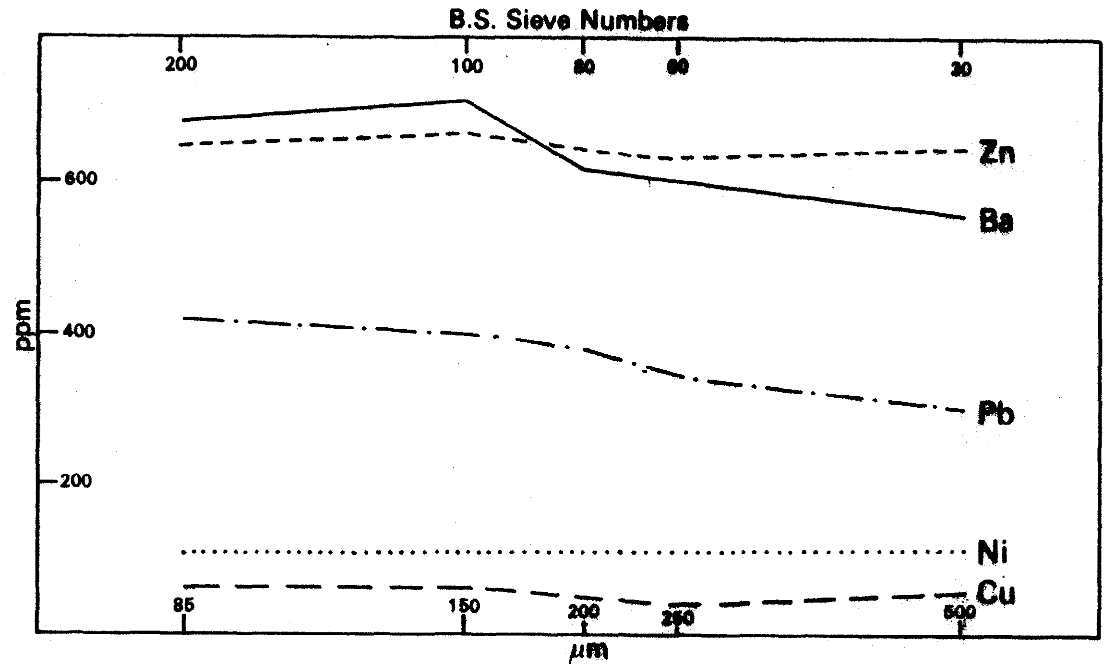

Fig. 13. Distribution of metals in different size fractions of anomalous soil east of Mine Sike (2940 8184).

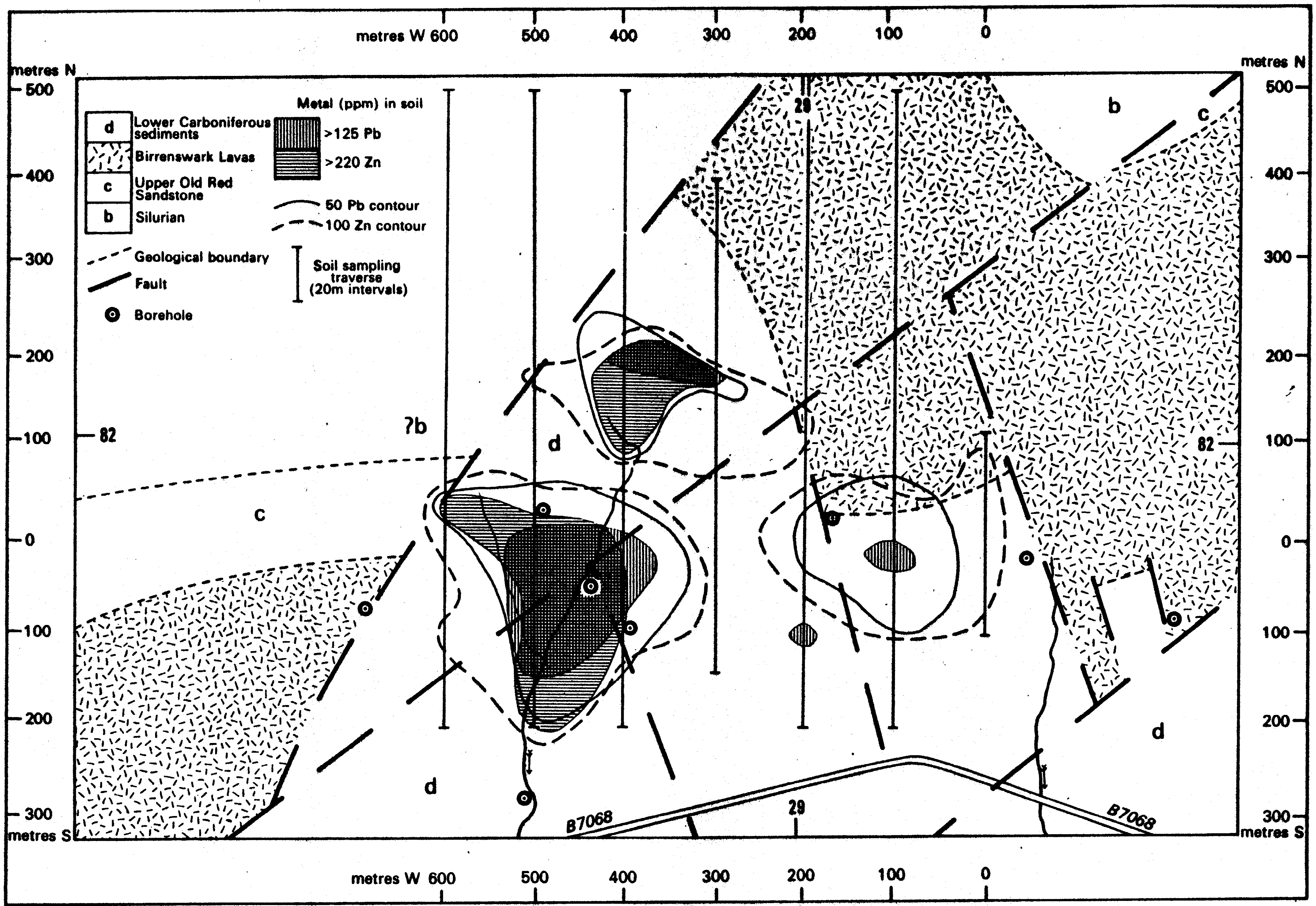

Fig. 14. Distribution of lead and zinc in 'C' horizon soils near Callisterhall.

of Pb and Zn are consistently anomalous over the size range examined (Fig. 13) and therefore no improvement in contrast results from screening at finer particle sizes (compare the contrasting results of Smith and Gallagher, 1975).

Further routine sampling of C horizon soils at an average depth of 0.60 m was based upon a 20 m sample interval on north-south traverses with a 100 m line separation. A high level of analytical agreement between XRF and AAS (hot nitric acid attack of -150 µm fraction) analyses for Cu, Pb and Zn over a range of concentrations confirmed that the lower cost and more rapid AAS method was an acceptable alternative for this sample type.

Threshold levels of 65 ppm Pb, 150 ppm Zn and 37 ppm Cu statistically calculated for the total population of 260 samples (see Appendix V, Table VIII) are somewhat lower than those quoted for similar environments in Ireland (Horsnail, 1975; Morrissey and Romer, 1973). However, three coherent areas of Pb-Zn anomaly were delineated (Fig. 14). The largest, apparently elongated for a distance of 130 m in a north-south direction, is sub-parallel to and straddles the headwater drainage of Pokeskine Sike. An intermediate anomaly centred some 80-90 m north-north-east of the main anomaly has a coincident high Pb-Zn core and trends approximately east-west, whilst a third is a roughly circular, high Pb-low Zn anomaly situated 350 m east of Pokeskine Sike and detectable over a distance of 100-130 m in all directions.

The relatively low geochemical contrast and the absence of a clearly defined source area for the near surface anomalies suggests that post glacial dispersion mechanisms are largely responsible for the observed distribution of patterns.

Till sampling

Guided by the recognition of limited geochemical dispersion in drainage samples and the generally poor contrast provided by shallow soils, an orientation programme of deep overburden sampling was initiated in the area between Pokeskine Sike and Mine Sike.

A power auger was used to penetrate the till to the bedrock interface in the manner described by Smith and Gallagher (1975). All material recovered from the lowermost 50-60 cm was combined to provide a 2-3 kg sample for on-site panning of a heavy mineral concentrate. A smaller 200 g sample from the maximum attainable depth was subsequently split to provide material for pH determination and the remainder dry sieved to -150 µm. Both sample types were analysed by XRF for the elements Ba, Sb, Cu, Pb, Zn, Ni, Fe and Mn.

Routine basal till sampling was conducted at 50 m north-south intervals along traverses with 100 m east-west spacing and supplemented by detailed profile sampling at selected sites on the 0, 100W, and 200W traverses where either mineralised rock fragments or panned concentrate ore minerals were observed. Additionally, the profiles of deep tills were sampled to examine possible geochemical variations between different stratigraphic layers in the drift.

In the area investigated (see Fig. 17) the till has an average depth of 3.3 m with a range of 1.2 to 9.3 m in 180 holes extending over a sampled strike-length of 3.5 km.

The magnitude of errors induced by the sub-sampling of predominantly coarse grained ore minerals are surprisingly small as demonstrated by precision calculations (Garrett, 1969) of the analyses for duplicate splits of 10 anomalous till concentrates.

Element	Precision (%)
Pb	2.6
Zn	14.3
Cu	1.0
Ba	9.3

Careful control at the end point of the panning operation helped to minimise error due to variable up-grading which, in extreme cases, could lead to unrealistically high concentrations. Heterogeneity of the sampling medium was also shown to be a serious source of error by replicate sampling at constant depth from several closely spaced holes. However, the combination of an initially large sample from at least the basal 50 cm of profile and analysis of a large representative sub-sample was considered to supercede the problem of in-depth heterogeneity.

Physical characteristics of tills

Texturally the tills are consistently clay rich exhibiting only minor variation between clay-silt and silty-clay except over the gently sloping valley sides adjacent to major drainage channels where thick sequences of stratified clay and sand rich bands separate up to five distinguishable layers of markedly different clast content.

Stone contents are generally quite small although in the basal 10-20 cm, and in shallow overburden over locally steep gradients, abundant angular clasts permit easy recognition of bedrock lithology. Further travelled clasts, many of which appear to be derived from Silurian shales and greywackes less than 0.5 km to the north, occupy the upper 2 m whilst the contribution from more local sources increases with depth thereafter. Apart from the presence of rare boulders erratically distributed in the upper parts of the profile, the finer till components (<0.5 mm) account for at least 90% by weight of the glacial sediments.

A wide variety of colours are developed laterally over the upper 2 m of till profile due to a combination of variable quantities of precipitated iron oxide, a fluctuating water table controlling redox reactions and the presence of relatively impermeable clay bands which restrict the vertical movement of ground waters. However in deeper tills the greater abundance of soluble iron in lava than in sedimentary rocks (see Appendix II, Table I) tends to impart a dark brown rather than a grey to buff colouration to the overburden thus providing a reliable monitor of the suboutcropping lava-sediment junction.

Till profile geochemistry

The extent to which the distribution of selected elements reflects the presence of disseminated lead and zinc mineralisation (at a site at 150W 50N) is illustrated in Fig. 15a. A sharp increase from background to highly anomalous concentrations occurs for all base metals associated with the mineralisation at depths exceeding 2 m in a manner similar to that described by Wilbur and Royall (1975) for copper in tills. Relative to bedrock, lead and zinc are concentrated in the sieved till by a factor of 2 to 3 and in the heavy mineral fraction by factors of 30 and 6 respectively.

Within the same anomalous area, 70 m downslope to the south west, a profile (at 200W 0N) exhibits two major anomalous zones separated by a barren section of 1.2 m. Bedrock mineralisation undoubtedly suboutcrops beneath the metal enriched basal till but higher in the till profile lava derived material containing only background metal concentrations may represent a different direction of glacial transport. The anomaly higher in the profile shows distinct enhancement in the heavy mineral fraction and is therefore assumed to be mainly the product of clastic dispersion, probably derived from the mineralisation at 150W 50N. Further evidence for this mechanism is provided by identical Pb/Zn ratios of 1.7 noted in the sieved till fraction in the upper till anomaly (200W 0N) and in the basal till at 150W 50N.

For anomalies of lesser magnitude the precise location of concentration maxima may very considerably in the till profile. At 0W 50N for example lead, zinc, copper and nickel show simultaneous enhancement between 1.0 and 3.8 m in depth, enclosed by background levels above and below (see Fig. 15c).

Over weakly mineralised lavas (200E 0N) metal anomalies are detectable in the basal 1.0 to 1.5 m of profile with values corresponding to 1-3 times background (Fig. 15b). A heavy mineral fraction may be advantageous under these circumstances where a higher degree of sensitivity may help distinguish

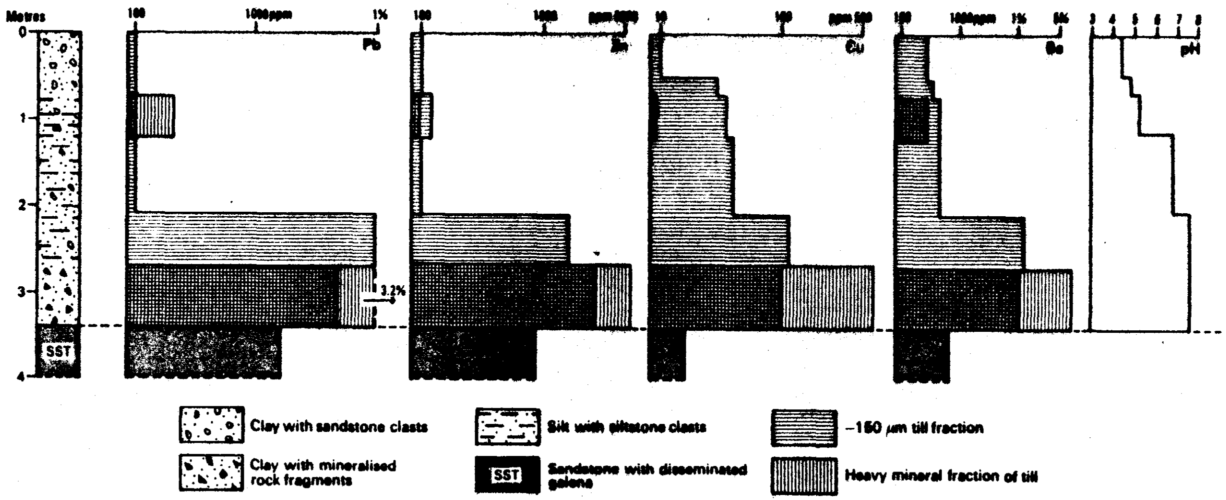

Fig. 15.a. Geochemical profile through soil and till overlying bedrock with low grade disseminated galena mineralisation (150W 50N).

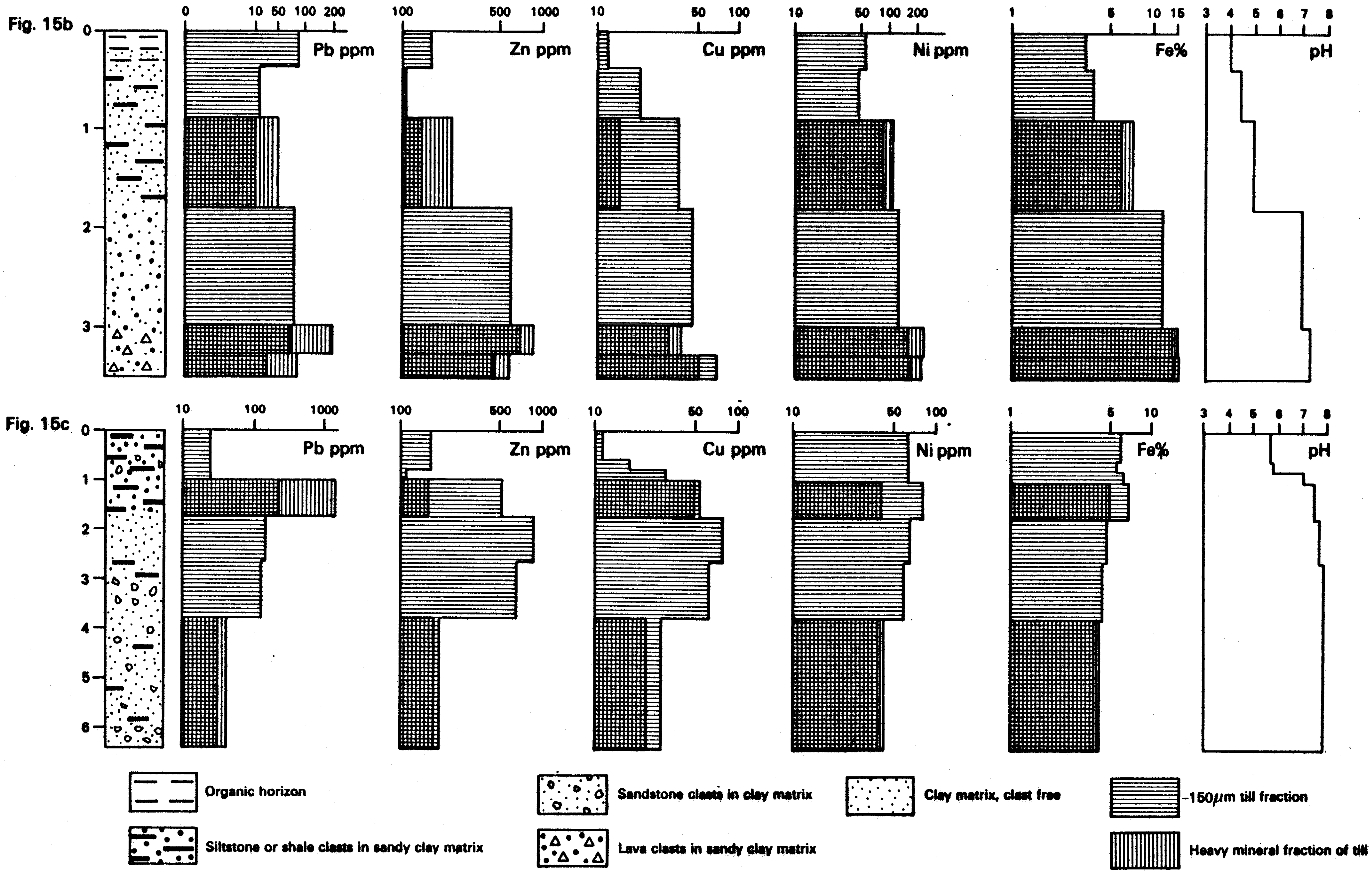

Fig. 15.b. Weak geochemical anomalies developed in basal till overlying lava near a mineralised lava-sediment junction (200E 0N)

Fig. 15.c. Geochemical anomalies developed in upper and middle till profile (0W 50N).

a genuine anomaly from enhancement due to a high background.

The characteristic feature of metal distributions in till profiles unaffected by mineralisation is the absence of any discernible trend for Cu, Pb and Zn except within the near surface zone of weathering where slight depletions may be noted. Background metal ranges are typically Cu 2-45 ppm, Pb 5-47 ppm, Zn 60-180 ppm in the -150 μm fraction of till with only very minor variations due to till composition. By contrast Ni, Fe, Mn and Ca show small increases toward the base of the profile over sedimentary rocks and more marked increases over the lavas.

<u>Anomaly patterns of metals in deep tills</u>

As compared with soil or shallow till sampling, anomalies located in deep tills are in general more numerous, of higher magnitude and more restricted in extent. The overall pattern in the heavy mineral fraction is one of discontinuous high intensity Pb and Zn anomalies erratically distributed in an east-west direction and spatially related to the conformable or faulted contacts of basal Carboniferous sediments with underlying lavas (Fig. 17a). In outline, individual major anomaly groups, defined by the 850 ppm inflections at Pb and 760 ppm Zn in the cumulative frequency plots may be highly irregular, bearing no obvious relationship to dip or strike directions in the underlying rock.

Identification of mineralised rock fragments in the profile of two holes on the 200W traverse (see Fig. 16) led to higher density sampling and subsequent definition of a narrow elongate zone of coincident high lead, zinc and minor copper values trending north-north-east for a distance of 300 m. Disseminated galena and minor sphalerite mineralisation in sandstone was discovered by shallow drilling near the centre of the southern lobe of the anomaly (borehole 9, see Fig. 1).

At upper Pokeskine Sike the lead anomaly centred on the 500W traverse is enclosed by a somewhat larger area of anomalous zinc (Fig. 17a). Both metals

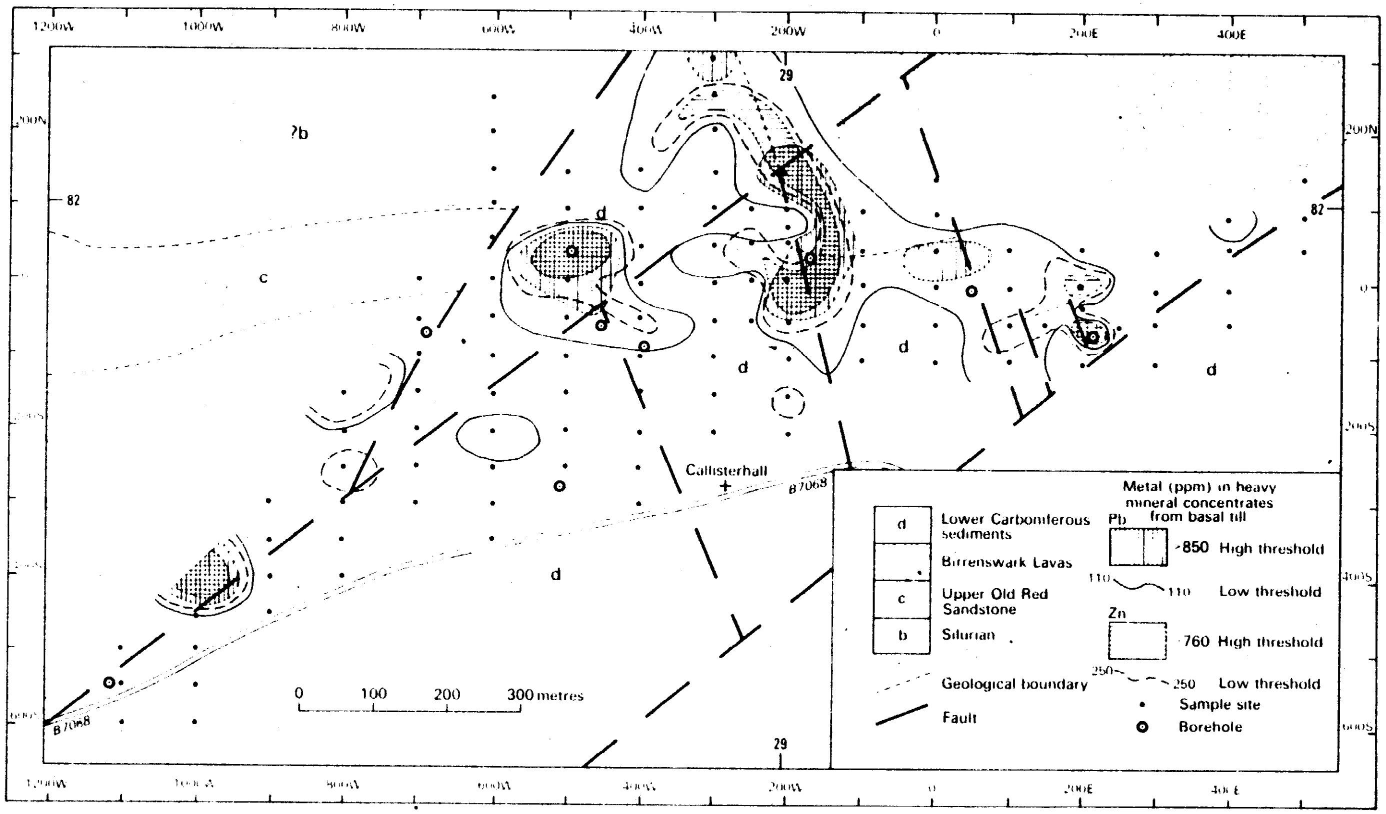

Fig. 17.a. Distribution of lead and zinc in heavy mineral concentrates from basal till near Callisterhall.

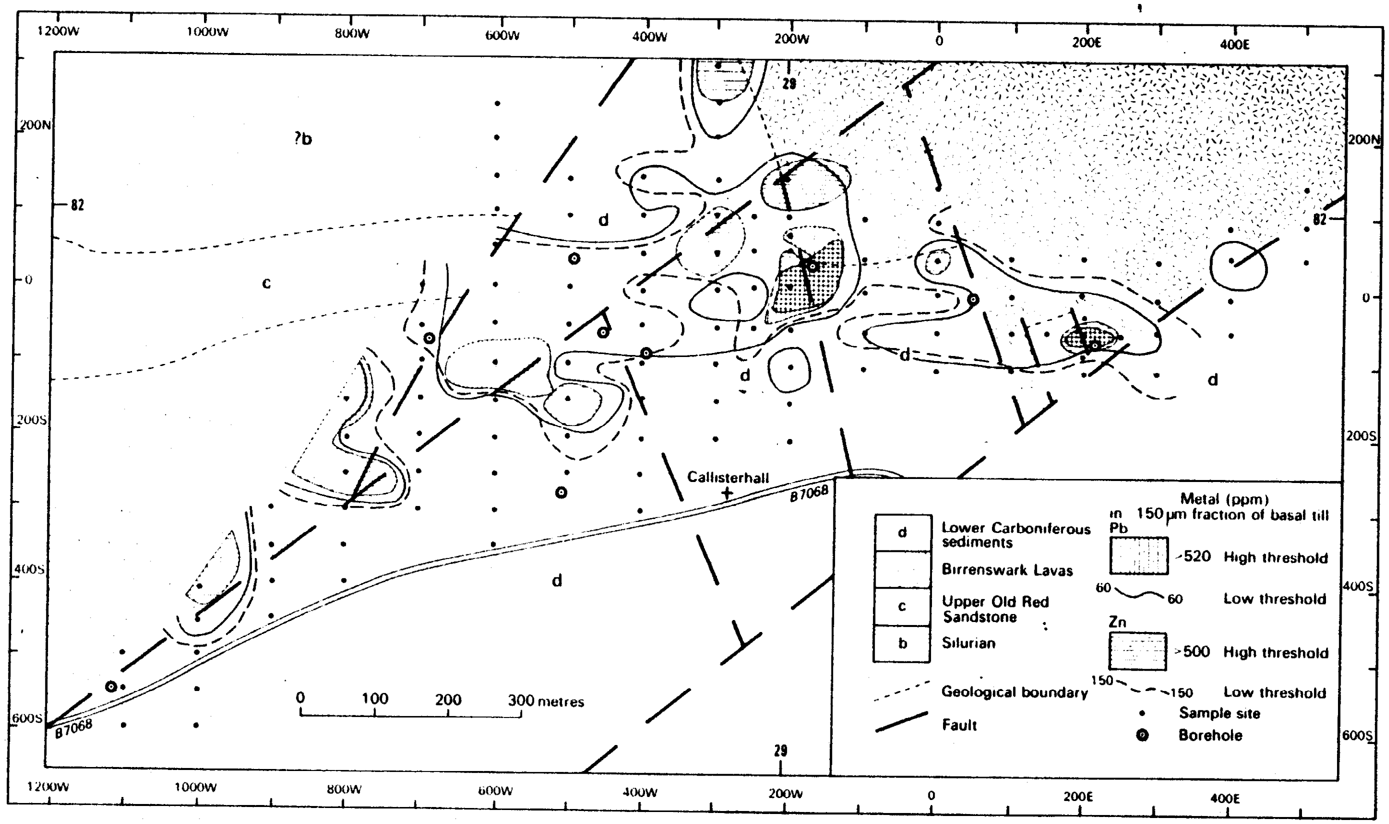

Fig. 17.b. Distribution of lead and zinc in -150 μm fraction of basal till near Callisterhall.

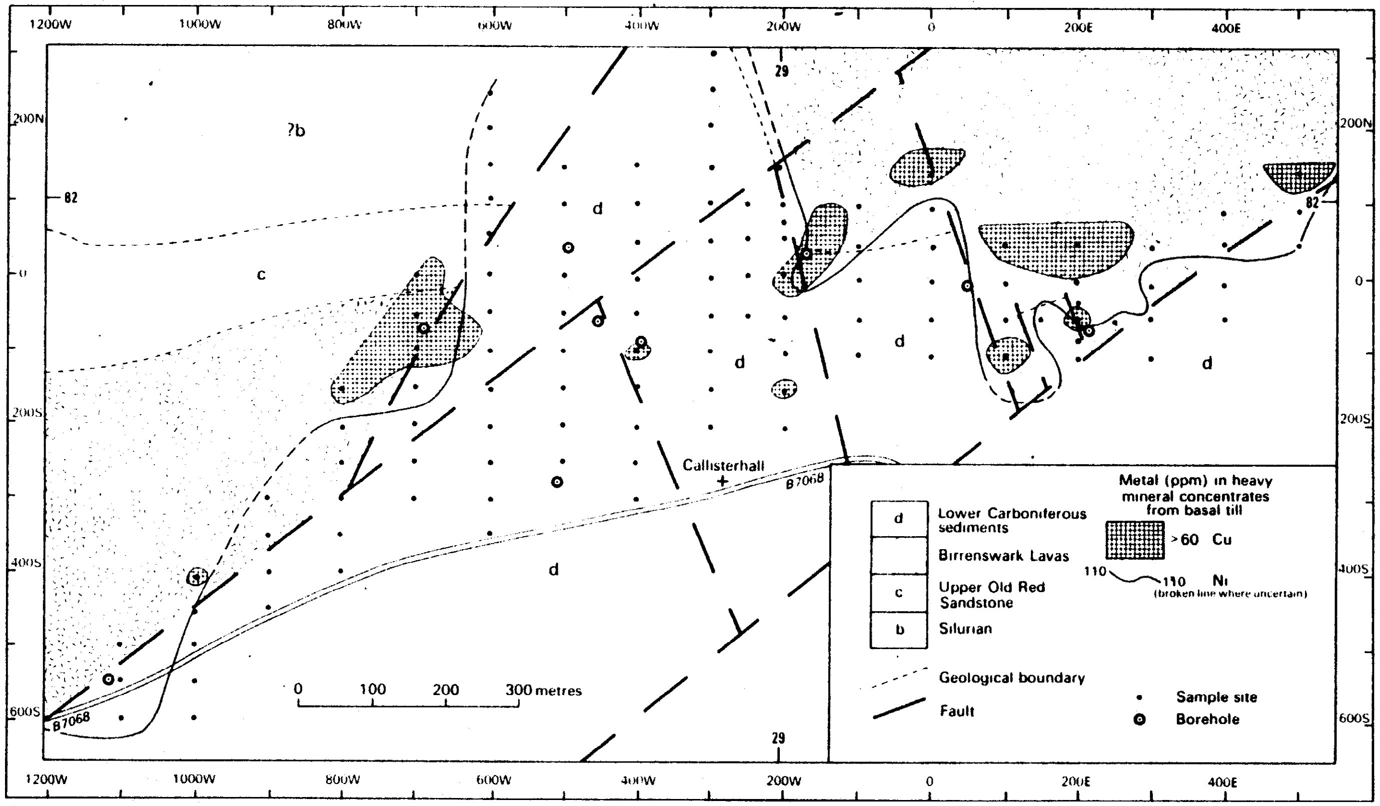

Fig. 17.c. Distribution of nickel and copper in heavy mineral concentrates from basal till near Callisterhall.

are however in lower abundance relative to sites 300 m east and subsequent drilling on this target (borehole 10) produced only minor amounts of galena and sphalerite in a sandstone-cementstone sequence.

Elsewhere, coincident high lead-zinc values occur at points on the 200E and 1000W lines dispersed over only limited distances of a few tens of metres. Because of the recognition of abundant coarse galena and baryte grains in the heavy mineral fraction these anomalies are attributed to narrow vein type mineralisation similar to that intersected by borehole 8.

Copper anomalies in basal till concentrates are of low magnitude (threshold 60 ppm), small in area and generally related to faulted lava-sediment junctions (see Fig. 17c) where chalcopyrite and pyrite may be locally disseminated in altered lava and in the adjacent fractured cementstones as exemplified by boreholes 11 and 12 (Appendix I, Tables XI-XII). Nickel is not observed to form an important constituent of any sulphide phases and its abundance in the heavy mineral fraction of the basal tills has been related to the mafic mineral component. Selection of a high threshold value of 110 ppm Ni reduces the effect of mechanical dispersion especially over locally steep gradients and is considered to delineate the lava suboutcrop (Fig. 17c). Geophysical, borehole and topographic evidence largely substantiate this conclusion but small discrepancies are possible because of the absence of geochemical information between traverse lines.

<u>Comparison of anomalies in panned till and -150 µm till fractions</u>

Essentially bimodal distributions characterise elements in the heavy mineral sample reflecting the improved anomaly resolution

whereas more complex sigmoidal distributions complicate recognition of meaningful thresholds for the sieved till fraction. Accordingly analysis of the sigmoidal curves was attempted using the method of Parslow (1975) and low anomaly thresholds selected from the upper limits of the background population appear in the table below.

Both the geochemical contrast and the number of identifiable anomalies are significantly greater for lead and barium in panned tills, whereas a larger number of zinc anomalies are observed in the sieved till fraction, but with reduced contrast. Summary statistics for all metals associated with the ore minerals and based on the total sample population appear in Appendix V, Table IX.

Element	Till concentrate		Till -150 µm fraction	
	Number of anomalies (expressed as % of total population)*	Threshold ppm	Number of anomalies (expressed as % of total population)*	Threshold ppm
Pb	20	110	16	60
Zn	12	250	19	150

* based on 140 sample pairs.

At twelve sites a significant Pb or Zn anomaly in the -150 µm fraction coincides with only background values in the concentrate. Examination of the till depths reveals that in every instance the sample originated from within the zone of chemical weathering (1.4 - 2.0 m). Higher mobility of trace elements within this zone would be expected to facilitate hydromorphic dispersion and simultaneously reduce the possibility of detecting detrital ore minerals. The partially coincident Zn-Pb anomaly detected only by the fine till fraction centred on 500 W in upper Pokeskine Sike is associated with shallow overburden of less than 1.5 m depth and considered to reflect this type of dispersion mechanism (see Fig. 17b).

In the deeper tills (>3 m) encountered 200 m due north, detrital galena and sphalerite are preserved resulting in a highly anomalous concentrate but only background metal levels in the -150 µm material.

A comparison of the spatial relationship between anomalies represented by the two sample types show broad similarity of pattern for zinc, although the position of major anomaly centres may be displaced downslope for distances up to 150 m in the sieved till fraction. At the low anomaly threshold levels (150 ppm Zn and 60 ppm Pb in the -150 μm fraction) a continuous but irregular E-W trending zone suggests minor hydromorphic dispersion from bedrock sources and sulphide grains concentrated toward the base of the till (Fig. 17b).

pH variation in till

As a guide to the expected mobility of metal ions dissolved from primary ore minerals in the till, pH measurements were made on untreated till-distilled water slurries at regular intervals along orientation profiles and routinely at the maximum sample depth. Typical variations are illustrated in Fig. 15 showing moderately acid conditions (pH 4.0 - 5.5) prevailing over the top 0-2 m zone of maximum eluviation, increasing markedly below 2 m to a constant neutral to mildly alkaline value, pH 7.4 - 8.0.

Statistical summaries of 130 pH determinations on tills classified by major parental lithology are shown in Tables X and XI, Appendix V. Sandstone derived tills have the highest mean pH and lowest correlation between pH and depth. By excluding measurements on till samples shallower than 2 m this result is unchanged for sandstone whilst for other lithologies the depth dependance of pH decreases beneath the surface weathering zone. In highly anomalous profiles reflecting underlying mineralisation there is a suggestion of a positive pH control with depth throughout the overburden.

The calcareous composition of the tills is a direct response to the high abundance of carbonate rocks in all basal Carboniferous lithologies, thus providing an inexhaustable reserve of bicarbonate anions on reaction with groundwater. Sulphide grains existing beneath the zone of eluviation and oxidation are therefore preserved to a large extent under the neutral to mildly alkaline and invariably waterlogged reducing conditions.

Till mineralogy

Mineralogical observations based on heavy mineral separations (specific gravity > 3.3 g/ml) supplemented by XRF and XRD confirmations have identified variable proportions of galena (often with cerussitic overgrowths), fresh sphalerite, chalcopyrite, tarnished cupriferous pyrite, and pyrite in varying stages of oxidation. The presence of significant concentrations of zinc, and less commonly lead, associated with coarse grained secondary iron oxides replacing ferromagnesian minerals is particularly evident in samples from the anomalous areas on the 1000W and 200E traverses. Faulting near to lava-sediment junctions is thought to have accelerated oxidation of sulphides and primary iron minerals prior to glaciation at these localities. Dispersion in the tills is limited to a small area and unlikely to have been modified to an appreciable extent by post-glacial processes.

Mineralogical comparison of the light and heavy fractions of till proved useful in indicating the genetic associations between fine grained galena and minor sphalerite in sandstone (500W 0S), coarse galena-sphalerite-baryte-minor chalcopyrite in mixed lava and sedimentary lithologies (150W 50N and 200E 50S) and minor amounts of fine grained galena-sphalerite in fine grained calcareous and mixed mudstone-siltstone lithologies (175W 50N, 500W 50N, 0W 50W).

Interelement correlations in tills

Improved anomaly contrast of till concentrates is reflected by stronger positive correlations between the ore elements compared with the sieved till fraction, but interelement associations are essentially very similar (see Appendix V, Table XII). Zinc is somewhat exceptional, exhibiting a close and sympathetic relationship with iron and nickel which are presumably related to the heavy minerals derived from mineralised lavas. Barium has an unexpectedly low correlation with zinc in both sample types whereas copper and lead are associated with barium throughout the represented particle size range.

Most correlations are easily understood by reference to the data on bedrock geochemistry summarised in Appendix II, Tables I-VII. The effects of solution and manganese with the more soluble trace elements, typical in acidic ground water conditions, are not apparent in the finer particle sizes of these calcareous tills.

<u>Till anomalies east of Glentenmont Burn</u>

The eastern limit of mechanical auger sampling coincides with St. Brides Hill [3130 8207] which forms a flat topped NW-SE ridge, approximately midway between Glentenmont Burn and Logan Water. Two isolated lava outcrops 50 m northwest of the end of a 530 m traverse provide the only evidence of bedrock lithology. Overburden depths in the vicinity of these outcrops are relatively shallow ($<$2 m) increasing southeastwards (4-6 m) in the assumed down-ice direction. The 100 m sampling interval was decreased towards the northwest end of the traverse where examination of till clasts indicated the close proximity of the lava-sediment junction.

A major Zn-Pb anomaly extends throughout till profiles (A, B and C) and laterally for a distance of some 30 m (Fig. 18). The marked increase in concentration with depth in profiles A and B was considered to be a favourable indication of underlying bedrock mineralisation. An extensive Zn anomaly in shallow soils sampled by hand auger can be traced for a total traverse length of 130 m, enclosed to the northwest and indicating a higher degree of hydromorphic dispersion compared with tills of the Callisterhall area. The profile variation of Pb is similar, but this metal has a more restricted dispersion train (80 m) in shallow tills, and is subsidiary to Zn in all samples.

From the available information, the geochemical anomaly probably originates from a bedrock source of limited subsurface outcrop located beneath site A. In cross section, the major anomaly outlined by the 1000 ppm Zn and 250 ppm Pb contours shows a predominant dispersal in a

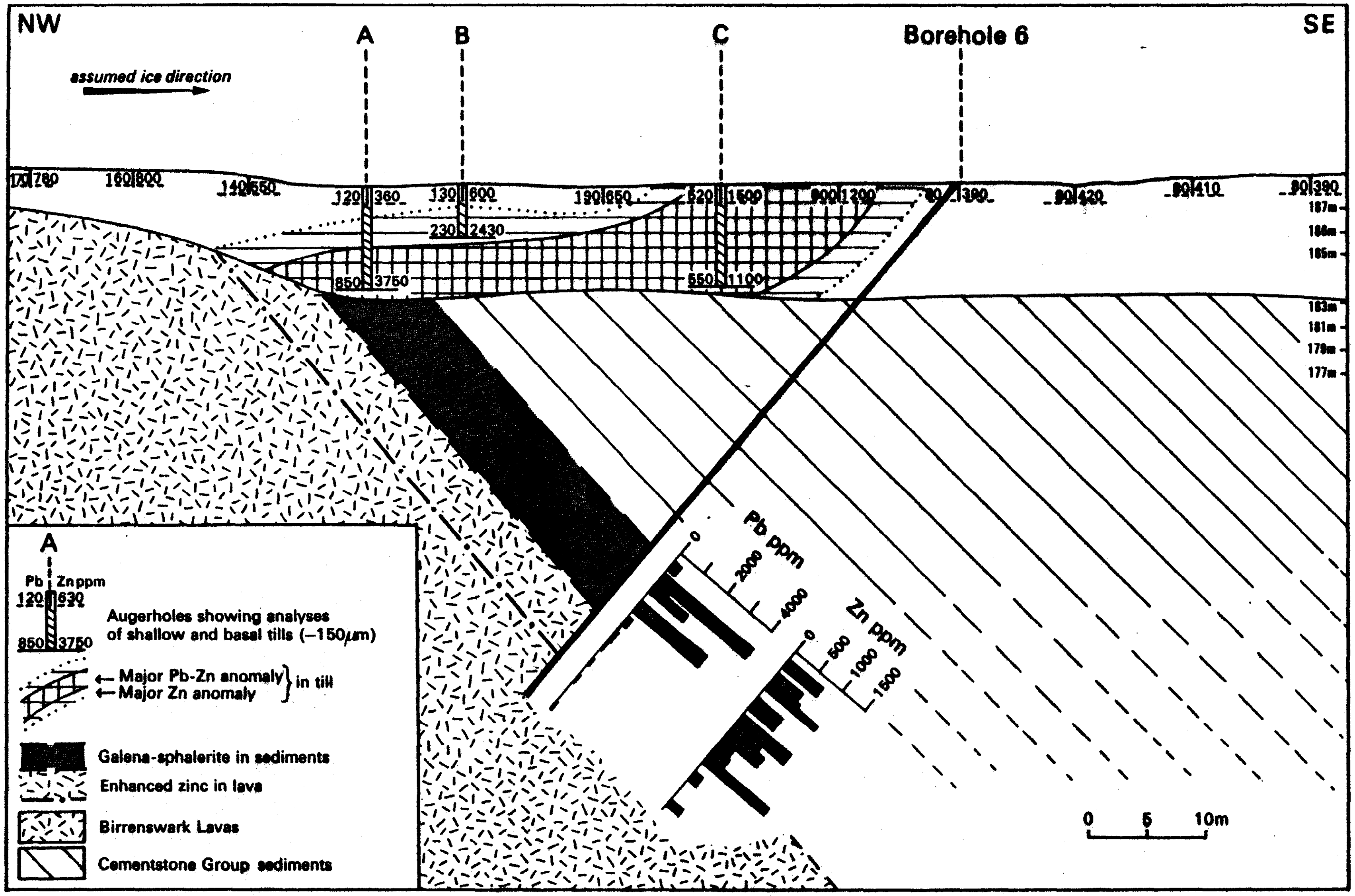

Fig. 18. Section through till and bedrock, St Brides Hill, showing relationship between lead and zinc in till and mineralisation in borehole No. 6. (3106 8249).

down-ice direction and a displacement of approximately 40 m to the south east as reflected by the shallow tills.

Borehole 6 intersected Pb-Zn mineralisation in a cementstone-sandstone sequence immediately overlying amgdaloidal lava. The overburden anomaly is considered to represent the projected suboutcrop of this zone of mineralisation and the Zn enrichment is associated with the highly altered (oxidised) top 3.0 m of lava. It is significant to note that mineralogical comparison of light and heavy (+3.3 g/ml) fractions of the panned tills revealed a high proportion of zinc in association with finely dispersed hematite (after ferromagnesian minerals) in lava fragments and only a minor contribution from detrital sulphides. Fault movements along the lava-sediment junction similar to that noted in Glentenmont Burn (Appendix III, Table IX) where Zn and minor Pb are also concentrated, may have induced localised weathering followed by scavenging of metals by secondary iron oxide phases.

A major copper anomaly (up to 1300 ppm) is present in the panned concentrates of a basal grey clay-rich till occurring at two adjacent sites [3083 8229] 50 m apart, 300 m due east of Westwater farm. The anomaly is not reproduced in the fine fraction. A sharp cut-off in copper values is noted at the boundary between the basal till unit and a thick (up to 5.5 m) stony brown till considered to be a reworked ablation deposit. The anomaly was investigated by deep sampling on a 25 m rectangular grid over an area 75 x 100 m. Abundant fresh pyrite, marcasite and small quantities of chalcopyrite were observed in panned concentrates from a zone 25-50 m wide coincident with a shallow topographic depression trending N 60°E. The light mineral assemblage of the mineralised samples consist of abundant angular quartz grains implying derivation from a sandstone lithology. Because of the small scale of the anomaly, its probable relationship with a fault and the predominance of iron sulphides no further evaluation was undertaken.

Reconnaissance overburden sampling southwest of Callisterhall

To the south-west of the area of detailed follow-up, deep overburden sampling was undertaken at a reconnaissance level using the mechanical auger or Cobra percussion drill to recover basal tills. The results for five traverses separated by distances of 1 to 1.5 km and orientated at right angles to the strike of the Birrenswark lavas, are summarised in Appendix IV, Tables II and III.

Uniformly low concentrations of Cu, Pb and Zn were recorded for all except traverse C (Appendix IV, Table III) located 100 m west and sub-parallel to Stoney Beck where drainage concentrates contain up to 3400 ppm Pb and significant amounts of pyromorphite. Moderately anomalous Zn and low anomalous Pb values occur both in the till concentrate and the -150 µm fraction of till at three adjacent sites near to the northwest end of the traverse. A further investigation based on a 50 m square grid was carried out at a late stage in the investigation but analytical results are not yet available. Optical examination of selected concentrates did not detect any ore minerals, the main concentration of Zn being associated with hematite.

Geochemistry of tills collected from the Frigg gas pipeline trench

The Frigg pipeline trench provides a continuous section through overburden in the southwest part of the area of Fig. 1. Samples were taken at intervals over 2700 m of trench southeastwards of the B7068 road crossing at Megsfield [2765 8112]. Basal tills were sampled from the trench walls close to the bedrock surface or, where bedrock was not exposed, from the bottom of the trench. Cu, Pb, Zn analyses of the -150 µm fraction are reported in Appendix IV, Table I.

Low anomalous Zn (maximum 220 ppm) and isolated high Pb (620 ppm) and Cu (80 ppm) values occur over the first 200 m of trench and are ascribed to minor galena sphalerite-pyrite mineralisation in cementstone blocks close to the lava-sediment junction: A zone of enhanced Cu values (maximum 350 ppm) extends for 520 m in shallow overburden at the southern extremity of sampling and appears to be related to suboutcropping red-brown mudstones in the purplish coloured sandstone group of the Lower Carboniferous.

The geochemistry of overburden and bedrock from the trench section provides convincing evidence that the type of mineralisation investigated in upper Pokeskine Sike and Mine Sike is confined to an east-west zone in the close vicinity of the Birrenswark lavas, at the margin of the Northumberland basin and does not extend southwards in arenaceous rocks exposed in the pipeline trench.

Geochemical variation in bedrock

Background trace element abundances were compared in the various lithologies of the Westwater district by selecting small numbers of unmineralised samples from the borehole cores (Appendix II, Table I and Fig. 19). Lead and zinc show minor enhancements in lava and cementstone relative to the remaining sediments. Copper and nickel are also significantly enriched in lava except in some of the very highly altered specimens where depletions are apparent. It is feasible therefore to associate chalcopyrite mineralisation represented in boreholes 11 and 12 with a process of copper leaching by late hydrothermal solutions circulating in the lavas.

Major element variations excluding manganese are consistent with petrographical observation and the order of abundance of mineral phases. The strong positive correlation and high absolute abundance of manganese and calcium in cementstone is indicative of co-precipitation of manganese oxide with carbonates in a brackish shallow water environment. The relatively high calcium content of sandstones undoubtedly represents carbonate cement commonly observed in this lithology and the high iron of mudstones may be attributed to precipitation of microscopic pyrite grains or the fixation of colloidal iron oxides deposited simultaneously with clay grade sediment. The

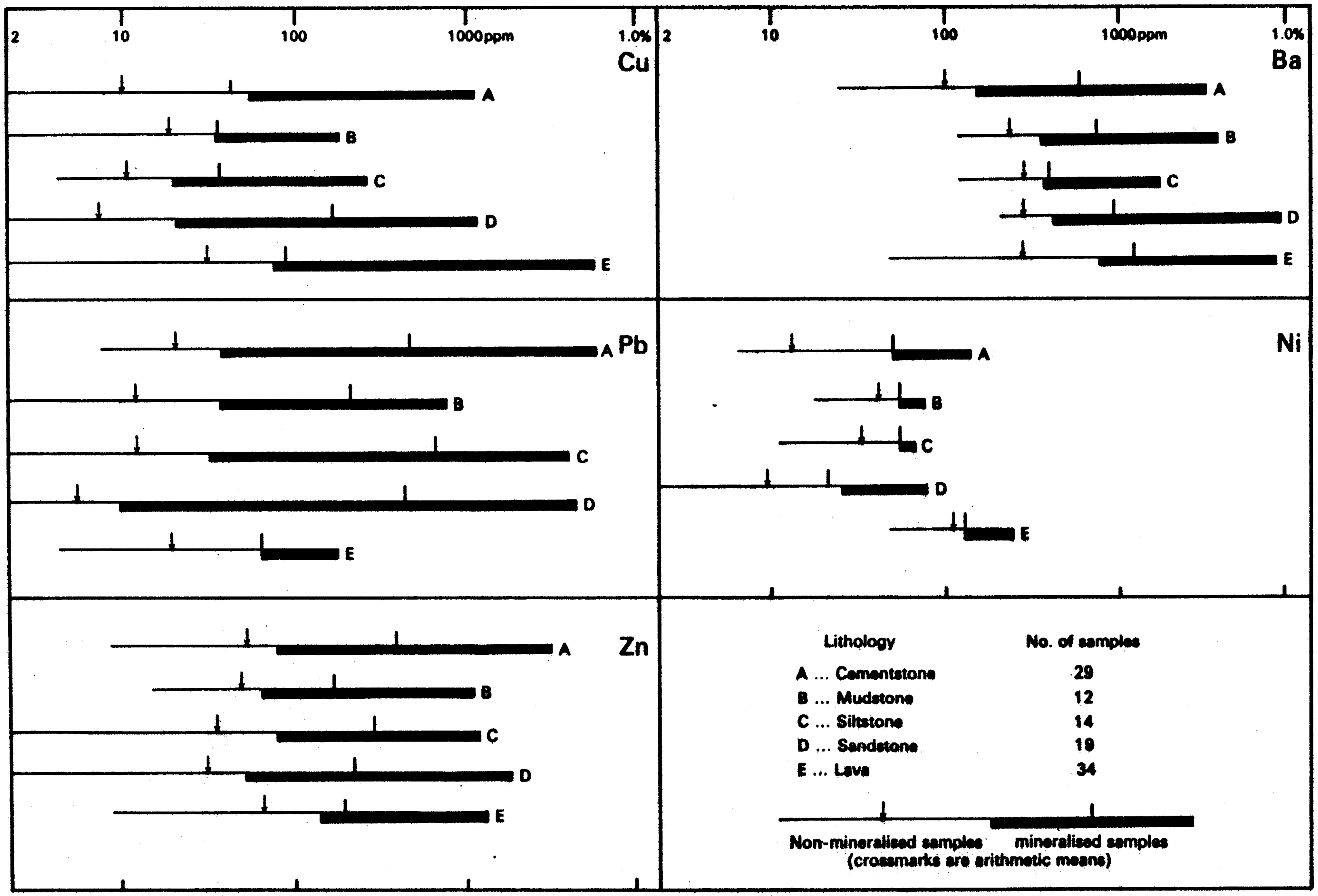

Fig. 19. Comparative metal content of borehole core samples from the Callisterhall-Westwater district, based on XRF analysis of 96.8 m of core. The average metal contents of mineralised and non-mineralised samples of each lithological type are indicated by cross marks.

possibility that the erosional products of lavas have been incorporated into siltstone and mudstone is evident from the enhanced titanium and nickel values compared with coarser grained sandstone and the chemically precipitated cementstones. Alternatively this geochemical similarity may arise from tuffaceous material indistinguishable in the fine grained detrital sediments.

The degree of association between different elements within lithologies is compared by means of correlation coefficients. For the majority of elements, correlations simply reflect high elemental abundances associated with sulphide mineralisation. Copper is unusual in showing no significant positive correlations at the 99.9% level thus copper mineralisation and lead-zinc-barium mineralisation are unlikely to be genetically associated despite the presence of small amounts of chalcopyrite in the mineral vein intersected in borehole 8.

Conclusions

As a result of glacial dispersion over short distances and post-glacial mass movement over locally steep gradients, the interpretation of geochemical patterns in shallow till and soils ($<$ 2 m deep) is complicated, but at greater depths the distribution of ore metals as defined by the heavy mineral fraction is closely related to suboutcropping mineralisation. The correct interpretation of till geochemistry leading to identification of drilling targets requires a knowledge of metal distribution down profile and of the partitioning of metals between heavy and light fractions of till, as well as the collection of a routine sample from the till-bedrock interface. Identification and classification of clasts 1-6 mm in size provides a rapid and simple method of studying dispersion parameters in the vicinity of known bedrock lithology changes.

MINERALOGY

Preamble

In the mineralised area base metal sulphides and associated minerals occur in bedded sediments of a variety of lithologies and in the underlying basalt lavas. Borehole evidence shows that although sandstones and siltstones together form the greater part of the sediments, mudstones and cementstones are generally significant. Intercalations of siltstone, mudstone and cementstone occur within the lava sequence.

Galena and sphalerite are the most common ore minerals present. Chalcopyrite and baryte are found in some parts of the area. Other ore minerals in the area include cerussite, smithsonite, graphite, gypsum, pyromorphite and malachite.

Dolomite, ferroan dolomite, pyrite and marcasite are the principle gangue minerals, accompanied by varying but generally small amounts of quartz and calcite. Mineralisation occurs mostly in or adjacent to breccia zones or networks of veins. Disseminated mineralisation occurs in two situations. The first is the presence in most of the cementstones of fine disseminated pyrite. The second is the presence of dispersed, relatively large crystals of galena often accompanied by sphalerite in certain beds of sandstone.

Despite the dominant role played by veining in controlling the mineralisation locally, it is evident that other structural factors guided its location and overall development.

The following account is a synthesis of mineralogical data compiled in Appendices I and III. The information presented incorporates results reported in I.G.S. Mineralogy Unit reports, notably those by Easterbrook (1976) and Fortey (1975; 1976).

Lithological control of mineralisation

The degree of local control by wall rock lithologies over the mineralisation was investigated by measuring the drill-core intersections of mineralised and barren rocks of different lithologies. Results given in Table 2 suggest that no lithology shows a consistent tendency to be mineralised more than the others.

TABLE 2

Mineralisation expressed as proportions of the different lithologies which show significant levels of mineralisation.

The results were obtained by measuring drill-core logs on which lithological variations are recorded alongside data recording the extents of geochemically anomalous core-samples. Owing to the limited availability of suitable information this approach could be applied only to certain drill-holes.

Drill-holes	6	7	8	9	11	12
Cementstone	17.6	47.7	16.6	29.9	76.8	38.7
Sandstone	63.3	9.0	32.8	62.5	9.7	33.3
Siltstone	71.2	0	0	0	90.4	0
Mudstone	36.4	0	0	0	23.7	5.8
Lava	8.7	9.5	37.1	20.9	8.2	42.1

Mineralogical sampling

Samples were collected primarily to investigate occurrences of mineralised rock rather than the full range of rock types present. In the case of the surface rock samples described in Appendix III this bias is enhanced by the restricted outcrop in the Westwater area. Hard cementstones account for more than half of the surface collection. The bias has made it impossible to give petrographic details of the mudstones and there is very little information on the siltstones.

In the following sections the lavas, cementstones, and sandstones are described. Petrographic data on which these passages are based are summarised in Appendices I and III.

Lavas

Basalt and dolerite lava form a compact sequence containing small intercalations of red siltstone, mudstone and cementstone (Fig. 2). These form a part of the Lower Carboniferous Birrenswark lavas described by Pallister (1952), Elliott (1960) and Lumsden et al. (1967). The flows are alkali basalts similar to the Lower Carboniferous basalts of the Midland Valley of Scotland (MacDonald, 1975). West of Langholm they are dominantly microporphyritic feldspar-rich Jedburgh types. The rocks are vesicular and rich in amygdales. Chloritisation and calcitisation are widespread. Lumsden et al. (1967) noted that breccia-veins in which lava fragments are set in a carbonate matrix break across flows in outcrops on Arkleton Hill north northeast of Langholm, and it is possible that this phenomenon is similar to the mineralised brecciated lavas in the area under investigation.

In all, 51 lava samples were examined, of which 13 consisted of brecciated lava set in a carbonate cement and all but two show moderate to strong alteration (see Appendices I and III). The rocks are mostly sparsely porphyritic Jedburgh and Markle types in which phenocrysts are labradorites and a small number of olivines. Two samples are of aphyric basalt.

Chloritic alteration of mafic silicates accompanied by calcite and minor sericitic feldspar alteration is normal. Hematite is commonly present, but pyrite is rare and magnetite has not been located. Amygdales usually consist of calcite with lesser amounts of chlorite and clay minerals. Zeolites are not common, but do occur in amygdales in certain specimens. Advanced illite-rich alteration in sample BFR 3606 (Appendix III, Table XI) is comparable with bole-type deep weathering (D J Morgan, pers. comm.).

The breccia zones consist of lava fragments set in dolomite and ferroan dolomite, and are frequently mineralised (see below).

Partial analyses of core samples of the Birrenswark Lavas that are relatively free of alteration and mineralisation are shown in Table 3.

TABLE 3

X-ray fluorescence analysis of core samples from the Birrenswark Lavas

	A		B
		%	
Ca	7.6		7.1
Ti	1.0		0.9
Mn	0.1		0.1
Fe	6.3		6.7
		ppm	
Ni	110		105
Cu	33		135
Zn	66		283
Ba	295		1750
Pb	19		78
No of samples	11		23

A basalt relatively free of alteration and mineralisation

B mineralised basalt

Cementstones

Beds of fine to medium-grained carbonate rock occur throughout the mineralised area. Thicknesses rarely exceed one metre and are generally closer to 0.2 metres. The most common lithology is that of a yellowish microcrystalline lutitic deposit containing darker intraclasts and detrital quartz, microcline and fine quartzite grains. Minute crystals of hematite and geothite are common, and it is likely that the general colouration is due to iron staining. Fine disseminated pyrite is often present.

Macrofossils are uncommon. Where present they are usually small lamellibranch valves (fragmented or entire) or plant debris. No investigations of microfauna have been attempted.

Local lithological variations are considerable. Banding expressed by the detrital fractions is not uncommon, and the proportion of detritus varies considerably. One sample (BFR 3598; Appendix III, Table VI) consists in part of approximately equal amounts of detritus and matrix, in which the detrital grains are dispersed so as to form a non-self-supporting fabric.

A small number of cementstones are peloidal. In rare cases sparry peloids (spheroidal microsparite clasts derived by erosion of intraclasts according to Leeder, 1975) and ooids of dolomite occur in a sparry dolomite matrix. In one sample (BFR 3533; Appendix III, Table III) sphalerite apparently of syngenetic or allogenetic origin occurs as angular anhedra within peloids, while minute blebs of pyrite are a trace constituent confined to the sparry matrix (Fig. 20). A similar occurence of sphalerite has been noted in sparry calcareous dolomite (BFR 4947) from outcrops in Hog Gill east of Langholm (NGR 4624 8938; report in preparation).

Sparry cementstones are subordinate to the lutitic lithology. In all cases the sparry rocks were found to be dolomites. Most contain detritus and trace amounts of fine disseminated pyrite. Some contain macrofossils. Sample BFR 3593 (Appendix III, Table XI) shows partial conversion has caused the development of a sinuous boundary between the lithologies in this rock.

Cementstone in outcrops in Pokeskine Sike (Appendix III, Table IV) are rich in small spheroidal bodies of coarse dolomite, often having cavities at

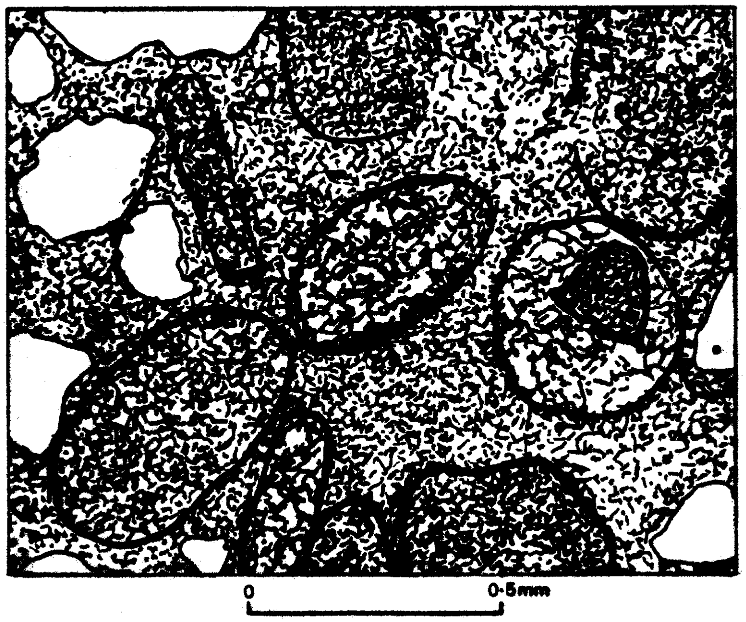

Fig. 20

Dolomite peloids and detrital quartz grains set in sparry dolomite cement. Note the presence of an angular crystal of sphalerite in one of the peloids.
BFR 3533 (Appendix III, Table III).

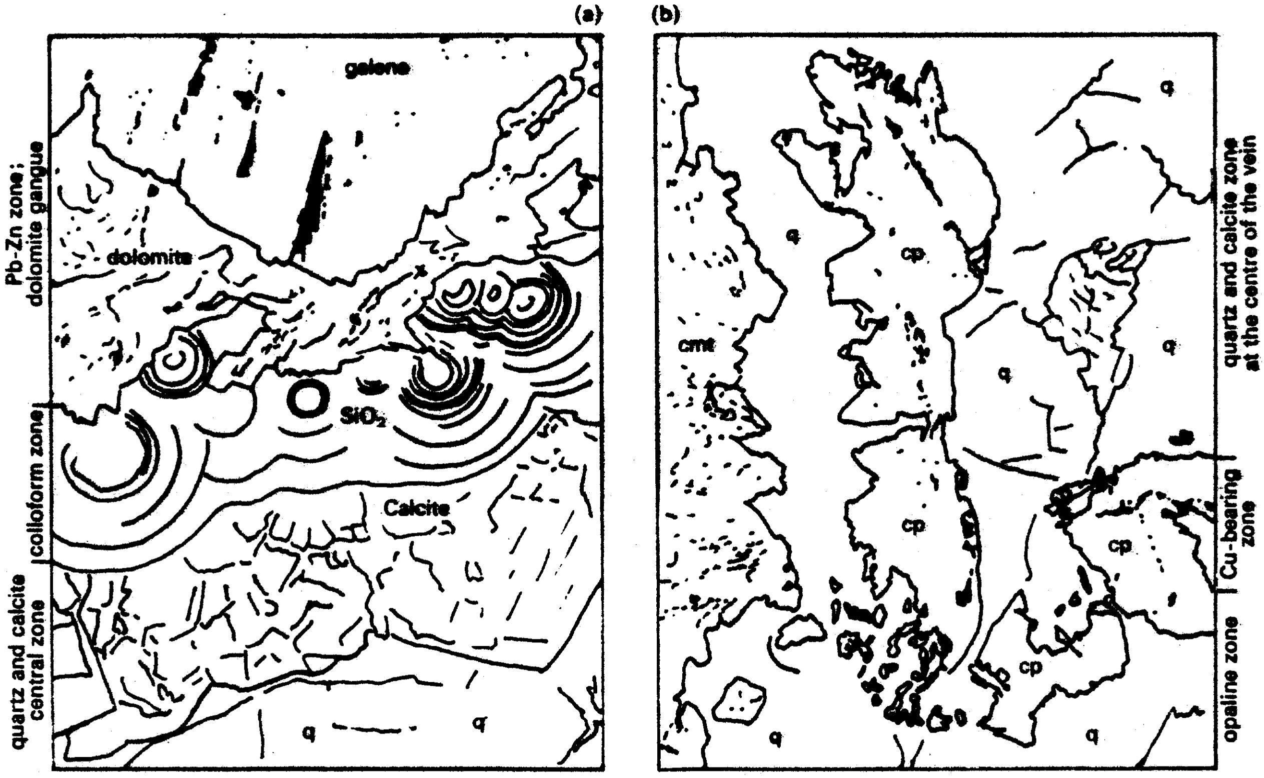

Fig. 21

Zoned sulphide-bearing vein in dolomitic cementstone (cmt). In (a) galena was deposited before the layer of coloform silica: in (b) chalcopyrite is seen to have been deposited at a later stage. Quartz - q; chalcopyrite - cp.
BFD 3647 (Appendix I, Table I).

their centres. Similar material was collected from borehole 2 (Appendix I, Table II, 25.52-26.12 m) and from a boulder in the bed of Wauchope Water (Appendix III, Table XI). The origin of the spheroidal bodies is not clear. Their distribution in outcrops shows some bedding control and is not related to the later veining. Adjacent ones tend to be separated by a thin wall of host sediment. Although coarse dolomite is the usual infilling, central zones of calcite are sometimes present. Where a central vug is present euhedral crystals of sphalerite (sample BFR 1049; Appendix III, Table IV) or gypsum (sample BFR 3400; Appendix III, Table IV) may be present.

It is suggested that the spheroids developed in original cavities formed before lithification by the trapping of bubbles of gas. The gas may have been methane of biogenic origin or have originated within the underlying lavas.

Staining of the cementstones produced in all cases a mauve colouration indicative of ferroan dolomite or ankerite (Allman and Lawrence, 1972). This is confirmed by XRD examination of crushed material (D Atkin) and by sluggish reactions with cold 5% HCl solution. Partial analyses of eight specimens of cementstone selected from the drill cores provided further confirmation. The results (see Table 4) show that the rocks are made up largely of ferroan dolomite, calcite and quartz. Estimates of the dolomite and calcite proportions assume that all the Fe and Mg occur in dolomites in which Ca/Fe + Mg = 1, and that all the Ca is partitioned between such dolomite and pure $CaCO_3$. Obviously this gives only a simplified indication of the true make-up of the rocks.

Deer, Howie and Zussman (1962) cite an Mg:Fe ratio of 4:1 as the critical divide between dolomite and ankerite. On this basis five of the eight specimens appear to contain ankerite rather than dolomite. However, the presence of pyrite and Fe-oxide minerals must lead to an over-estimate of $FeCO_3$ in this simple treatment. It is probable that in BFD's 3734, 3780 and 3781 ankerite occurs, while in all the others a ferroan dolomite is present.

TABLE 4

Semi-quantitative XRF analyses of cementstones

Results for Fe, Ca and Mg expressed as carbonates, Si as oxide

Drill hole	10	10	11	12	12	6	6	6
Sample number (BFD)	3705	3706	3726	3731	3734	3774	3780	3781
Depth (m)	28.06-29.92	29.92-30.38	45.35-45.75	48.75-49.99	51.62-51.90	22.40-23.04	32.35-32.80	34.07-34.79
SiO_2 [1]	20.2	26.3	5.3	10.5	53.7	17.1	24.7	24.4
$FeCO_3$ [1]	7.1	6.3	7.0	4.2	9.0	6.5	9.0	9.0
$CaCO_3$ [2]	39.7	37.7	58.7	60.6	15.0	42.2	31.9	23.9
$MgCO_3$ [1]	24.1	21.1	29.7	34.1	10.9	27.6	23.0	22.8
Total	91.1	91.4	100.7	99.4	88.6	93.4	88.6	80.1
$\frac{Ca}{Fe + Mg}$	1.78	1.94	2.23	1.86	1.04	1.78	1.33	1.08
Mg/Fe	3.50	3.90	4.17	7.75	1.45	5.00	2.31	2.69
$\frac{\text{\% Calcite}}{\text{Total carb.}}$	28.9	33.0	39.3	31.4	2.0	29.0	14.5	3.9

[1] - Analyses by D J Bland; [2] - analyses by T K Smith.

Leeder (1974b) noted that dolomite is widespread in cementstones of the Lower Border Group, but in a later paper (Leeder, 1975) records dolomite contents no greater than 15%. The cementstones in the Westwater area thus appear to be anomalously rich in magnesium. Preservation of primary lutitic textures and the independence of conversion to sparry carbonate from mineral veining imply a syngenetic and digenetic origin for much of the dolomite.

Belt, Freshney and Read (1967) observed that dolomite is widespread in Carboniferous cementstones but found negative correlation between pyrite and carbonate in interbedded sandstone-cementstone sequences. However, Mossler (1971) describes pyrite formed before dolomite during diagenesis of limestones of the Swope Formation of Kansas. It is considered that in the cementstones of the Westwater district dolomitisation occurred in carbonate muds possibly already rich in primary dolomite.

Sandstones

The sandstones examined are poorly sorted rocks containing sub-angular grains in which quartz, as monocrystalline unstrained grains, is the major constituent. Also present are grains of strained quartz, quartz grains showing intergrown 'hydrothermal' textures, fine quartzite, microcline, albite and orthoclase. Heavy minerals are rare, zircon being the one most frequently encountered. This lithology resembles that which is characteristic of sandstones of the Whita Formation (Nairn, 1958) and is thus typical of the Whita fluvio-deltaic system (Leeder, 1974).

Certain samples contain intraclasts of carbonate mud. Beds closely overlying lava flows often contain lava fragments and amygdales. A sample from borehole 6 (BFD 3801; Appendix I, Table VI) which possesses a green clay-rich cement and grains of basaltic pyroxene is considered to be tuffaceous (see also basal sediments in borehole 4; Appendix I, Table IV).

The normal sandstones have a white, ganister-like appearance. Specimens from beds close to the lavas are reddened. A red colouration is also developed where oxidation has produced secondary limonite and goethite from sulphides.

A large number of samples have a sparry cement of calcite or dolomite. In many cases minute blebs of pyrite occur dispersed thinly through the cement. Pyrite contents in these rocks are, however, generally very low.

Mineralisation in the sandstones is characterised by rocks in which crystals of galena larger than the detrital quartz grains occur singly or in clusters dispersed evenly or in planar groupings through the rock. Sphalerite may accompany the galena. In rare instances chalcopyrite has been seen to occur in a like fashion.

Where present in this dispersed fashion the sulphides form porous crystals enclosing detrital grains. In some cases they have formed by replacement of carbonate cement, but they occur also in carbonate-free sandstones (possibly due to solution of cement by ground waters after sulphide deposition).

Vein-controlled occurrences of sulphides are much less common in the sandstone than the dispersed type. Of 46 samples seventeen contained dispersed sulphides and five had vein-controlled mineralisation. This distribution is in contrast to the predominantly vein controlled mineralisation observed in the cementstones (see below).

Ore mineralogy and paragenesis

With the exception of very rare attenuated veinlets of chalcopyrite, all the mineral veins observed contain gangue minerals in great excess over metalliferous phases. In the cementstones mineralisation occurs where networks of veins of dolomite are developed. Individual veins are thin, rarely exceeding 5 mm in width. The networks indicate disruption of the strata followed by minor deformation. Evidence of shearing is rare, yet it is possible that the vein-formation was a result of deformation which accompanied faulting in the area. In borehole 12 a mineralised fault breccia was intercepted at a lava-sediment boundary. At Mine Sike mineralisation occurs in a vein about 0.7 m thick developed on a fault in lavas.

Many specimens show evidence of up to four episodes of dilation and vein formation. The earliest is represented by rare occurrences of barren quartz veins in lavas and sandstones (BFR 3569, BFR 3570; Appendix III,

Table XI; and others). The next two episodes are represented by sets of dolomite veins, of which the earlier is barren and is distinct only in cementstones (e.g. BFR's 1005, 1009, 1013, 3623 and others - see Appendices I and III). The later set carries sulphides and is common in all the lithologies. Its development was episodic as evidenced by: growth zones of carbonate rich in minute inclusions of goethitic material; zones of colloform silica; siting of sulphides in certain zones; occurrences of late-formed calcite. The last set of veins are post-mineralisation calcite veins which, though not common, are widespread through the sediments. Core-sample BFD 3647 (Appendix I, Table I) is notable for dolomitic veins in which two late stages of growth are marked by a zone of colloform silica and later 'eyes' of calcite and quartz. Galena, sphalerite and marcasite occur in the early dolomite zone, and later-formed chalcopyrite occurs at the inner surface of the colloform zone (Fig. 21).

Staining indicates that the vein dolomite is somewhat variable in composition, some being of a ferroan variety. Siderite has been identified in three core specimens (BFD 3811 and 3817 from drill hole 8, and BFD 3850 from drill hole 12; Appendix I). Baryte occurs in veins and irregular replacement pockets in cementstones and brecciated lavas from the Frigg pipeline trench (Appendix III, Tables I and II). It was also reported in lavas, cementstones, sandstones and siltstones in certain boreholes (Appendix I, Tables IV, V, VI, IX and XII) and is clearly widespread though of lesser importance than the sulphides (see below).

In the sandstones veins are less common than in the cementstones. This may reflect differences between the mechanical responses to stress of the rock types. Mineralisation is mostly of the dispersed type described above. Only ten of the sandstone samples show carbonate veining, of which seven carry vein-controlled mineralisation.

In the lavas disseminated sulphide was observed in only one specimen, and in this it occurs in fragments set in a sparry dolomite (BFD 3649; Appendix I, Table I). In all other cases sulphide mineralisation occurs within margins of veins of breccia-cement areas. There is no indication that the pervasive alteration of the lavas is other than a deuteric phenomenon which pre-dates the veining and mineralisation.

Remobilisation of the base metals by groundwater circulation appears to have been very restricted. Secondary phases are very minor. In the vicinity of faults in Green Burn panned concentrates yielded pyromorphite far in excess over galena (Appendix V), and it seems likely that the mineral originated in post-mineralisation fault gouges. In highly weathered lava from a site on St Brides Hill (BFR 3569; Appendix XIII, Table XI) significant concentrations of Pb and Zn occur in clay and limonite. Traces of malachite were observed in three samples (sandstone BFD 3816, Appendix I, Table VIII; cementstone BFR 3593, Appendix III, Table XI; lava BFR 3513, Appendix III, Table II).

Galena, sphalerite, marcasite, pyrite, and chalcopyrite are the commonest metalliferous minerals. The distributions of the first three are very similar. Chalcopyrite was deposited later and has a more restricted distribution. Pyrite is widespread in the area.

Galena occurs as isolated subhedral of euhedral crystals sited on mineral veins, or as 'poikiloblastic' crystals in sandstones such as BFR 1003 (Appendix III, Table IV; illustrated in Fig. 22) as described above. In cementstone BFR 1001 (Appendix III, Table IV) it forms thin plate-like 'blooms' within veinlets. In all cases the mineral has been found to be free of inclusions. XRF examination of a galena concentrate from one specimen (Appendix III, Table IV, BFR 1003) gave the following data: Ag - 230 ppm; Sb between 50 and 100 ppm; As and Bi not detected (equivalent figures are 8.24 oz Ag and 2.69 oz Sb per ton). These figures compare with levels of about 10 oz Ag per ton of pig lead recorded for a number of the Lake District lead-zinc deposits

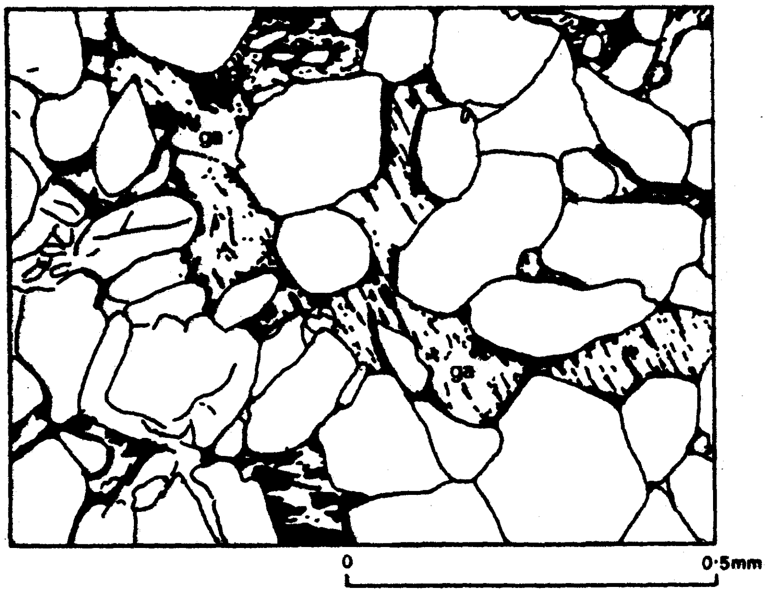

Fig. 22

Galena (ga) grown in the interstices of the primary fabric of sandstone.
BFR 1003 (Appendix III, Table IV).

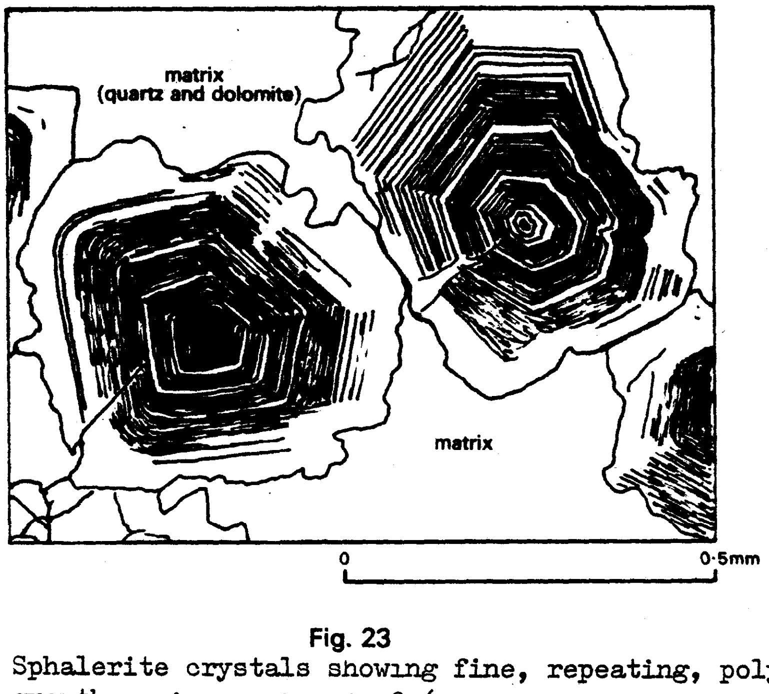

Fig. 23
Sphalerite crystals showing fine, repeating, polygonal growth zoning.   BFR 1008 (Appendix III, Table V).

(Eastwood, 1959) and at least 5.8 oz Ag per ton of lead ore in the Wanlockhead-Leadhills deposits (Mackay, 1959), but considerably exceed that of approximately 3 oz Ag per ton of sulphide ore in the Tynagh deposits (Morrissey and Whitehead, 1969).

Sphalerite occurs as anhedral crystals or as small groups of anhedra usually sited in veins or in wall rock adjacent to veins, though dispersed sphalerite accompanying galena in sandstone has been observed (BFR 1000, Appendix III, Table IV). The crystals are usually red to yellow in colour. Growth zoning is present in rare examples, the most notable being crystals in a loose block of cementstone in lower Pokeskine Sike (Appendix III, Table V, BFR 1008) which contain concentric sets of thin zones of dark (violet to indigo in thin section) material (Fig. 23).

Marcasite occurs as patches of irregular or radiating bladed crystals sited on veins, and usually accompanies galena and sphalerite.

Pyrite occurs with galena and sphalerite as irregular grains and patches in veins or in the adjacent wall rock. In some cases it is overgrown by marcasite while in others it forms overgrowths on sphalerite or galena crystals. In BFR 1008 patches of massive pyrite enclose sphalerites and rare cuboidal galenas. Pyrite also occurs with the later formed chalcopyrite.

Chalcopyrite occurs as irregular veins and patches sited on veinlets or in the margins of veins. It also occurs as dispersed grains in a few samples of sandstone. In a number of samples it can be shown to have formed later than galena and sphalerite (BFR 3647 described above; BFR 3576, Appendix III, Table VI; BFR 2592, Appendix III, Table XI; and others).

Baryte is a minor though widespread constituent (see above). Gypsum was observed in vuggy cavities in one sample of cementstone (BFR 3400, Appendix III, Table IV).

Accessory smithsonite closely associated with sphalerite occurs in BFR 1001

(Appendix III, Table I). Cerussite was observed in BFR 1009 (Appendix III, Table V) and has been located in stream sediments from Green Burn.

In sample BFD 3650 (Appendix I, Table I) graphite occurs as cores to minute hollow spheres of radiating marcasite.

General levels of mineralisation are low to very low. Exceptions are very localised. Levels exceeding 1000 ppm are found in drill holes 1, 5, 6, 8, 9 and 12 and very locally in others. Levels exceeding 1% are uncommon.

ECONOMIC GEOLOGY

Lead, zinc and copper sulphides have been located over 4 km of Lower Carboniferous strike in the Westwater district and traces of chalcopyrite found for a further 2 km (see Figs. 1 and 12). Grades obtained in shallow boreholes are usually 0.1-0.3% total metal over 1-2 m but one fissure vein intersected in borehole 8 is of substantially higher grade and a thick zone of weak galena mineralisation in present in borehole 1. The principal intersections are summarised in Table 5 together with analyses of channel samples from mineralised exposures. Galena and sphalerite are more common than chalcopyrite and much of the mineralisation is in the form of narrow veins where dolomite is the dominant gangue mineral.

Sulphide mineralisation extends from lava contacts for at least 20 m into the sediments in narrow dolomite veins and as disseminations whereas in the lavas it is chiefly restricted to veins at or near faulted junctions against the sediments. Disseminated galena occurs only in sandstones together with minor amounts of disseminated sphalerite and chalcopyrite (see Appendix I, Tables I and IX). Baryte is normally found in veins and breccias, especially in the Birrenswark Lavas (Table V) but also occurs with sulphides in the vein at Westwater trial (Table VIII).

Controls of the lead, zinc and copper mineralisation observed near Westwater are:

TABLE 5

Grade and thickness of mineralised zones in the Lower Carboniferous rocks of the Westwater district

	Location (see Figs 2-3)	Lithology	Ore minerals	Channel length or intersection, m	True width, m (approx)	ppm Cu	ppm Zn	ppm Pb
1.	Green Burn adjacent to BH5	Cementstone, sandstone, clay, faulted and weathered above Birrenswark lavas	Galena	11.8	3.5	30	200	1270
2.	Glentenmont Burn adjacent to BH4	Basalt lava, faulted and rotten against Lower Carboniferous sediments	Not observed	1.6	1.6	70	3970	340
3.	Glentenmont Burn near Westwater	Cementstones	Galena, sphalerite	10.3	2.3	17	290	670
4.	Borehole, 0.00-7.00 m	Sandstone and cementstone	Galena (disseminated in sandstone)	7.00	7	40	27	1260
5.	Borehole 1, 14.45-15.94 m	Basalt lavas	Galena, sphalerite, chalcopyrite	1.49	1.5	210	310	2500
6.	Borehole 2, 18.43-19.70 m	Cementstone and siltstone	Sphalerite, galena	1.27	1	20	2560	280
7.	Borehole 3, 0.00-17.80 m	Cementstone, siltstone, mudstone, sandstone	Galena	17.80	17	16	530	80
8.	Borehole 6, 35.35-37.51 m	Sandstone	Galena, sphalerite	2.16	1.7	11	540	2220
9.	Borehole 8, 15.83-16.92 m	Fissure vein	Galena, sphalerite, chalcopyrite	1.09	0.7	560	7820	1.01%
10.	Borehole 9, 3.91-5.52 m	Sandstone	Galena (disseminated)	1.57	1	17	990	2300
11.	Borehole 12, 50.36-53.56 m	Fault zone (sediment and lava)	Chalcopyrite, galena	3.20	1-2	1860	55	1330

NB For fuller details see Appendix III, Tables VIII-X for localities 1-3, and Appendix I, Tables I - XII for localities 4-11

1. Stratigraphic position - sulphides occur only in rocks at or near the base of the Dinantian succession.

2. Facies variation - mineralisation is restricted to a zone where basalt eruption was succeeded by lagoonal carbonate sediments rather than deltaic sequences.

3. Faulting - sulphides were mainly deposited in fractures related to northeasterly normal faults and crossfaults.

4. Lithological variation - sulphides crystallised with dolomite in fractures in hard, compact cementstones but in some porous sandstones they are disseminated.

These controls are quite well defined and could be applicable in further exploration of the Northumberland basin and also the Midland Valley of Scotland.

CONCLUSIONS

Although the sulphide concentrations found in basal Carboniferous rocks of the Westwater district are not of economic significance in themselves, it should be noted that the 4 to 6 km of strike over which they occur is largely obscured by glacial deposits and only a limited amount of subsurface exploration has been carried out. Down dip extension of the mineralisation is likely but concealed faults would hamper exploration at depth. The absence of base metal anomalies from drainage sampled over a large tract of the higher Carboniferous rocks in the Northumberland basin (Fig. 12) is not unexpected in view of the extent and thickness of glacial deposits observed in pipeline trenches crossing the basin. The results obtained in this investigation indicate that careful sampling of the basal section of the overburden profile is the best method of detecting suboutcropping mineralisation.

Certain factors suggest that a part of the mineralisation is of syngenetic or diagenetic origin. These are:

1. The presence of apparently pre-diagenetic sphalerite in the peloidal dolomite sample BFR 3580.

2. The presence of small amounts of fine, evenly disseminated pyrite in many of the cementstone samples.

3. Disseminated mineralisation is at least as common as vein-controlled mineralisation in the sandstones.

4. The dolomitic gangue of the sulphide-bearing veins resembles in composition the dolomitic cementstones of the area.

While admitting the probable diagenetic origin of the disseminated pyrite and the possibly pre-diagenetic origin of sphalerite in sample BFR 3580, the last two points remain equivocal. It may be argued that the dolomitic wall-rocks could have affected the compositions of the vein carbonates at times long after diagenesis. With regard to the dispersed mineralisation, it was observed that in certain samples (e.g. BFR 3529, Appendix III, Table II) the sulphide grains occur in planar groupings suggesting development on otherwise cryptic fissures. Furthermore, the similarity between the sulphide assemblages in the dispersed and vein-controlled types of occurrence suggests a genetic relationship between them. The balance of evidence favours a post-diagenetic origin for most of the metalliferous minerals.

Small lead-zinc baryte deposits with subsidiary copper are common in certain parts of Britain. In the main they are vein deposits controlled by faulting. Where the wall-rock is Carboniferous limestone joint-controlled mineralisation and replacement flats and pipes may develop (Smith, Rhys and Eden, 1967). The Westwater mineralisation resembles this type of occurrence in many ways, although replacements have been observed only on a very small, local scale (e.g. massive pyrite with sphalerite and galena in mineralised cementstone boulder BFR 1008, Appendix III, Table V). The degree to which mineralised faults such as those encountered at Mine Sike and in drill hole

12 controlled mineralisation in the sediments remains somewhat uncertain, and it could be that mineralisation on these structures developed by redistribution of metals already present as disseminated-dispersed and joint controlled sulphides. Such a model carries the additional complication of requiring separate origins for the networks of minor veins and the more substantial veins and faults, and an early (possibly diagenetic) origin for the sulphides, for which there is only limited evidence (see above).

Fluid inclusions observed in a reconnaissance of the polished sections were found to be very small, infrequent and suggestive of low temperature conditions of the order of 100°C or less (T J Shepherd, pers. comm.). Such temperatures are easily reconciled with a Lower Carboniferous age of mineralisation in which the overburden was thin and the fluids were brines originating in the Northumberland basin. However, they may equally apply to telethermal epigenetic mineralisation at a later time if the source of the fluids was remote and the depth of burial not great (as may have been the case on the lip of the basin during Permian times).

It is regretted that no isotopic age determinations have been made for the Westwater deposits. The faults in the area, including that at Mine Sike, belong to the intense fault system in the Northumberland basin which cuts the Coal Measures (Lumsden et al., 1967) in the Northumberland basin. A Permian age is thus a possibility for the mineralisation, and a comparison with deposits in the baryte-zone of the North Pennines orefield (Dunham, 1959) may be suggested.

On grounds of mineralogy the Westwater deposits may equally be compared with deposits in the northern Lake District (Eastwood, 1959) and the Wanlockhead-Leadhills district (Temple, 1956; Mackay, 1959). In these areas chalcopyrite is a minor constituent and the lead-ores carry amounts of silver comparable with that recorded for sample BFR 1003 (see above). In none of these deposits including those of the North Pennines is dolomite or ankerite the dominant gangue mineral, although they are often present in minor amounts. It is thus unwise to draw a strong comparison with the North Pennines deposits alone on the basis of the comparable ages of the wall-rocks.

Ineson and Mitchell (1974a and b) record a great variety of ages for hydrothermal clays associated with base-metal deposits. For the Newlands area the dominant ages are 360 m.y. (very low Carboniferous) with some rejuvenation 50 m.y. later. For the Greenside, Threlkeld and Brundholme mines they give ages close to 325 m.y. (middle Carboniferous). For the Wanlockhead-Leadhills district their ages range from 353 m.y. to 265 m.y. Their ages for the Caldbeck mine range into the Jurassic. For the Derbyshire orefield ages range from Permian to Jurassic (Ineson and Mitchell, 1972). For the North Pennines orefield Ineson (1976) favours an episodic history with the first phases in the Permian. Provided the Westwater mineralisation is of similar age to the Pennine deposits then a Permian epigenetic interpretation would seem to apply, but middle and Lower Carboniferous ages have been obtained for other mineralogically similar deposits and so the possibility remains that the Westwater deposits originated before the main phase of fault development, and the brines giving rise to them were of local derivation.

RECOMMENDATIONS

1. Further work in the Westwater mineralised zone is not justifiable on the basis of the lead, zinc and copper values obtained in this investigation.
2. Reconnaissance geochemical exploration already in hand of the basal Carboniferous rocks of south Scotland, northeastwards along strike from Westwater, should be completed and anomaly patterns assessed in the light of the results obtained around Westwater.
3. Extension of the Westwater mineralisation down-dip to the south is probable but drilling to much greater depths than in the present study will be required in any exploration.

4. Mineralisation controls recognised at Westwater should be utilised in further exploration of the Lower Carboniferous of south and central Scotland.

ACKNOWLEDGEMENTS

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APPENDIX I TABLE I BH No. 1

NGR 35 . 28758182 One-inch map: Sheet 10 Six-inch map: Sheet NY28SE

Collar elevation 240.7 m OD Vertical hole

Location: in coniferous plantation 270 m N40°W of Callisterhall croft and some 7 km WSW of Langholm

Drilling by RMMU Winkie drill. Average core recovery 65%

Depth m	Thickness m	Lithology	Mineralisation	Cu	ppm Zn	Pb	Section No.	Depth m
0.00		LOWER CARBONIFEROUS SEDIMENTS						
0.36	0.36	Sandstone with mudstone partings and clasts, weakly calcareous	Disseminated galena in clusters up to 9 mm diameter of small grains	5	20	3550	PTS 2506	0.25
4.31	3.95	Micrite with pyrite-marcasite blebs and abundant angular quartz grains, followed by sandstone	Galena-calcite veins in micrite; minor galena-pyrite-calcite veins in sandstone	10	30	160	TS 3506	1.15
5.21	0.90	Sandstone, light grey with carbonaceous fragments and sphaero-radiate marcasite	Vertical calcite-quartz veinlets with pyrite	35	30	150		
7.00	1.79	Sandstone, massive to porous with small quartz pebbles and flattened mudstone clasts Uncertain junction with lavas below	Disseminated galena in granular clusters	115	20	3800	TS 3507	6.03
		BIRRENSWARK LAVAS						
9.16	2.16	Basalt, brownish grey with chlorite veinlets	Traces of pyrite	60	130	200		
11.23	2.07	Basalt with chlorite-calcite amygdales (40%) up to 30 mm diameter	Pyrite rims to quartz-calcite veinlets	35	80	40		
13.37	2.14	Basalt with fewer and smaller amygdales		75	160	30		
14.45	1.08	Basalt with calcite-quartz amygdales (30%) Probable fault		25	60	130		
15.94	1.49	Basalt, amygdaloidal with interbedded dark micrite (15.00-15.19 m) veined by sparry calcite and opaline mineral	Galena, sphalerite, chalcopyrite and marcasite occur in veins and pyrite is disseminated in the micrite	210	310	2500	PTS 2507	15.05
17.99	2.05	Basalt, light brownish grey with numerous amygdales, strongly altered to calcite and clay		80	20	80		
19.90	1.91	Basalt, brecciated and cemented by probable dolomite which is veined by clear carbonate Fault, dip 74°	Galena and sphalerite in lava fragments and cement; traces of pyrite	45	600	190	TS 3509	18.14
		LOWER CARBONIFEROUS SEDIMENTS						
21.10	1.20	Micrite, dark brown, brecciated and veined by sparry calcite. Shell-like radiating clusters of marcasite enclosing cores of graphitic material also present Probable fault	Sphalerite and pyrite in veins	15	2450	400	PTS 2508	20.47
23.44	2.34	(?) Micrite, finely banded to massive	Occasional quartz-galena veinlets	15	330	400		
23.44		Bore complete						

APPENDIX I TABLE II BH No. 2

NGR 35.28818180 One-inch map: Sheet 10 Six-inch map Sheet NY28SE

Collar elevation 240.8 m OD Vertical hole

Location: in coniferous plantation 210 m N30°W of Callisterhall croft some 7 km WSW of Langholm

Drilling by RMMU Winkie drill. Average core recovery 64%. [Analytical data in footnote]

Depth m	Thickness m	Lithology	Mineralisation	Section No.	Depth m
0.00					
2.04	2.04	Superficial deposits			
		LOWER CARBONIFEROUS SEDIMENTS			
2.25	0.21	Cementstone			
2.35	0.10	Siltstone, micaceous	Traces sulphide; calcite veinlets		
3.50	1.15	Cementstone, dark grey - a micrite with abundant detrital quartz fragments and a few detrital grains of silt-grade quartzite, K-feldspar and muscovite		TS 3510	2.68
4.28	0.78	Cementstone - a dark micrite rich in lithic micrite fragments; shell fragments and detrital quartz and muscovite grains occur: detrital quartz grains are present in sparry calcite veins	Calcite veinlets	TS 3511	4.25
4.67	0.39	Siltstone, bedding approximately horizontal			
6.11	1.44	Siltstone grading into sandstone consisting of coarse angular fragments of quartz and quartzite set in a poorly-sorted matrix; small fragments of siltstone, albite, clouded K-feldspar and rare muscovite flakes are present and granules of hematitic material are common		TS 3512	5.33
8.33	2.22	Cementstone, massive, dark grey			
8.79	0.46	Sandstone and siltstone			
9.45	0.66	Clay recovered - (?) fault			
10.17	0.72	Sandstone, fine-grained			
10.70	0.53	Cementstone, carbonaceous			
11.25	0.55	Cementstone, weakly laminated			
11.86	0.61	Siltstone composed mainly of fine sand-grade sub-rounded quartz and feldspar set in a framework of plates of chlorite with some unaltered muscovite and abundant opaque plates and laminae	Occasional blebs of pyrite	TS 3513	11.50
12.93	1.07	Siltstone laminated with mudstone			
13.21	0.28	Clay recovered - (?) fault			
13.41	0.20	Cementstone			
14.20	0.79	Sandstone, fine-grained, silty			
15.30	1.10	Calcareous siltstone showing horizontal bedding, and cementstone			
17.00	1.70	Cementstone with limonite-stained joints			
18.32	1.32	Sandstone, fine-grained with shaly partings, passing into siltstone			
19.10	0.78	Cementstone with numerous nearly vertical calcite veinlets up to 8 mm thick	Galena and sphalerite in veins		
19.70	0.60	Siltstone with gradational contact against cementstone above			
20.35	0.65	Sandstone composed of angular to sub-angular grains of quartz and minor amounts of microcline, likely clouded orthoclase, siltstone and rare albite grains; the detrital fabric is porous and areas of sparry calcite cement are present together with accessory zircon and a few hematitic fragments.		TS 3514	20.22
20.82	0.47	Cementstone, even-grained	Calcite-sphalerite veinlets		
22.00	1.18	Clay and rock fragments - probable fault			
22.65	0.65	Sandstone and siltstone in which laminae change abruptly from nearly horizontal to a dip of about 40° at 22.6 m			
24.62	1.97	Cementstone with calcite veinlets and slickensides; laminae revert to horizontal at 24.5 m	Galena in veinlets		
25.52	0.31	Clay recovered - (?) fault			
26.12	0.60	Cementstone with vesicles up to 4 mm in diameter. The rock is a banded dark micrite with a small content of detrital quartz, containing a complex system of veins and spheroidal bodies of sparry calcite in which a few coarse grains of sphalerite and galena occur. Minute pyrite blebs are disseminated through the micrite. Calcite-infilling of the vesicle-like cavities was probably at a late stage as part of the sulphide mineralisation and calcite veining	Sphalerite and galena	PTS 2509	25.95
27.72	0.60	Siltstone with partings depping at 30°			
27.00	0.28	Cementstone	Trace of galena		
27.00		Bore complete			

Analyses

Depth m	Thickness m	Lithology	Ni (ppm)	Cu (ppm)	Zn (ppm)	Pb (ppm)	Ag (ppm)
18.43 19.70	1.27	Cementstone and siltstone	30	20	2560	280	3
23.82 24.62	0.80	Cementstone	25	15	540	670	3

APPENDIX I TABLE III BH No 3

NGR 35.28708161 One-inch map: Sheet 10 Six-inch map: Sheet NY28SE

Collar elevation 221.5 m OD Hole inclined 80° to 030°

Location: in coniferous plantation 210 m W of Callisterhall croft and some 7 km WSW of Langholm

Drilling by [illegible] Winkie drill. Average core recovery 78%

Inclined depth, m	Intersection, m	Lithology	Mineralisation	Cu (ppm)	Zn (ppm)	Pb (ppm)	Ni (ppm)	Ag (ppm)
0.00		LOWER CARBONIFEROUS SEDIMENTS						
0.42	0.42	Cementstone with abundant cavities, dipping 6–8° to 030°. The cavities are irregularly ovoid, 8–40 mm in diameter (average 18 mm) and usually lined with coarse calcite exhibiting "nail-head spar" terminations. Coarse-grained gypsum is sometimes a central infilling of larger cavities. Dark micritic limestone forms the rock matrix. The composition of the rock is estimated as 60% calcite crystals, 25% open cavity 14% matrix and 1% gypsum.		(1) 10 (2) 10	370 550	50 180	20 nd	4 5
1.10	0.68	Sandstone, light grey, fine-grained and calcareous						
2.35	1.25	Cementstone, dark grey, calcareous	Traces of pyrite	15	430	40	40	2
4.87	2.52	Cementstone, dark grey and highly laminated becoming more even-grained towards bottom	Hair-line calcite veinlet with galena	20	950	180	35	2
5.85	0.98	Siltstone, sandy, laminated						
6.52	0.67	Cementstone, medium dark grey, variably laminated or even-grained, occasionally calcareous		25	30	40	40	2
7.40	0.88	Siltstode, laminated with mudstone partings						
8.10	0.70	Cementstone, medium dark grey, with siltstone bands	Calcite veins, disseminated sulphides					
8.43	0.32	Siltstone, sandy		15	240	70	35	3
8.75	0.32	Mudstone, dark grey						
9.30	0.55	Cementstone, medium-grey and even-grained	Hair-line veinlet with galena					
9.64	0.34	Siltstone						
9.96	0.32	Cementstone	Traces of galena in near-vertical calcite veinlets					
10.64 11.10	0.68 0.46	Cementstone, quartzose, finely-banded and possibly tuffaceous to 10.26 m		10	1440	140	20	3
11.30	0.20	Siltstone, laminated		20	90	40	30	2
12.80	1.50	Cementstone with films of coal at 12.62 and 12.66 m	Vertical calcite veinlets					
13.55	0.75							
14.13	0.58	Siltstone, striped by alternating light grey and dark grey bands		20	370	60	25	3
14.93	0.80	Cementstone, quartzose, medium grey						
15.12	0.19	Siltstone, laminated with reddish-brown mudstone						
15.24	0.12	Sandstone, very light grey with mudstone partings		10	840	150	20	3
15.58	0.34	Cementstone, quartzose, medium-grey, even-grained	Trace of galena					
16.59	1.01	Sandstone, fine-grained with mudstone laminae, grading into alternating black shaly mudstone and paler quartzose mudstone						
16.75	0.16	Cementstone with calcite-lined cavity 5 mm diameter at 16.72 m	Galena grains to 8 mm rim cavity; pyrite on joints	10	370	50	25	1
17.80	1.05	Sandstone, light grey with irregular shaly partings and clasts						
17.80		Bottom of bore						

APPENDIX I TABLE IV BH No 4

NGR 35.30448259 One-inch map: Sheet 10 Six-inch map: Sheet NY38SW

Collar elevation 164.3 m Hole inclined 45° to 312°

Location: east bank of Glentenmont Burn 300 m N of Westwater Farm and some 6 km WSW of Langholm

Drilling by Rock Fall Co Ltd Diamec 250 drill

Inclined depth, m	Intersection m	Lithology	Mineralisation	Cu (ppm)	Zn (ppm)	Pb (ppm)
0.00						
4.15	4.15	Superficial deposits				
		LOWER CARBONIFEROUS SEDIMENTS				
4.22	0.07	Mudstone, silty, sandy laminae, dip flat				
4.80	0.58	Siltstone, calcareous, grey	A few calcite veins			
4.95	0.15	Siltstone, limonitic, yellow brown, well bedded				
5.54	0.59	Cementstone, dark grey, silty top with coaly plant fragments and limonitic base	Calcite-filled cavity 20 mm diameter near base			
6.08	0.54	Mudstone, dark grey, crushed with fragments of siltstone				
		Possible fault				
6.87	0.79	Mudstone, silty, dark grey with sandstone laminae				
7.18	0.31	Cementstone, limonitic, rotten	Carbonate veins up to 5 mm thick	3	217	120
7.54	0.36	Mudstone, silty, brownish grey, badly broken, sandy fragments				
		Possible fault				
8.28	0.74	Sandstone, calcareous, fine grained and pale brown with dark grey mudstone ribs and laminae, some slump features		11	210	67
8.72	0.44	Cementstone, limonitic, rotten	Irregular carbonate-sphalerite veins			
9.04	0.32	Siltstone, sandy, micaceous and pale brown with irregular ribs and laminae of mudstone, some small-scale slumping				
9.19	0.15	Mudstone, clayey, soft and grey				
9.61	0.42	Core lost				
10.08	0.47	Cementstone, grey and hard with a limonitic base	Carbonate veins and patches with traces of galena	4	568	116
10.51	0.43	Mudstone, clayey, grey and broken with cementstone nodules up to 10 cm across	Calcite veinlets			
10.74	0.23	Cementstone, grey and hard with some limonitic ribs				
11.12	0.38	Sandstone, grey and medium grained with somefiner grained bands and dark grey silty mudstone partings				
11.34	0.22	Cementstone, grey and hard				
12.18	0.84	Sandstone, grey, mostly fine grained with some silty bands and silty mudstone laminae; a few small slumps	Calcite veinlets with traces of galena at 11.54 m			
12.74	0.56	Cementstone, grey and hard with some limonitic joints at base	Thin carbonate veinlets			
14.41	1.67	Sandstone, grey and rather soft with some broken silty bands and dark grey mudstone bands; some slumping	Patch of pyrite 4 mm in diameter at 13.82 m			
14.92	0.51	Cementstone, pale grey and hard with nearly vertical quartz veins	Veins contain black sphalerite and lesser galena with (?) smithsonite at 14.67 m	5	518	268
15.31	0.39	Siltstone, sandy and brownish grey with mudstone ribs, irregularly bedded, some slumping; dip (corrected) c. 5°		28	665	1680
15.47	0.16	Cementstone, silty and limonitic				
16.07	0.60	Sandstone, grey and medium grained with a limonitic top				
16.84	0.77	Cementstone, grey and hard with a limonitic central part and coarser grained base; some carbonaceous plant fragments	Carbonate patches in central part			
18.30	1.46	Mudstone, silty and dark grey				
19.74	1.44	Cementstone, grey and hard with limonitic bands	Irregular carbonate veinlets containing galena at 18.74 m			
20.25	0.51	Mudstone, carbonaceous, micaceous and dark grey				
21.08	0.83	Cementstone, grey and hard with a few limonitic fractures	Quartz veinlets with yellow sphalerite			
21.42	0.34	Siltstone, finely micaceous and dark grey with mudstone ribs				
21.52	0.10	Mudstone, dark grey and crushed	Thin quartz veins with traces of galena			
21.68	0.16	Cementstone, grey and hard	Some quartz veins			
21.88	0.20	Mudstone, dark grey with a crushed top				
22.08	0.20	Cementstone, grey and hard with some limonite stained fractures	Baryte veinlets with (?) sphalerite			
22.42	0.34	Sandstone, grey with silty mudstone ribs and some irregular bedding				
22.99	0.57	Siltstone, grey, hard and cementy with silty mudstone laminae at base. Dip c. 15°				

23.22	0.23	Mudstone, dark grey and soft				
24.37	1.15	Sandstone, grey with bands of silty mudstone				
25.36	0.99	Mudstone, silty and dark grey				
27.04	1.68	Sandstone, grey to white and fine grained with darker laminae (dip 15°) and carbonaceous plant fragments	Baryte veinlets at 26.7–26.86 m with traces of galena			
27.36	0.32	Mudstone, dark grey and carbonaceous	Granular blebs of marcasite			
28.27	0.91	Sandstone with silty mudstone ribs showing slumping	Blebs of marcasite up to 10 mm			
28.90	0.63	Cementstone, silty and hard	Baryte and galena veinlets			
29.70	0.80	Mudstone, dark grey, soft		17	983	126
30.05	0.35	Silty mudstone				
30.67	0.62	Sandstone, grey and hard, fine to medium grained, with calcareous bands	Carbonate-galena veinlets in calcareous bands	14	1810	741
30.93	0.26	Cementstone, grey and hard				
31.07	0.14	Mudstone, greenish grey; lower half tuffaceous				
31.16	0.09	Silty mudstone, grey				
31.30	0.14	Cementstone, grey and hard				
31.61	0.31	Siltstone and silty mudstone with a tuffaceous basal 30 mm				
31.96	0.35	Cementstone, limonitic and fairly rotten with graded beds 5–15 mm thick consisting of a sand fraction decreasing in particle size upwards. Small rock fragments (?altered basalt) also occur	Thin veinlets of reddish-brown carbonate (?siderite) contain sulphide at 31.7 m			
33.01	1.05	Siltstone and silty mudstone with sandy beds, stained reddish brown below 32.52 m and including probable tuffaceous material		7	79	4
33.14	0.13	Siltstone with sandy ribs and probably tuffaceous yellow brown ribs				
33.37	0.23	Siltstone, grey and micaceous with sandy ribs and laminae				
33.55	0.18	Siltstone, sandy with tuff patches				
33.89	0.34	Tuff, fairly coarse and layered with rough bands of altered angular to sub-rounded fragments of (?) basalt up to 20 mm across set in a yellowish brown matrix, moderately calcareous and limonitic	Veinlets of quartz and baryte (0.54% Ba in sample)	49	36	7
34.33	0.44	Siltstone with mudstone and tuffaceous bands, grey with some red-stained bands				
		BIRRENSWARK LAVAS				
34.39	0.06	Basalt, rotten, reddish brown. Contact with mudstone above dips c. 5° but is irregular while the contact with less altered basalt beneath dips c. 10°				
34.73	0.34	Basalt, highly altered but hard with abundant amygdales preserved in iron oxide and set in a dusky yellow matrix				
34.75	0.02	Narrow zone of brecciation		2	84	8
35.33	0.58	Basalt, probably same flow as basalt above but with conspicuous "streaked-out" altered amygdales in red, yellow and brown iron oxides				
35.72	0.39	Basalt, highly ferruginous and further altered against baryte zone c. 20 mm thick	Baryte impregnation on near-vertical fracture			
36.05	0.33	Basalt, highly ferruginous, and rubbly core				
36.85	0.80	Basalt with fewer amygdales, maximum diameter 20 mm	(?) baryte veinlets			
37.60	0.75	Basalt, weakly to moderately amygdaloidal, soft at base	Baryte veinlets			
37.72	0.08	(?) Bole, reddish brown, fine-grained and rather soft with specks of yellowish (?) limonite				
38.40	0.68	Basalt with irregular veinlets of iron oxide and chlorite, becoming paler coloured towards base	(?) Baryte veinlets			
40.33	1.93	Basalt "white trap", soft and yellowish grey, non amygdaloidal	Limonite veinlets to 5 mm thick			
41.01	0.78	Basalt, altered but hard with replaced amygdales micaceous at 40.60 - 40.85 m; below this depth, the entire core is reddish brown and possibly impregnated with baryte	Baryte veins to 6 mm thick common in amygdaloidal zone			
41.60	0.59	Basalt, altered with abundant yellow to brown iron oxides probably developed on movement surfaces; passes downwards into greenish (?) mudstone which displays an approximately horizontal conformable contact against rock beneath				
42.76	1.16	MUDSTONE, brick-red, soft with green reduction spots				
42.79	0.03	Basalt, rotten, amygdaloidal; junction against overlying mudstone apparently conformable, dipping at c. 15°		35	49	2
43.25	0.46	Basalt, variably amygdaloidal with calcite patches up to 15 mm				
43.27	0.02	Dense grey rock in vertical band marks fault	Calcite and (?) baryte cement			
43.46	0.19	Basalt, highly amygdaloidal and altered. Iron oxides abundant in amygdales and in anastomosing veinlets				
43.46		Bottom of bore				

APPENDIX I TABLE V BH No 5

NGR 35.30308254 One-inch map Sheet 10 Six-inch map Sheet NY38SW

Collar elevation: 171.7 m Hole inclined 45° to 281°

Location: in coniferous plantation on north bank of Green Burn, 330 m N 32° E of Westwater farm and some 6 km WSW of Langholm

Inclined depth, m	Intersection m	Lithology	Mineralisation	Cu (ppm)	Zn (ppm)	Pb (ppm)
0.00						
8.14	8.14	Superficial deposits				
		BIRRENSWARK LAVAS				
9.60	1.46	Basalt lava, rotten, amygdaloidal with greenish chlorite patches and dusky brown carbonate veins up to 3 mm thick common over 9.3 - 9.5 m	Carbonate veins			
10.30	0.70	Fault gouge and breccia				
10.60	0.30	Basalt, light brown and highly altered	Carbonate veins			
10.64	0.04	Fault gouge				
10.71	0.07	Siltstone, micaceous and cleaved, dip c. 15°				
10.80	0.09	Mudstone or siltstone, highly cleaved, soft, dusky green				
11.06	0.26	Basalt, brown and highly altered with anastomosing veinlets of greyish brown (?) mudstone				
11.16	0.10	Mudstone				
11.52	0.36	Basalt, brown and highly altered	Thin baryte vein, vertical			
11.81	0.29	Fault gouge with rounded quartz fragments 25 mm across				
12.18	0.37	Silicified zone of fine-grained quartz; second generation quartz and carbonate occupies cavities and joints	Carbonate			
12.50	0.32	(?) Basalt altered to soft clay				
13.33	0.83	Basalt, altered with small quartz amygdales	Baryte vein, vertical			
14.00	0.67	Basalt, greenish grey and fine-grained becoming ferruginous and amygdaloidal near base				
14.46 15.12	0.46 0.66	(?) Basalt, altered, broken and cemented by anastomosing veinlets and near-vertical veins up to 5 mm thick	The veins are composed of reddish brown baryte			
15.58 16.83 17.17 17.83	0.46 1.25 0.34 0.66	Basalt, altered, greyish black and soft with some quartz blebs (?amygdale sites) and soft reddish coloured patches; mottled green and reddish brown near base	Traces of baryte	168	42	8
17.89	0.06	Fault gouge and breccia, mottled greenish grey and reddish brown with steeply-dipping fractures against sediments beneath	Presence of fine-grained baryte suggested by 0.92% Ba in sample			
		(?) UPPER OLD RED SANDSTONE		139	32	5
18.22	0.33	Sandstone, well cemented (?silicified) with rough partings running horizontally marked by friable sandstone				
18.42	0.20	Mudstone, deep red brown with a few green reduction patches and some movement surfaces		22	104	2
18.64 18.88 19.92	0.22 0.24 1.04	Sandstone, feldspathic, buff and medium grained with some coarse bands, bands of mudstone and a band of rounded quartz pebbles near the base				
20.10	0.18	Sandstone, silty, greenish grey and rather friable				
20.78	0.68	Sandstone, coarse grained and fairly hard with small iron stained pebbles and a few fragments of greenish grey siltstone				
20.88	0.10	Siltstone, soft and greenish grey				
20.93	0.05	Pebbly sandstone				
21.68	0.75	Siltstone, rather soft, greenish grey with yellow and red mottled bands and some sandy bands		7	51	3
22.66 23.40	0.98 0.74	Mudstone, greenish grey top becoming deep red brown near base with small (1 cm) irony nodules, base undulating				
24.40	1.00	Sandstone, grey to buff, fine grained, fairly hard				
24.75	0.35	Mudstone, deep red		7	36	17
24.97	0.22	Sandstone, green to grey, red stained, fairly hard				
25.32	0.35	Mudstone, deep red				
25.70	0.38	Mudstone, deep red, some green to grey sandstone ribs				
25.98	0.28	Sandstone grey to buff, fine to medium grained, fairly soft		3	0	4
25.98		Bore completed				

APPENDIX I TABLE VI BH No 6

NGR 35.31068249 One-inch map Sheet 10 Six-inch map Sheet NY38SW

Collar elevation 188.0 m Hole inclined 50° to 000°

Location: 640 m N69°E of Westwater farm and about 5.5 km WSW of Langholm

Drilling by Rock Fall Co Ltd Diamec 250 drill. Open-hole drilling to 19.95 m

Inclined depth, m	Intersection, m	Lithology	Mineralisation	ppm Cu	ppm Zn	ppm Pb	Section PTS No	Section Depth, m
19.95		LOWER CARBONIFEROUS SEDIMENTS						
20.23	0.28	Sandstone, pale brown, medium grained						
20.44	0.11	Mudstone, silty, grey and crushed						
20.88	0.44	Siltstone, grey, micaceous with sandy laminae and silty mudstone bands, lowermost 10 cm sandy, dip c. 5°						
21.59	0.71	Sandstone, grey with silty bands and some contorted bedding, and faultlets shown by darker silty laminae	Galena occurs on joint at 21.09 m					
21.79	0.20	Mudstone, silty, grey and rather broken						
22.06	0.27	Cementstone, grey and hard						
22.09	0.03	Mudstone, silty, dark grey with limonitic staining						
22.35	0.26	Cementstone, grey and hard with limonite stained fractures	Carbonate veins and galena smears					
22.40 22.45	0.05 0.05	Siltstone, sandy and grey with limonite staining		2	70	20		
23.04	0.59	Cementstone, pale brownish grey, patchy limonite staining	Galena and sphalerite grains in calcite veins; calcite lined cavities					
23.55	0.51	Sandstone, grey and silty with pale grey sandstone filling worm burrows in some bands; fairly hard with some cementy bands						
24.46	0.91	Sandstone, grey, fine to medium grained with micaceous laminae; broken from 23.95 m to base						
24.54	0.08	Mudstone, silty, grey and micaceous with siltstone ribs						
24.81	0.27	Cementstone, silty, grey, fairly hard and compact	Chalcopyrite grains in calcite veinlets					
25.74	0.93	Mudstone, silty, grey and rather broken with a cementstone nodule						
25.89	0.15	Cementstone, grey and hard						
26.24	0.35	Sandstone, pale grey and fine to medium grained with darker siltstone ribs	Cluster of fine-grained galena, 2 mm across					
26.44	0.20	Sandstone, cementy, grey and hard	Much carbonate veining					
26.66 26.73	0.22 0.07	Sandstone, medium grained, rough bedded, grey to white						
27.40	0.67	Mudstone, dark grey and soft with silty bands and sandstone fragments	Galena joint coating; yellow (?) sphalerite in veinlet and pyrite patches	14	120	320		
27.59 27.64	0.19 0.05	Sandstone, medium grained, grey to white with siltstone band						
27.91	0.27	Cementstone, silty, grey and hard	Baryte, chalcopyrite and galena in discontinuous wispy veinlets	8	670	210		
28.04 29.38	0.13 1.34	Sandstone, hard, siliceous, grey and brownish grey with cementy patches	Minor pyrite, sphalerite in quartz veins; galena on joint	4	640	205		
29.50 29.53	0.12 0.03	Sandstone, fine grained, brown to grey, spotted dark grey grading into broken siltstone with a steep and irregular junction against the underlying cementstone						
29.76	0.23	Cementstone, silty, grey with small calcite-lined cavities common		19	210	480		
30.06	0.30	Cementstone, thin bedded with sandy laminae common	galena associated with carbonate veins					

30.32	0.26	Sandstone, grey and dark grey with a slumped, irregular top 10 cm; dark grey broken siltstone ribs below						
30.62	0.30	Siltstone, grey with sandy ribs, broken, crushed bands						
30.94	0.32	Cementstone, irregular top with a few lenticular silty ribs, hard and compact						
31.47	0.53	Sandstone, grey with darker grey siltstone ribs, broken						
31.78	0.31	Sandstone, brown to grey, hard						
31.94	0.16	Sandstone, silty, with silty mudstone bands						
32.09	0.15	Cementstone, silty, grey and hard	Sphalerite in one of many quartz veins	1	2980	150		
32.14	0.05							
32.29	0.15	Mudstone, grey, crushed and broken						
32.35	0.06	Cementstone, brown to grey with a rather brecciated top; some limonite staining	Rare galena and sphalerite in quartz veins	3	80	520		
32.65	0.30							
32.80	0.15	Sandstone, brown and pale buff with darker carbonaceous laminae and lenticular ribs						
32.91	0.11							
34.07	1.16	Sandstone, fine to medium grained, pale brown and rusty stained, coarser bands, bands with dark grey micaceous siltstone laminae showing irregular and wavy bedding						
34.15	0.08		Carbonate veins in harder compact bands	7	680	350		
34.49	0.34	Cementstone, silty, rusty stained sandy patches	Quartz veins with sulphides, trace baryte					
34.79	0.30	Sandstone, grey and pale brown, fine to medium grained with dark grey siltstone ribs	Some carbonate veins					
35.03	0.24							
35.35	0.32	Cementstone, grey and hard with limonite stains						
36.24	0.89	Sandstone, medium grained, pale brown, broken and hard with some softer ribs	Galena common at top contact	15	90	3970		
36.84	0.60		Sphalerite and galena associated with limonite veinlets	10	590	430		
37.51	0.67	Sandstone (part of unit above), medium grained composed of angular quartz and perthitic feldspar. Grain boundaries undulose yielding a mortar texture. Secondary silica rims some quartz grains in optical continuity. Mesh-like networks of veins enclose angular fragments of the sandstone giving a brecciated appearance	Coarse euhedral galena and minor marcasite intensely altered to hematite occur in the buff-coloured veins of siderite, baryte and minor calcite	8	1090	1500	2779	37.20
38.24	0.73	Sandstone, greenish grey, fine to medium grained with rusty patches and bands. Composed of both angular and well rounded clastic grains of quartz and perthitic feldspar (shattered along cleavages) set in a greenish brown chloritic matrix	Galena in quartz vein at 37.93 m				2780	38.16
38.84	0.60	Sandstone (part of unit above)	Galena and sphalerite in limonite-baryte (0.2% Ba) veins	3	560	2930		
39.62	0.78	Sandstone, grey to white, hard and siliceous with rusty brown stained fractures and joints; fine to medium grained						
39.85	0.23							
39.90	0.05		Calcite-pyrite veinlets					
40.30	0.40	Mudstone, soft, crushed, structureless, greenish grey	Fine grained sulphides	120	1010	190		
40.90	0.60	Sandstone and silty sandstone with some rotten (?) tuffaceous ribs, mostly rusty brown stained						
41.40	0.50			10	520	24		
41.55	0.15	Sandstone, silty, greenish grey						
		BIRRENSWARK LAVAS						
42.38	0.83	Basalt lava, rotten, greenish grey and rusty brown, amygdaloidal with patches of pink baryte	0.14% Ba in sample	38	720	140		
43.58	1.20		2.5% Ba in sample	15	235	52		
44.61	1.03	Altered silty mudstone clasts, both rounded and angular, set in an intensely altered, fine grained, greenish brown matrix which includes some small fragments of quartz and feldspar. The clasts are often completely altered to secondary ferruginous material. Some fine grained lava fragments, less altered quartz fragments and one of dolomite also occur. The rock appears to be sedimentary		12	290	15	2781	44.46
45.14	0.53		0.7% Ba in sample	84	1310	147		
46.30	1.16							
47.35	1.05	Probably altered basalt lava, greenish grey and purplish brown, mostly amygdaloidal but with some compact non-vesicular bands towards base	0.3% Ba in sample	17	126	33		
49.40	2.05		Pyrite grains common					
50.08	0.68		0.8% Ba in sample	4	5	0		
50.74	0.66							
50.74		Bore complete						

APPENDIX I TABLE VII BH No 7

NGR 35.2492 8182 One-inch map Sheet 10 Six-inch map Sheet 28SE

Collar elevation 230.6 m Hole inclined 60° to 327°

Location: east of Mine Sike, 520 m N68°E of Callisterhall croft and some 7 km WSW of Langholm

Drilling by Rock Fall Co Ltd Diamec 250 drill

Inclined depth, m	Intersection, m	Lithology	Mineralisation	ppm Cu	ppm Zn	ppm Pb	Section PTS No	Section Depth m
0.00								
3.94	3.94	Superficial deposits						
		BIRRENSWARK LAVAS						
5.78	1.84	Basalt lava, hard and medium grained with limonitic joints, non vesicular						
7.48	1.70	Lava with amygdales filled by calcite and limonite in a soft grey matrix						
14.75 15.88	7.27 1.13	Lava, grey to green, highly altered with pervasive limonite staining, calcite-limonite veinlets	Minor sulphide in brecciated zone 15.70-15.88 m	56	72	12		
16.65	0.77	Lava, dark purple, altered with a strongly amygdaloidal top	Minor galena					
17.51	0.86	Lava, dark grey and very broken						
18.30	0.79	Clay representing lava transitional to unit beneath						
20.98	1.68	Lava, highly altered, non vesicular						
21.48	0.50	Lava, grey green and altered with anastomosing carbonate veinlets	Pyrite and galena in veinlets	31	86	119		
22.13	0.65	Lava, porphyritic, medium to coarse grained, dark green and intensely altered to greenish chlorite especially at vein contacts. The lava is brecciated and thickly veined by vuggy carbonate. One vein is composed of dolomite rhombs and hexagonal crystals with ferroan rims. Some rhombs contain inclusions arranged in hexagonal fashion	Minor galena, and spherulitic aggregates and fairly euhedral crystals of marcasite are associated with the dolomite	6	45	119	2782	22.01
24.31	2.18	Lava, similar to unit above but paler coloured	Marcasite rims veins	13	88	4		
24.61	0.30	Lava, grey to green and altered	Minor carbonate veins					
		CEMENTSTONE						
24.91	0.30	Massive and grey with paler coloured segregations	Minor marcasite, and galena at 24.62 m	0	51	134		
25.80	0.89	Lava, reddish brown, very crushed and broken	Sample contains 11.8% Fe	44	430	132		
26.32	0.52	Lava, very broken						
		Fault						
		LOWER CARBONIFEROUS SEDIMENTS						
26.73	0.41	Sandstone, very fine grained, dense and hard with a little calcareous cement						
26.83	0.10	(?) Mudstone, grey and soft						
27.29	0.46	Sandstone, grey, fine grained, hard and broken						
27.30	0.01	Mudstone, soft and crushed with sandstone fragments						
27.85	0.55	Sandstone, grey and brown, micaceous with silty ribs, broken						
27.93 28.56	0.08 0.63	Cementstone, grey to brown stained, lower half limonitic, basal 5 cm broken and brecciated	Some galena in anastomosing carbonate veins	3	274	212		
29.38	0.82	Sandstone, cementy, and dark grey mudstone, broken						
29.54 29.68	0.16 0.14	Sandstone, grey with soft mudstone and silty ribs, micaceous, dip probably shallow	Carbonate veins	18	115	660		
29.76	0.08	Cementstone, rotten, limonitic with clay patches	Fine grained sulphide					
30.05 30.33	0.29 0.28	Clay, grey and soft, and dark grey mudstone						

30.50	0.17	Cementstone, grey and hard	Patches and veins of carbonate					
30.62	0.12	Sandstone, grey with silty bands and a harder siliceous or cementy band	Patches and veins of carbonate					
31.22	0.60	Cementstone or sandstone, siliceous, grey and hard; lowermost 15 cm broken and brecciated	Marcasite abundant in numerous carbonate veins	6	255	190		
31.42	0.20	Sandstone, grey and soft						
31.77	0.35	Cementstone, yellow to brown, limonitic	Carbonate veinlets					
33.28	1.51	Sandstone, pale buff and brown, medium jointed with a soft, silty top 10 cm						
34.48 34.51	1.20 0.03	Sandstone, grey and hard with silty ribs, micaceous laminae and a broken softer band 34.13–34.25 m		0	16	60		
34.85 34.98	0.34 0.13	Sandstone, grey and hard, fine to medium grained, top 5 cm limonite stained	Galena and (?) baryte in carbonate veinlets					
35.20	0.22	Sandstone, grey with coarser white sandstone ribs and laminae						
35.52	0.32	Sandstone, fine grained, grey, hard and siliceous	Carbonate veins					
35.65	0.13	Sandstone, pale buff and grey, micaceous laminae						
35.88	0.23	Sandstone, pale buff, fine grained, hard	Carbonate veins					
38.82 39.32	2.74 0.50	Sandstone, buff and pale brown, medium grained with a few darker silty micaceous ribs and laminae						
39.79	0.47	Sandstone, dark grey and carbonaceous with a few ribs of mudstone and paler grey sandstone laminae and ribs. The sectioned core fragment consists of layered sandy mudstone with coarse and fine-grained layers of angular quartz and perthitic feldspar. A few prisms of muscovite occur orientated parallel to bedding planes	Minor sphalerite and galena are disseminated in the coarser laminae; altered pyrite and hematite observed in section	19	520	363	2783	39.60
40.03	0.24	Sandstone (part of unit below)						
40.52	0.49	Sandstone, grey and siliceous, fine grained with cementy patches, very hard and compact. Some patchy limonite staining and (?) decalcitised patches	Some thin, irregular carbonate veins					
44.18	3.66	Sandstone, medium to coarse grained and friable with a few darker silty ribs						
44.62 44.70	0.44 0.08	Sandstone, grey, fine grained, with micaceous laminae						
45.05	0.25	Mudstone, grey with some bluish grey patches, rather soft; some silty ribs and greenish sandy bands		20	58	5		
45.53	0.48	Sandstone, grey, medium to coarse grained						
45.53		Bore complete						

APPENDIX I TABLE VIII BH No 8

NGR 35.2925 8188 One-inch map Sheet 10 Six-inch map Sheet NY28SE

Collar elevation 232.9 m Hole inclined 60° to 040°

Location: west bank of Mine Sike, 400 m N51°E of Callisterhall croft and some 7 km WSW of Langholm
Drilling by Rock Fall Co Ltd Diamec 250 drill

Inclined depth, m	Intersection m	Lithology	Mineralisation	Cu (ppm)	Zn (ppm)	Pb (ppm)	Section PTS No	Section Depth, m
0.00								
5.02	5.02	Superficial deposits						
		LOWER CARBONIFEROUS SEDIMENTS						
5.17	0.15	Mudstone, dark grey and soft						
5.38	0.21	Sandstone, siliceous, grey, reddish staining present, brecciated	Calcite veins; 0.15% Ba	12	153	17		
5.47	0.09	Cementstone, pale brown to grey, hard	Calcite-lined cavities abundant					
6.21	0.74	Sandstone, grey with a soft reddish top incorporating darker micaceous laminae, and a siliceous hard lower part						
6.68	0.27	Mudstone, dark grey and soft with cementy ribs						
6.86	0.18	Cementstone, grey, hard and compact	Rare calcite veinlets					
7.35	0.49	Mudstone, dark grey and rather soft						
7.61	0.26	Cementstone, grey, hard and compact with a siliceous base	A few thin carbonate veins					
7.78	0.17	Sandstone, grey, red stained and medium grained with dark grey siltstone ribs and laminae, mudstone and cementy ribs, some broken brecciated ribs and deep red iron-stained patches	Chalcopyrite in veins	1170	4	18		
8.61	0.83			5	188	17		
9.74	1.13	Cementstone, grey, red stained, broken, siliceous bands and patches, deep red hematite staining common	Carbonate in veins and patches					
9.88	0.14	Sandstone, red stained and rotten						
10.21	0.33	Cementstone, limonitic and yellow brown with siliceous bands						
10.68	0.47	Cementstone, rotten, limonitic with patchy hematite staining						
11.59	0.91	Cementstone or chert fragments [core lost]	Carbonate veins					
11.95	0.36	Sandstone fragments, brown, hard and fine to medium grained; much broken with some rotten patches						
11.98	0.03			49	204	88		
12.03	0.05	Broken (?) chert in reddish coloured crushed rock						
		Fault						
		BIRRENSWARK LAVAS						
13.28	1.25	Basalt lava, rotten, red stained rubble at top, purple coloured alteration to 12.66 m, then greenish to 13.08 m where a 12 mm vein of massive quartz is present. With the quartz are associated water-clear calcite and dusty euhedral rhombs of siderite and dolomite. The vein is fractured in places and fragments of crushed carbonate have been smeared into these fissures	Pyrite and spherulitic marcasite occur in the carbonate-rich parts of the quartz vein rather than where only quartz is present; 0.24% Ba in sample	9	232	23	2784	13.14
13.36	0.08	Cherty recrystallised sandstone fragments						
15.83	2.47	Lava, amygdaloidal and altered with a crushed top, becoming increasingly calcareous towards base	Quartz vein at 14.48-14.73 m with drusy quartz-calcite infillings					
		MINERAL VEIN						
		Dolomite vein with galena, sphalerite, chalcopyrite, pyrite and baryte. The dolomite occurs as euhedral rhombs with zoned ferroan rims. Pink baryte infills vuggy cavities. Pyrite, galena and sphalerite are euhedral and some dolomite euhedra are enclosed by sphalerite. A second section through the veins shows that small fragments of intensely altered lava are present. Sphalerite occurs as small euhedral clusters					2785	16.01
16.92	1.09	and the pyrite is fine grained and disseminated. The galena is quite strongly deformed with small microfolds suggesting post-mineralisation deformation but sphalerite is less affected. The analysed sample contains 5.5% Ba and 17 ppm Sb		560	7820	1.01%	2786	16.90
		BIRRENSWARK LAVAS						
18.51	1.59	Lava, pale green with thin calcite and baryte veins and impregnations; crushed from 18.97-19.67	Hematite, chalcopyrite marcasite and pyrite in carbonate veins	178	468	48		
19.95	1.44							
20.17	0.22	Lava, brecciated and (?) silicified with stringers of carbonate	Pyrite, disseminated and in the stringers					

20.93	0.76	Lava, greyish green, altered, vesicular and porphyritic. Plagioclase phenocrysts are set in an intensely altered fine grained to crypto-crystalline matrix. The rock is brecciated and veined by euhedral crustiform overgrowths of dolomite with minor calcite, succeeded by radiating, spherulitic overgrowths of ankerite or ferroan dolomite. Thin ankerite veins with fine grained pyrite cut the lava.	Relatively coarse grained pyrite and sphalerite occur in the veins of euhedral dolomite. Sphalerite occurs at vein margins suggesting crystallisation before the pyrite stringers nearer the centre of the veins				2787	20.63
		(?) Fault						
		LOWER CARBONIFEROUS SEDIMENTS						
22.47	1.54	Sandstone, grey, siliceous, very hard and baked with a few diffuse cementy ribs veined by carbonate	Minor sulphide and (?) malachite on fractures surfaces	34	177	28		
22.67	0.20	Sandstone, medium grained and grey with darker grey micaceous siltstone laminae						
22.97	0.30	Sandstone, grey, fine grained, hard, compact						
23.25	0.28	Cementstone, grey and silty with siliceous patches and deep red stained joints	Some carbonate veinlets					
23.55	0.30	Sandstone, grey, fine grained, hard and siliceous. In section, the rock contains abundant clasts of quartz and perthitic feldspar, relatively unaltered and unstrained, set in a fine grained quartz-rich matrix together with minor muscovite	Chalcopyrite in thin veinlets of calcite is altered to green secondary on weathered surfaces at 23.35 m	47	90	14	2788	23.34
23.75	0.20	Mudstone, dark grey and silty with soft ribs						
23.91	0.16	Sandstone, grey, fine grained and laminated						
24.16	0.25	Cementstone, grey, hard, limonite stained joints and siliceous patches	Irregular carbonate veins					
24.29	0.13	Sandstone, siliceous, grey and hard						
25.07	0.78	Sandstone, thinly bedded, fine grained and grey						
25.62	0.55	Cementstone, grey, hard and compact with red stained patches and veins	Pyrite cube in quartz vein; carbonate veins					
26.22	0.60	Sandstone, grey with darker silty and micaceous laminae						
26.36	0.14	Cementstone, grey, hard and massive. Patches of green illite are set in a fine grained dolomitic matrix	Anastomosing calcite veins				2789	26.25
26.62	0.26	Siltstone with sandstone ribs, grey, a few wavy micaceous laminae						
26.92	0.30	Cementstone, pale grey, red stained, fairly soft						
26.98	0.06	Sandstone, fine to medium grained, micaceous and friable with hematite flakes						
27.24	0.26	Cementstone, silty, grey and red stained						
27.36	0.12	Mudstone, silty, micaceous, greenish grey						
28.65	1.29	Sandstone, red to brown and fine to medium grained with darker bands.						
29.58	0.93	Siltstone, dark grey with paler grey sandstone ribs and laminae showing slight wavy bedding						
29.91	0.33	Cementstone, silty, grey and hard with a thin micaceous laminated sandstone parting						
30.17	0.26	Mudstone, grey with silty laminae						
30.39	0.22	Cementstone, silty, grey and hard with limonite stained joints	Carbonate veinlets					
30.44	0.05	Mudstone, dark grey						
30.60	0.16	Sandstone, grey, calcareous and fine grained, silty laminae dip 5-10°. Some coarser grained layers contain angular fragments of quartz, perthitic feldspar and altered lava. The matrix is very fine grained, altered and dark brown					2790	30.55
30.72	0.12	Mudstone, black and soft						
31.00	0.28	Sandstone, grey to green, medium grained with silty laminae						
31.25	0.25	Mudstone, grey to black with silty laminae						
32.76	1.51	Sandstone, grey, hard with darker laminae, paler and more massive below	Chalcopyrite locally disseminated in greenish sandstone	111	10	6		
34.10	1.32	Sandstone, grey, fine to medium grained with dark grey silty laminae and some thin harder ribs						
34.28	0.18	Sandstone, fine grained, pale grey, siliceous hard						
35.12	0.84	Sandstone buff, fine grained, siliceous, hard						
35.40	0.28	Sandstone, pale brown and medium grained						
35.49	0.09	Siltstone, grey and micaceous						
35.72	0.23	Sandstone, fine to medium grained, grey and buff						
35.72		Bore complete						

APPENDIX I TABLE IX BH No. 9

NGR 35.29058191 One inch map: Sheet 10 Six inch map: Sheet NY28SE

Collar elevation 249.8 m Hole inclined 50° to 048°

Location: hillside west of Mine Sike, 310 m N19°E of Callisterhall croft and some 7 km WSW of Langholm

Drilling by Rock Fall Co Ltd Diamec 250 drill

Inclined depth, m	Intersection m	Lithology	Mineralisation	Cu	Zn	Pb	PTS No	Depth, M
0.00								
3.56	3.56	Superficial deposits						
		LOWER CARBONIFEROUS SEDIMENTS						
3.92	0.36	Sandstone, grey and fine grained, hard with cementy patches	Galena grain at 3.92 m, some pink baryte					
4.88	0.94	Sandstone fragments in soft clay		22	1170	1020		
5.51	0.63	} Sandstone medium grained and pale brown	Disseminated, fine grained	9	720	4200		
5.92	0.41	} with a few harder fine grained bands	galena 5.20-5.92 m					
6.09	0.17	Mudstone, soft and grey						
6.45	0.30	Cementstone, silty, pale brownish grey, hard, limonite staining on joints						
6.75	0.30	Siltstone, grey and micaceous with pale grey sandstone ribs and laminae	Calcite and baryte in veins	33	390	33		
		BIRRENSWARK LAVAS						
7.01	0.26	Basalt lava, grey to green, vesicular	Rare galena in carbonate veins; 0.2% Ba in sample	57	650	150		
8.16	1.15	Lava, grey to mauve, vesicular	Pyrite at edges of quartz-carbonate vein					
9.13	0.97	Lava, altered, fairly coarse grained and amygdaloidal. Plagioclase phenocrysts occur in an altered, fine grained matrix with minor muscovite and very finely disseminated ilmenite prisms. Vesicles are rimmed with green fibrous chlorite and illite, and the centres filled with coarsely crystalline spheralitic ankerite and water clear calcite	Pyrite rims some thin quartz-calcite veinlets; minor marcasite in the central cores of some amygdales. 0.3% Ba in sample	22	88	16	2791	8.22
10.38	1.25	Lava as above						
11.53	1.15	Lava, grey to green, non-vesicular, intensely sheared and altered, and thickly veined by turbid, fine grained ankerite or dolomite and by pinkish coloured baryte. Some of the carbonate grains have curved crystal faces with zoned ferroan ribs	Coarse grained marcasite and lesser coarse grained galena, sphalerite and chalcopyrite occur in the carbonate veins				27922	10.82
12.84	1.31	Lava, dark grey, less altered, non vesicular, minor veining						
15.30	2.46	Lava, grey to mauve and coarse grained, consisting of plagioclase phenocrysts in an altered, dark grey, fine grained matrix. Amygdales are composed of encrusting fibrous green chlorite, illite, brown limonite, fine and coarse grained calcite and turbid ankerite	Fine grained dolomite with altered pyrite in veins				2793	13.55
16.75	1.45	Lava, non-vesiculer with a dense, grey altered matrix		24	137	6		
17.15	0.40	CEMENTSTONE, grey and massive. The contact with the underlying lava, seen in section, is very irregular and "intrusive" rather than structural. Carbonates in the cementstone show the characteristic zoned rhombic outlines of dolomite which is ankeritic in composition	Quartz vein with drusy cavities at 16.90-17.10 Finely disseminated pyrite, probably authigenic, is the only sulphide present in the cementstone	56	40	39	2791	17.20
17.82	0.67	The lava in contact with the cementstone consists of plagioclase phenocrysts, intensely altered to a brown isotropic material, set in an altered dark brown matrix. Fine grained prismatic ilmenite is common. Amygdales consist of fibrous green chlorite, illite and zoned dolomite, or may be entirely filled by fibrous, spheralitic encrustations of chlorite	Thin quartz-calcite veinlets cut both cementstone and lava. Pyrite occurs with dolomite in amygdales. Analysed sample contains 0.2% Ba					
19.90	2.08	Lava, dark grey and vesicular						
20.07	0.17	CEMENTSTONE, grey	Pyrite rims carbonate veins. 13% Fe in sample	25	112	9		
21.30	1.23	Lava, pale grey, chlorite spots, non-vesicular with thin CEMENTSTONE intercalation	Small chalcopyrite grains	142	177	48		
22.14	0.34	Lava, pale grey, chlorite patches, vesicular						
22.14		Bore complete						

APPENDIX I TABLE X BH No 10

NGR 35.28728192 One-inch map Sheet 10 Six-inch map Sheet NY28SE

Collar elevation 248.7 m Hole inclined 50° to 000°

Location: on hillside north of the head of Pokeskine Sike 370 m N35°W of Callisterhall croft and about 7.5 km WSW of Langholm

Drilling by Rock Fall Co Ltd Diamec 250 drill

Inclined depth, m	Intersection, m	Lithology	Mineralisation	Cu (ppm)	Zn (ppm)	Pb (ppm)	Section PTS No	Section Depth m
0.00								
2.25	2.25	Superficial deposits						
		LOWER CARBONIFEROUS SEDIMENTS						
3.01	0.76	Sandstone, grey, fine grained, hard, compact, siliceous, carbonaceous plant fragments	Pyrite disseminated along bedding					
3.79	0.78	Broken core, fragments of mudstone, cementstone and sandstone		5	290	520		
3.97 4.19	0.18 0.22	Cementstone, silty in parts, calcite filled cavities, broken, carbonate veins common	Galena and yellow sphalerite in cavities	0	330	60		
4.60 4.97	0.41 0.37	Mudstone, dark grey, soft, broken (20 cm)						
5.69	0.72	Sandstone, grey, fine grained, hard, compact, siliceous						
5.93	0.24	Cementstone, dark grey, patchy carbonate veining	Galena veinlets up to 0.5 mm thick	6	800	1850		
6.29	0.36	Siltstone, dark grey, paler grey sandstone ribs showing slight wavy bedding and slumping						
6.43	0.14	Cementstone, pale grey, hard, compact						
6.56	0.13	Siltstone, dark grey, pale grey sandstone wisps and ribs						
6.73	0.17	Cementstone, grey, hard, compact, limonitic stained joints						
6.77	0.04	Siltstone, dark grey						
6.92	0.15	Cementstone, grey, hard, compact limonitic stained joints						
6.97	0.05	Siltstone, dark grey						
7.22	0.25	Cementstone, grey, mottled darker grey, some limonitic staining						
7.34 7.57	0.12 0.23	Siltstone, sandy, wavy bedding						
7.86	0.29	Mudstone, silty, dark grey, broken dip probably shallow	Spherulitic pyrite	16	64	37		
8.16	0.30	Cementstone, grey, hard, compact, sandy lower part						
8.21	0.05	Mudstone, dark grey, soft						
8.36	0.15	Cementstone, silty, grey, hard						
9.24	0.88	Mudstone, grey, silty top, sandy lower 10 cm, rather rough bedding, micaceous, few irregular sandstone laminae and wisps						
9.44	0.20	Cementstone, grey and hard						
10.06	0.62	Sandstone, dark grey, silty bands, rough bedding						
10.26	0.20	Cementstone, grey, hard, compact	Carbonate veins					
11.41	1.15	Sandstone, grey, pale grey harder ribs and bands showing slumped and irregular bedding						
11.61	0.20	Sandstone, fine grained, hard	Carbonate veins					
11.90	0.29	Mudstone, silty, grey, sandy top 10 cm						
12.40	0.50	Cementstone, grey, hard, compact	Carbonate veinlets					
12.64	0.24	Siltstone, grey, pale grey sandstone ribs and laminae						
12.78	0.14	Cementstone, dark grey, hard, compact, splintery						
12.85	0.07	Mudstone, dark grey finely micaceous						
13.37	0.52	Cementstone, grey, hard, compact, calcite lined cavities, some slight brecciation	Carbonate veins	5	570	300		
13.47	0.10	Sandstone, grey speckled white, rough bedding, medium grained						
13.67	0.20	Cementstone, grey hard, dolomitic matrix cut by a thick crystalline vein of dolomite, ankerite and calcite	Carbonate veins with galena, disseminated pyrite					
13.92	0.25	Mudstone, dark grey, shaly, finely micaceous						
14.05	0.13	Cementstone, grey, hard, compact, splintery						
14.22	0.17	Sandstone, fine-medium grained, slumped, contorted bedding						

14.51	0.29	Cementstone, dark and fine grained with a coarser quartz-rich sandstone band. The dolomitic matrix is veined by a thick complex vein of coarsely crystalline dolomite, ankerite and calcite. Some grains are clear, others turbid (particularly ankerite). Minor quartz is also present	Galena and lesser sphalerite in the vein; fine grained disseminated pyrite in the sediment				2795	14.46
15.47	0.96	Sandstone, grey and pale grey, wavy bedding, darker silty ribs, dip probably shallow, finely micaceous throughout						
15.91	0.44	Cementstone, grey, hard and compact with carbonate veins	Galena in veins					
16.82	0.91	Sandstone, grey, fine grained, darker silty ribs, dip probably shallow; some wavy bedding, harder siliceous bands						
16.94	0.12	Cementstone, grey, limonitic stained joints, hard, compact						
17.02	0.08	Siltstone, dark grey						
17.44	0.42	Cementstone, pale grey, hard, compact carbonate veins and patches	Pyrite rims carbonate patches					
17.69	0.25	Siltstone, grey, micaceous, well bedded						
17.86	0.17	Cementstone, slightly silty, grey, hard and compact	Carbonate veins					
17.97	0.11	Crushed broken mudstone, siltstone fragments						
18.24	0.27	Sandstone, grey, hard, compact, siliceous fine-medium grained, very splintery, dark grey siltstone at top, few hematite stained joints						
19.31	1.07			21	43	6		
19.66	0.35	Cementstone, grey, hard, compact carbonate patches and veins	Minor pyrite and chalcopyrite at 19.54 m					
21.27	1.61	Sandstone, fine to medium grained, hard, compact, splintery, some calcite-lined cavities with limonite staining, siliceous						
21.47	0.20	Cementstone, grey, fine, hard, compact, splintery						
21.81	0.34	Sandstone, fine-grained, hard, compact, siliceous cement, few cementy patches with carbonate veins						
22.33	0.52	Sandstone, medium grained, grey to white, micaceous, silty laminae						
22.83	0.50	Mudstone, dark grey, very finely micaceous, irregular sandy laminae	Pyrite patches in sandy laminae					
23.39	0.56	Sandstone, grey to buff, fine grained, hard cementy ribs, limonitic lower 5 cm						
23.60	0.21	Cementstone, grey, hard, compact						
25.00	1.40	Sandstone, grey and buff, fine to medium grained, carbonaceous or micaceous ribs, some slumped bedding						
25.65	0.65	Mudstone, dark grey, dip probably shallow, silty base						
25.86	0.21	Sandstone, grey and fine grained with darker silty ribs. Band of mauve sandstone at 25.86 m composed of angular clastic quartz, perthitic feldspar and platey muscovite in an altered brownish matrix	Chalcopyrite and altered pyrite disseminated in sandstone matrix at 25.86 m Chalcopyrite in calcite veinlets					
25.89	0.03			520	95	8	2796	25.86
26.38	0.49							
26.59	0.21	Mudstone, dark grey						
26.64	0.05	Sandstone, grey, micaceous						
26.97	0.33	Cementstone, faintly red stained, grey, hard, compact, splintery, irregular patchy and anastomosing carbonate veinlets						
27.32	0.35	Sandstone, fine to medium grained, rather broken, micaceous	Anastomosing calcite-hematite veinlets					
28.06	0.74	Mudstone, dark grey, contorted, crushed to 27.86 m						
28.56	0.50	Sandstone, grey, medium grained, fairly hard, compact, some steep joints and paler calcareous bands	Fine grained pyrite in calcareous bands	10	39	8		
28.89	0.33	Cementstone, grey, hard, compact	Carbonate veins					
28.99	0.10	Mudstone, grey, red stained, soft						
29.15	0.16	Cementstone, grey, slight red staining, hard, compact	Hematite veinlets					
29.69	0.54	Sandstone, fine grained, grey and red mottled, cementy patches (?) brecciated	Carbonate veins					
29.90	0.21	Broken sandstone and mudstone						
30.38	0.48	Sandstone, fine grained, grey, hard, siliceous	Some carbonate veins	19	80	7		

30.70	0.32	Sandstone, silty and grey with sphaerosiderite patches						
34.38 35.52 37.17	3.68 1.14 1.65	Sandstone, medium grained, hard and compact; some coarse bands, grey bands, hard, red and red brown softer bands, and cementy bands		0	36	8		
37.57	0.40	Mudstone, silty with a red brown top, greenish grey below, soft, some sandy laminae						
38.28	0.71	Siltstone, greenish grey, pale grey sandstone ribs and laminae, showing some small slumps and wavy bedding						
38.60	0.32	Cementstone, pale brown grey, patchy staining						
38.67 39.34	0.07 0.67	Mudstone, silty, deep red brown, some soft bands becoming increasingly grey towards lava junction. Conformable junction with lava, dip probably shallow		0	36	18		
		BIRRENSWARK LAVAS						
40.14	0.80	Basalt lava, amygdaloidal, greenish grey, rotten with red brown top and patches; fine sediment with lava clasts at 40.04 m	Trace of galena in amygdale at 39.4 m	2	48	11		
46.72 47.07	6.58 0.35	Lava, grey green, amygdaloidal, paler below, less amygdaloidal at depth. Coarse grained with altered plagioclase phenocrysts and ilmenite laths in an intensely altered dark brown matrix. Amygdales of illite and green chloritic material. Veined by euhedral, zoned rhombs of dolomite with	Pyrite and chalcopyrite in carbonate -quartz vein network at 46.72-47.07 m	147	61	143		
51.72	4.65	associated turbid spherulitic overgrowths of ankerite and minor quartz	Pyrite and marcasite at the edges of some veins				2797	49.28
51.72		Bore complete						

APPENDIX I TABLE XI BH No 11

NGR 35.28538189 One-inch map Sheet 10 Six-inch map Sheet NY28SE

Collar elevation 244.7 m Hole inclined 60° to 215°

Location: west of the head of Pokeskine Syke, 450 m N63°W of Callisterhall croft and some 7.5 km WSW of Langholm

Drilling by Rock Fall Co Ltd Diamec 250 drill

Inclined depth, m	Intersection m	Lithology	Mineralisation	ppm Cu	Zn	Pb	Section PTS No	Depth, m
0.00								
2.98	2.98	Superficial deposits						
		LOWER CARBONIFEROUS SEDIMENTS						
5.98	3.00	Sandstone, pale grey, fine to medium grained, fairly hard, with angular fragments of grey mudstone and siltstone in top 20 cm, pale brown lower half						
6.33	0.35	Mudstone, dark grey and broken with stringers, clusters and disseminations of pyrite	Pyrite					
6.83	0.50	Mudstone, dark grey with a carbonaceous top, broken, silty ribs and sandy ribs with sulphides	Pyrite in carbonaceous material. Fine grained sphalerite, galena and chalcopyrite in a 15 mm thick sandstone rib	37	1140	660		
7.28	0.45	Siltstone, greenish grey, fairly hard, broken	Chalcopyrite in basal 5 mm					
		BIRRENSWARK LAVAS		260	42	7		
7.48 7.79	0.20 0.31	Basalt lava, grey green, calcareous amygdaloidal	Pyrite and limonite at edges of calcite veins to 15 mm thick	77	61	5		
15.78	7.99	Lava, fewer amygdales, grey, broken in places	Carbonate on fractures					
19.90	4.12	Lava, medium grained, sparsely amygdaloidal, relatively unaltered. Twinned plagioclase phenocrysts and abundant large ilmenite prisms are set in a light coloured chloritic matrix, sometimes in felted "mats" with patchy carbonate	Intense carbonate veining at 16.08-16.27 m and 18.60-18.99 m (analysed sample) with associated pyrite	17	157	3	2815	15.91
26.34	6.44	Lava, locally amygdaloidal, altered and pale grey below 26.01 m, brecciated and crushed from 26.37 m to 26.34 m (analysed sample)		20	640	97		
		LOWER CARBONIFEROUS SEDIMENTS						
26.36	0.02	Siltstone conformable with lava above						
27.07	0.21	Siltstone, sandy, grey, patches of kaolinite, roughly bedded						

27.45	0.38	Siltstone, dark grey, roughly bedded, micaceous, some silty mudstone ribs at top						
27.64	0.19	Cementstone, pale grey, hard, limonitic joints						
28.16	0.52	Siltstone, dark grey, micaceous, a few sandy laminae	Chalcopyrite at 27.93 m	20	31	32		
28.56	0.40	Cementstone, grey, silty top, hard, silty layers	Carbonate veins					
28.68	0.12	Mudstone, dark grey, carbonaceous						
28.88	0.20	Cementstone, brownish grey, hard, compact	Anastomosing carbonate veinlets					
29.17	0.29	Mudstone, silty, grey, irregular cementstone fragments, dip probably fairly shallow	Much carbonate veining					
29.63	0.46	Mudstone, silty, grey with siltstone ribs						
29.74	0.11	Cementstone, grey, silty upper half, fairly hard, very fine grained hard lower half with mudstone laminae						
30.27	0.53		Carbonate veins					
30.62	0.35	Siltstone, grey, cementy ribs, dark grey mudstone partings	Some carbonate veins with galena and pyrite	3	48	380		
30.97	0.35	Cementstone, grey, hard, laminated and quartzose with broken branching carbonate veins (faultlets)	Galena and pyrite in dolomite-calcite veins, quartz veins				2816	30.86
31.04	0.07							
31.40	0.36	Mudstone, silty with siltstone and mudstone ribs, finely micaceous	Galena in carbonate veinlets	7	178	1290		
31.73	0.33	Cementstone, grey, fairly hard, irregular mudstone laminae in lower 10 cm	Galena grains to 3 mm across in carbonate veins					
31.83	0.10							
32.40	0.57	Mudstone, silty, finely micaceous with a few cementy ribs, dip probably shallow						
32.62	0.22	Cementstone, brown to grey, silty, hard	Carbonate veins	12	44	790		
32.81	0.19	Mudstone, dark grey, silty, sandy laminae	Galena stringers					
32.86	0.05	Siltstone, pale grey, laminated, mudstone bands	Galena in 2 cm thick calcite vein					
33.02	0.16	Siltstone, grey, faintly greenish, broken with contorted and possibly vertical bedding in parts	Much calcite veining with minor galena	13	360	1520		
		(?) Fault						
33.15	0.13	Siltstone, grey with paler cementy ribs, sandy ribs and darker grey silty mudstone ribs, dip probably shallow	Probable galena in carbonate veinlets perpendicular to bedding					
33.78	0.63							
33.98	0.20	Cementstone, pale brown grey and hard	Irregular carbonate veins					
34.20	0.22	Siltstone, grey micaceous	Trace of disseminated chalcopyrite					
34.35	0.15	Cementstone, grey and hard	Carbonate veinlets					
34.44	0.09	Siltstone, dark grey, micaceous, sandy laminae						
34.86	0.42	Cementstone, pale brown grey, hard, compact, limonite stained joints, some irregular mudstone patches	Carbonate veinlets					
34.96	0.10	Siltstone, grey and broken						
36.57	1.61	Sandstone, grey, fine grained, hard, slightly cementy top 10 cm	Carbonate veinlets					
36.71	0.14	Siltstone, grey, thin bedded, sandy laminae						
36.89	0.18	Cementstone grey, very fine grained and hard	Carbonate veinlets					
37.04	0.15	Siltstone, sandy, green grey	(?) Sphaerosideritic					
37.17	0.13	Cementstone, silty, green grey, much broken and fractured, some hematite staining	Minor sulphide in carbonate veinlets					
37.39	0.22	Sandstone, deep red purple stained						
37.59	0.20	Cementstone, silty, grey, red stained with veins and veinlets, some broken	Carbonate veins	176	44	11		
37.79	0.20	Sandstone, silty matrix, brown red stained	Chalcopyrite stringers					
38.31	0.52	Siltstone and silty sandstone, green grey top 10 cm, dark grey below with some carbonaceous partings						
38.73	0.42	Mudstone, grey and green grey, badly broken and crushed with some rotten lava patches at top						

		Fault						
38.39 39.02	0.16 0.13	Sandstone, fine grained, green grey and some red brown, patches, rather broken	Disseminated chalcopyrite	810	41	17		
39.06 39.32	0.04 0.26	Cementstone, brown grey, hard with anastomosing veinlets of carbonate and patches of carbonate	Carbonate veins					
39.65	0.33	Crushed grey mudstone, (?) fault						
40.18	0.53	Sandstone, silty and grey with patches and rather broken veins of carbonate	Carbonate veins					
40.43 40.49	0.25 0.06	Mudstone, silty, crushed and broken						
40.64	0.15	Siltstone, cementy, grey, thinly bedded	Carbonate veins					
40.94	0.30	Mudstone, crushed and broken, grey, cementy fragments						
41.34	0.40	Cementstone, silty parts, brecciated veins and patches of carbonate, irregular dark mudstone laminae		10	71	174		
41.67	0.33	Siltstone, grey, micaceous, sandy laminae and ribs showing irregular and wavy bedding, some small scale slumping						
41.73 42.14	0.06 0.41	Cementstone, grey and pale grey, rather irregularly bedded top 30 cm with irregular dark grey mudstone veins and veinlets	Some disseminated pyrite patches					
43.23	1.09	Sandstone, grey, fine to medium grained silty layers	Carbonate veins with galena and pyrite					
44.16	0.93	Sandstone, brownish grey, fine grained, cementy patches, irregular dark grey mudstone patches and veins	Chalcopyrite in irregular carbonate veins					
44.80	0.64	Siltstone, grey, sandy ribs and laminae, red staining	Irregular carbonate veins					
45.07	0.27	Mudstone, silty, grey, rather broken						
45.35	0.28	Siltstone, grey and hard with cementy ribs and silty mudstone ribs	Some carbonate veining					
45.75	0.40	Cementstone, brown grey, hard and compact with sulphides in or at edges of veins, and locally disseminated	Sphalerite and galena in veins, galena smeared on joint surface	0	420	270		
46.24 46.30	0.49 0.06	Siltstone, grey and green grey with dark grey mudstone ribs at top, cementy ribs below	Galena and sphalerite in veinlets, pyrite on joint					
46.50	0.20	Mudstone, silty, dark grey	Sulphide disseminated					
46.71	0.21	Cementstone, silty, sandy in parts	Galena and sphalerite in veinlet, coarse pyrite in fracture, chalcopyrite on joint	181	158	314		
47.26	0.55	Siltstone, sandy, purple stained, grey						
47.28 47.45	0.02 0.17	Cementstone, brown grey, hard and compact	Broken carbonate veins					
47.65	0.20	Sandstone, silty, grey with purple overtones, roughly bedded appearing conformable on underlying lava						
		BIRRENSWARK LAVAS						
50.25	2.59	Basalt lava, mauve, amygdaloidal, hematite-coated joints, pale grey zone, brecciated zone	Pyrite disseminated and in carbonate veinlets					
		(?) Fault						
51.47 53.16	1.23 1.69	Lava, slightly altered, matrix red to grey, finely crystalline and silicified. Feldspar prisms fairly fresh, some chloritic alteration of matrix especially at vein contacts and patchy replacement by carbonate and quartz. Irregular veins consist of quartz, dolomite, ankerite, baryte and calcite. Baryte occurs mainly as cavity infillings	Pyrite occurs as patchy disseminations in the lava and in the veinlets especially at their contacts; 0.3% Ba in sample	26	38	6	2817	52.46
53.44	0.28	Lava, altered and sheared with abundant hematite						
53.88 54.76	0.44 0.88	Lava, amygdaloidal top, fine grained, mauve with altered pale grey bands, hematite fracture fillings and patches of clay mineral	Pyrite locally abundant - either disseminated, in veinlets or with hematite	61	44	44		
55.37	0.61	Lava, pale grey to white ("white trap") with original texture destroyed, irregularly fractured	Pyrite and other fine grained sulphide disseminated and in clusters	224	127	175		
56.24	0.87	A pale grey carbonate rock, probably a mineralised breccia with traces of intensely altered volcanic fragments. Composed mainly of dolomite or ankerite with abundant sulphides, some of which have been sheared or displaced indicating post-mineralisation brecciation	Occasional grains and local disseminations of chalcopyrite and lesser sphalerite, galena and pyrite. Sulphides absent from thin cross cutting calcite veins	580	66	82	2818	56.05
57.70 59.00 59.45	1.46 1.30 0.45	Mineralised breccia as above	Carbonate veins with chalcopyrite	16 33	45 53	36 11		
59.45		Bore complete						

APPENDIX I TABLE XII BH No. 12

NGR 35.28108134 One-inch map: Sheet 10 Six-inch map: Sheet NY28SE

Collar elevation: 217.5 Hole inclined 70° to 330°

Location: at edge of coniferous plantation 850 m S73°W of Callisterhall croft and nearly 8 km WSW of Langholm

Drilling by Rock Fall Co Ltd Diamec 250 drill

Inclined depth, m	Intersection m	Lithology	Mineralisation	ppm Cu	ppm Zn	ppm Pb	Section Pts No	Section Depth m
0.00	9.15	Superficial deposits						
		LOWER CARBONIFEROUS SEDIMENTS						
9.33	0.18	Mudstone, grey						
9.45	0.12	Cementstone, grey						
9.65	0.20	Sandstone						
12.39	2.74	Mudstone, silty mudstone and sandstone						
12.69	0.30	Cementstone, rotten, limonitic						
13.00	0.31	Silty mudstone						
13.22	0.22	Cementstone, rotten, limonitic						
13.38	0.16	Mudstone						
13.51	0.13	Cementstone, silty, rotten, limonitic						
14.00	0.49	Mudstone, grey						
14.24	0.24	Cementstone, rotten, limonitic						
15.33	1.09	Mudstone, grey, massive bedded						
16.08	0.75	Calcareous siltstone, grey, hard	Galena, calcite on joint					
16.28	0.20	Sandstone, silty with limonitic partings						
16.91	0.63	Cementstone, limonitic	Galena in calcite veinlet					
17.13	0.22	Sandstone, silty, calcareous with a few (pp) rhynchonellids						
17.72	0.59	Mudstone, silty						
17.92	0.20	Cementstone with a rotten limonitic top packed with rhynchonnellid fragments						
18.06	0.14	Mudstone, silty						
18.20	0.14	Calcareous siltstone, grey, hard	Calcite veinlets					
18.30	0.10	Cementstone, grey, hard						
19.50	1.20	Siltstone and silty mudstone, fairly flat bedded						
20.41	0.91	Cementstone, grey, very hard	Pyrite and hematite in calcite veinlets					
20.83	0.42	Calcareous siltstone, grey						
21.07	0.24	Cementstone						
21.84	0.77	Siltstone, grey, flat bedded						
22.26	0.42	Sandstone, medium-grained, pale brown	Calcite veinlets					
22.54	0.28	Cementstone, grey, limonite-stained joints	Calcite veinlets					
23.31	0.77	Sandstone, buff, fine to medium-grained						
23.82	0.51	Cementstone, brownish-grey, hard	Carbonate veinlets					
23.92	0.10	Silty sandstone						
24.24	0.32	Cementstone, grey	Carbonate veinlets					
24.37	0.13	Mudstone, dark grey						
24.53	0.16	Cementstone, speckled grey	Carbonate patches					
25.09	0.56	Mudstone, dark grey						
26.30	1.21	Siltstone, grey with sandy laminae showing bioturbation and worm burrows	Chalcopyrite smear					
26.95	0.65		Chalcopyrite, galena, pyrite stringers	126	240	350		
28.14	1.19							
28.66	0.52	Micritic cementstone containing a few clastic fragments of quartz and perthitic feldspar in a matrix of fine-grained ankeritic dolomite	Chalcopyrite and pyrite in dolomite-siderite vein				2819	28.49
28.92	0.26	Mudstone, dark grey, flat bedded						
29.26	0.34	Siltstone, dark grey, bioturbated						
29.40	0.14	Mudstone						
29.74	0.34	Cementstone, creamy-grey, hard	Calcite veinlets with chalcopyrite					
30.96	1.22	Sandstone, impure, pale grey to brown	Calcite veins, pyrite specks					
31.31	0.35	Mudstone	Pyrite and chalcopyrite specks					
31.70	0.39	Cementstone, silty, grey, hard	Carbonate veinlets					

32.35	1.15	Siltstone, grey with some wavy bedding						
33.15	0.30	Cementstone, grey, hard	Carbonate veinlets					
35.22	2.07	Siltstone, grey, flat bedded with some sandy ribs and harder cementy bands	Small lenses of pyrite and (?) chalcopyrite					
35.62	0.40	Cementstone, silty, grey	Carbonate or baryte veins					
37.31	2.19	Siltstone, grey	Calcite veins common					
37.62	0.31	Cementstone, grey with some mudstone partings	Carbonate veins, chalcopyrite in irregular fracture					
38.95	0.33	Mudstone, dark grey and soft	Coarse-grained chalcopyrite enclosing sphalerite in dolomite; disseminated pyrite; late calcite veinlets					
39.14	0.19	Siltstone, fine-grained, grey with larger clastic grains of quartz and perthitic feldspar and some patches of dolomite					2820	39.00
40.03	0.89	Sandstone, fine-grained, hard with irregular carbonaceous laminae showing slumps						
41.71	1.68	Siltstone, dark grey with sandy ribs showing slumping and bioturbation	Pyrite or chalcopyrite in rare grains					
42.10	0.39	Cementstone, pale grey, sandy in parts	Carbonate veinlet with galena					
42.58	0.48	Sandstone, fine-grained	Traces of galena in isolated patches					
42.92	0.34	Siltstone with sandstone wisps						
43.48	0.56	Sandstone, buff with micaceous laminae						
43.61	0.13	Cementstone, pale brown-grey	Galena smear on joint					
44.30	0.69	Sandstone, grey with silty bands common and bioturbated bands with worm burrows						
44.39	0.09	} Cementstone, silty top	} Galena smears in calcite veinlets	28	112	232		
44.83	0.44							
44.95	0.12							
45.43	0.48	Siltstone, grey with sandy laminae						
45.65	0.22	Cementstone, silty, grey and hard	Carbonate veinlets					
46.13	0.48	Siltstone, grey with sandy bands						
46.34	0.21	Cementstone, silty						
46.66	0.32	Siltstone, finely banded with clastic quartz grains and orientated muscovite plates	Galena in dolomite veins and late calcite veinlets	16	25	1210	2821	46.39
47.80	1.14	Siltstone, grey with some sandstone bands						
47.93	0.13	Mudstone, soft						
48.30	0.37	Cementstone, grey to brownish grey	Calcite veinlets with chalcopyrite in clusters to 4 mm	1020	9	15		
48.55	0.25	Siltstone, grey with sandstone bands						
48.75	0.20	} Cementstone, pale brown-grey, silty in parts with a few dark mudstone partings	Carbonate and baryte veins with coarse galena	46	9	920		
49.99	1.24							
		FAULT ZONE						
50.24	0.25	Siltstone, grey, and fragments of sandstone	Galena in veinlets					
50.36	0.12	Mudstone, soft	Chalcopyrite in thin carbonate stringers					
51.03	0.67	Cementstone, dark grey and fragmentary mudstone	Galena and lesser sphalerite in abundant carbonate veins	17	183	5720		
51.49	0.46	Mudstone, broken with cementstone and sandstone fragments	Pyrite and (?)galena in harder bands					
51.62	0.13	} Cementstone, fragments, indicating possible fault		20	15	237		
51.90	0.28			30	20	30		
52.54	0.64	Altered fragments of sandstone, mudstone and lava in a dark brown, intensely altered matrix, brecciated and slightly dolomitised. The lava is fine-grained and porphyritic with twinned plagioclase phenocrysts	Dolomite veins with marcasite, pyrite; some disseminated pyrite; chalcopyrite common with pyrite in late calcite veins	4050	24	209	2822 2823 2824	51.94 52.35 52.42
53.04	0.50	Brecciated rock with intensely altered lava fragments in a dolomitic matrix	Chalcopyrite stringers in veins of ankeritic dolomite	5410	44	127	2825	52.70
53.56	0.52	Breccia with lava fragments	Chalcopyrite stringers	1120	7	13		
		BIRRENSWARK LAVAS						
54.08	0.52	Altered, pale grey, amygdaloidal	Chalcopyrite in calcite veins	378	10	11		
54.83	0.75	Breccia of altered lava fragments in coarse dolomite; calcite absent	Coarse euhedral marcasite in dolomite	12	8	15	2826	54.66
55.53	0.70	Altered, grey, amygdaloidal lava with a limonitic zone at 55.75-55.92 m	Chalcopyrite, pyrite, baryte	211	27	48		
56.29	0.76		Pyrite common in veinlets	28	13	51		
57.82	1.53	Altered, fine to medium-grained porphyritic lava with mesh-like networks and patchy replacements of dolomite with ankerite	Corroded pyrite and marcasite common in replaced patches, cupriferous where alteration is intense	676	8	32	2827	57.56
58.57	0.75	} Lava, hard but altered, pale brown to grey	} No sulphides seen, some pink baryte	22	22	22		
59.30	0.73			15	36	25		
60.09	0.79			23	21	67		
60.09		Bore complete						

APPENDIX I TABLE XIII BH No 13

NGR 35.33238229 One-inch map Sheet 10 Six-inch map Sheet NY38SW

Collar elevation 121 m OD Hole inclined 70° to 090°

Location: in field on south side of Wauchope Water 1170 m N24°E of Bloch farm and some 3 km SW of Langholm

Drilling by Rock Fall Co Ltd Diamec 250 drill

Inclined depth, m	Intersection, m	Lithology	Mineralisation
0.00			
8.25	8.25	Superficial deposits	
		LOWER CARBONIFEROUS SEDIMENTS	
12.07	3.82	Sandstone, pale buff and yellow brown, mostly medium grained and rather friable. Some rusty speckled bands and steep joints. Small, round (?) lava pebbles in upper part. Magnetite-rich band at 9.27 m	
12.84	0.77	Siltstone, grey and soft with fragments of pale grey sandstone; sandstone ribs in lower part; dip c. 55-60°	
13.54	0.70	Cementstone, rotten and limonitic	Hairline calcite veinlets
14.16	0.62	Sandstone, red-brown stained, fine to medium-grained, top is limonitic and cementy	
14.66	0.50	Sandstone, buff, fine-grained with red-stained joints	
15.90	1.24	Siltstone and silty mudstone, soft, grey and micaceous with sandstone laminae and carbonaceous or micaceous laminae	
16.04	0.14	Cementstone, pale brown and limonitic	Hematite-calcite veinlets
16.33	0.29	Fragments of broken, soft, grey mudstone	
17.88	1.55	Cementstone, limonitic, yellow-brown and sandy; lower half is mottled purple and pale brown and contains very sandy pebbles	
18.22	0.34	Sandstone, purple brown, fine grained, very soft and uncemented	
19.03	0.81	Sandstone, fine to medium-grained, pale brown and uniform	
19.41	0.38	Cementstone, irregular, sandy, limonitic and yellow brown	
31.13	11.72	Sandstone, pale brown and fine to medium-grained, uniform except for occasional irregular patches of limonitic sandy cementstone, slightly purple bands and carbonate blebs; hematitic joints in lower part and carbonaceous or micaceous laminae over the basal 30 cm	
31.96	0.83	Mudstone, silty, grey and soft with fragments of cementstone at 31.34 - 31.44 m and sandstone fragments; generally very broken below 31.44 m	
33.06	1.10	Sandstone, grey, hard and compact; cementy in places with red-brown staining along joints	Minor pyrite and chalcopyrite in quartz vein at 32.59 m; (?) siderite vein with pyrite at 32.74 m
33.45	0.39	Mudstone, soft, crushed, broken and greenish grey	
39.14	5.69	Sandstone, grey top, buff below, fine to medium grained, dip apparently very steep; broken band at 35.80 - 35.97 m; badly broken and crushed sandstone with mudstone fragments from 38.34 m to base denoting possible fault	
39.14		Bore complete	

Analyses

Inclined depth, m	Intersection, m	Lithology	Cu (ppm)	Zn (ppm)	Pb (ppm)
12.87					
13.54	0.67	Cementstone	4	5	0
18.93					
19.50	0.57	Cementstone, minor sandstone	0	0	0
32.40					
33.06	0.66	Sandstone	7	9	0
35.74					
36.01	0.27	Sandstone, broken, limonitic specks and joint coatings	540	9	1

APPENDIX I TABLE XIII BH No 13

NGR 35.33238229 One-inch map Sheet 10 Six-inch map Sheet NY38SW

Collar elevation 121 m OD Hole inclined 70° to 090°

Location: in field on south side of Wauchope Water 1170 m N24°E of Bloch farm and some 3 km SW of Langholm

Drilling by Rock Fall Co Ltd Diamec 250 drill

Inclined depth, m	Intersection, m	Lithology	Mineralisation
0.00			
8.25	8.25	Superficial deposits	
		LOWER CARBONIFEROUS SEDIMENTS	
12.07	3.82	Sandstone, pale buff and yellow brown, mostly medium grained and rather friable. Some rusty speckled bands and steep joints. Small, round (?) lava pebbles in upper part. Magnetite-rich band at 9.27 m	
12.84	0.77	Siltstone, grey and soft with fragments of pale grey sandstone; sandstone ribs in lower part; dip c. 55-60°	
13.54	0.70	Cementstone, rotten and limonitic	Hairline calcite veinlets
14.16	0.62	Sandstone, red-brown stained, fine to medium-grained, top is limonitic and cementy	
14.66	0.50	Sandstone, buff, fine-grained with red-stained joints	
15.90	1.24	Siltstone and silty mudstone, soft, grey and micaceous with sandstone laminae and carbonaceous or micaceous laminae	
16.04	0.14	Cementstone, pale brown and limonitic	Hematite-calcite veinlets
16.33	0.29	Fragments of broken, soft, grey mudstone	
17.88	1.55	Cementstone, limonitic, yellow-brown and sandy; lower half is mottled purple and pale brown and contains very sandy pebbles	
18.22	0.34	Sandstone, purple brown, fine grained, very soft and uncemented	
19.03	0.81	Sandstone, fine to medium-grained, pale brown and uniform	
19.41	0.38	Cementstone, irregular, sandy, limonitic and yellow brown	
31.13	11.72	Sandstone, pale brown and fine to medium-grained, uniform except for occasional irregular patches of limonitic sandy cementstone, slightly purple bands and carbonate blebs; hematitic joints in lower part and carbonaceous or micaceous laminae over the basal 30 cm	
31.96	0.83	Mudstone, silty, grey and soft with fragments of cementstone at 31.34 - 31.44 m and sandstone fragments; generally very broken below 31.44 m	
33.06	1.10	Sandstone, grey, hard and compact; cementy in places with red-brown staining along joints	Minor pyrite and chalcopyrite in quartz vein at 32.59 m; (?) siderite vein with pyrite at 32.74 m
33.45	0.39	Mudstone, soft, crushed, broken and greenish grey	
39.14	5.69	Sandstone, grey top, buff below, fine to medium grained, dip apparently very steep; broken band at 35.80 - 35.97 m; badly broken and crushed sandstone with mudstone fragments from 38.34 m to base denoting possible fault	
39.14		Bore complete	

Analyses

Inclined depth, m	Intersection, m	Lithology	Cu (ppm)	Zn (ppm)	Pb (ppm)
12.87					
13.54	0.67	Cementstone	4	5	0
18.93					
19.50	0.57	Cementstone, minor sandstone	0	0	0
32.40					
33.06	0.66	Sandstone	7	9	0
35.74					
36.01	0.27	Sandstone, broken, limonitic specks and joint coatings	540	9	1

APPENDIX II TABLE Ia Background metal concentrations of non-mineralised cores selected from boreholes 6 to 13

LITH-OLOGY	No. of samples / Total core length, m	WEIGHTED MEAN VALUES								
		ppm					%			
		Ba	Pb	Zn	Cu	Ni	Ca	Fe	Mn	Ti
A	11 / 11.9m	295	19	66	33	110	7.63	6.28	0.111	1.00
B	4 / 3.09m	100	21	53	10	13	14.60	3.62	0.180	0.21
C	6 / 4.18m	294	5	30	7	9	6.94	2.58	0.091	0.24
D	4 / 3.40m	300	13	35	11	34	5.87	4.59	0.043	0.56
E	5 / 3.19m	247	13	49	19	42	1.68	6.3	0.013	0.55

APPENDIX II TABLE Ib Metal concentrations of combined mudstone and siltstone, mineralised and non-mineralised

LITH-OLOGY	No. of samples / Total core length, m	Ba ppm	Pb ppm	Zn ppm	Cu ppm	Ni ppm	Ca %	Fe %	Mn %	Ti %
E + B	12 + 14 / 8.48+9.98m	611	428	222	39	42	5.02	4.58	0.060	0.435

Lithologies: A - Lava, B - Cementstone, C - Sandstone, D - Siltstone, E - Mudstone

APPENDIX II TABLE II Chemistry of siltstones (14 samples)

ELEMENT	MEAN		STD. DEV.		RANGE	CORRELATION SIGNIFICANT	
	Arith.	Log_{10}	Arith.	Log_{10}	MIN. MAX.	99-99.9%	>99.9%
Ba	422	2.50	444	0.305	123.0 -1819.0	-	-
Pb	652	2.06	1075	1.098	0.0 -3965.0	Zn	-
Zn	281	1.93	357	0.870	0.0 -1139.0	Pb, Ni	-
Cu	40	1.25	70	0.505	4.0 - 258.0	-	-
Ca	6.78%	0.48	5.76	0.747	0.09- 15.36%	-Ti	Mn
Ni	40	1.54	20	0.267	11.0 - 70.0	Zn	Fe
Fe	4.09%	0.57	1.57	0.184	1.29- 7.46%	-	Ni
Mn	0.08%	-1.25	0.05	0.415	0.01- 0.17%	-	Ca,-Ti
Ti	0.38%	-0.50	0.29	0.286	0.13- 1.18%	-Ca	-Mn

APPENDIX II TABLE III Chemistry of cementstones (29 samples)

ELEMENT	MEAN		STD. DEV.		RANGE	CORRELATION SIGNIFICANT	
	Arith.	Log_{10}	Arith.	Log_{10}	MIN. MAX.	99-99.9.	>99.9%
Ba	628	2.44	827	0.571	24.0 -3285.0	-	-
Pb	465	2.07	1092	0.744	7.0 -5717.0	-	-
Zn	380	2.21	573	0.624	8.0 -2975.0	-	-Cu
Cu	46	0.87	187	0.646	0.0 -1019.0	-	-Zn
Ca	13.73%	0.99	6.09	0.540	0.11- 23.51%	-	-Ni, Mn,-Ti
Ni	26	1.31	25	0.303	6.0 - 135.0	-	-Ca, Fe,-Mn, Ti
Fe	3.88%	0.56	1.89	0.141	2.01- 12.93%	-	Ni,Ti
Mn	0.15%	-0.89	0.07	0.353	0.00- 0.32%	-	Ca,-Ni,-Ti
Ti	0.21%	-0.80	0.22	0.327	0.03- 1.10%	-	-Ca,Ni,Fe,-Mn

APPENDIX II TABLE IV Chemistry of samples of breccia, faulted rocks, silicified rocks and mineral veins (11 samples)

ELEMENT	MEAN		STD. DEV		RANGE	CORRELATION SIGNIFICANT	
	Arith.	Log_{10}	Arith.	Log_{10}	MIN MAX	99-99.9%	>99.9%
Ba	3566	2.51	10708	0.813	44.0 -35837.0	Ti	Pb,Zn
Pb	1428	2.49	2936	0.880	13.0 -10117.0	Ti	Ba,Zn
Zn	1042	2.23	2286	0.963	7.0 -7818.0	-	Ba,Pb
Cu	1030	1.95	1905	1.103	8.0 -5479.0	Ni	-
Ca	9.35%	0.71	7.48	0.610	0.29-19.61%	Ni, Fe	Mn
Ni	40	1.52	25.5	0.295	11.0 -85.0	Cu,Ca,Mn	Fe
Fe	3.91%	0.55	1.58	0.216	1.45-5.98%	Ca	Ni,Mn
Mn	0.13%	-1.07	0.11	0.500	0.01 -0.33%	Ni	Ca,Fe
Ti	0.27%	-0.65	0.17	0.308	0.08 -0.58%	Ba, Pb	-

APPENDIX II TABLE V Chemistry of mudstones (12 samples)

ELEMENT	MEAN		STD. DEV.		RANGE	CORRELATION SIGNIFICANT	
	Arith.	Log_{10}	Arith.	Log_{10}	MIN. MAX.	99-99.9%	>99.9%
Ba	801	2.56	1289	0.485	119.0-3920.0	-	-
Pb	204	1.71	250	0.948	2.0-791.0	Ca,-Fe	Mn
Zn	164	1.91	275	0.482	15.0-1007.0	-	-
Cu	37	1.23	54	0.593	0.0-181.0	-	-
Ca	3.26%	0.21	3.1	0.618	0.14-13.04	Pb, -Fe	Mn
Ni	44	1.59	19	0.211	18.0-76.0	-	-
Fe	5.07%	0.68	1.68	0.152	2.86-7.91%	-Pb,-Ca,Ti	-
Mn	0.04%	-1.58	0.03	0.470	0.00-0.14%	-	Pb,Ca
Ti	0.49%	-0.33	0.13	0.161	0.17-0.62%	Fe	-

APPENDIX II TABLE VI Chemistry of sandstones (19 samples)

ELEMENT	MEAN		STD. DEV.		RANGE		CORRELATION SIGNIFICANT	
	Arith.	Log_{10}	Arith.	Log_{10}	MIN.	MAX.	99-99.9%	>99.9%
Ba	986	2.68	2050	0.412	214.0 -	9191.0	-	-
Pb	428	1.35	1140	0.981	0.0 -	4215.0	-	Zn
Zn	207	1.61	434	0.882	0.0 -	1809.0	-	Pb
Cu	161	1.33	321	0.979	0.0 -	1168.0	-	-
Ca	4.59%	0.30	5.15	0.673	0.06-	17.81%	Ti	Mn
Ni	22	1.14	24	0.442	2.0 -	80.0	-	Fe, Ti
Fe	3.12%	0.41	2.07	0.281	0.67-	8.32%	-	Ni
Mn	0.074%	-1.48	0.09	0.641	0.00-	0.33%	-Ti	Ca
Ti	0.369%	-0.57	0.34	0.355	0.05-	1.26%	Ca,-Mn	Ni

APPENDIX II TABLE VII Chemistry of Birrenswark Lavas (34 samples)

ELEMENT	MEAN		STD. DEV.		RANGE		CORRELATION SIGNIFICANT	
	Arith.	Log_{10}	Arith.	Log_{10}	MIN.	MAX.	99-99.9%	>99.9%
Ba	1262	2.68	1979	0.602	49.0 -	8811.0	Ni	Zn
Pb	55	1.49	53	0.513	4.0 -	175.0	Mn	Zn
Zn	190	1.96	275	0.521	8.0 -	1305.0	Fe	Ba,Pb,Ni
Cu	91	1.57	149	0.609	0.0 -	676.0	-	-
Ca	6.73%	0.72	3.95	0.361	0.34-	17.08%	-Ni	Mn,-Ti
Ni	107	1.99	44	0.167	51.0 -	237.0	Ba,-Ca	Zn,Fe
Fe	6.35%	0.77	2.25	0.181	1.74-	11.83%	Zn,Mn	Ni
Mn	0.11%	-1.02	0.06	0.256	0.02-	0.24%	Pb,Fe	Ca,-Ti
Ti	1.03%	-0.03	0.46	0.234	0.16-	2.20%	-	-Ca,-Mn

APPENDIX III

LITHOLOGY, MINERALOGY AND GEOCHEMICAL ANALYSIS OF SURFACE ROCK SAMPLES FROM THE WESTWATER DISTRICT

Preamble

Petrographical data are listed in Tables I-XI for surface rocks from the main outcrops in the Westwater district and from the British Gas Frigg Pipeline trench. In addition to examination using binocular and polarising microscopes, X-ray diffractometry, X-ray fluorescence analysis and carbonate staining with Alizarin-red S solution as described by Dickson (1965) and Hutchinson (1974) were carried out where appropriate.

Tables I-III deal with samples of Lower Carboniferous sediments and Birrenswark Lavas collected from Frigg Pipeline trench. Sampling was from trench walls in the main but also from loose blasted material of local derivation and from glacial boulders in sections of trench wholly within the till profile. One group of samples (BFR 354-3554 in Table I) represent lavas and intercalated sediments from the trench section northwest of the B 7068 road (see Fig. 1). A second (BFR 3512-3582 in Table II) relates to lavas and mineralised basal Carboniferous sediments from the section immediately southeast of the road where an early inspection pit yielded mineralised blocks. Unmineralised sediments exposed by the trench southeast of Pokeskine Sike are dealt with in Table III.

Table IV lists the main petrographical features shown by rock exposures in the headwaters of Pokeskine Sike and feeder drainage ditches (see Fig. 3).

The petrography and geochemistry of mineralised boulders found in the middle reaches of Pokeskine Sike is summarised in Table V. Immediately to the east, sample BFR 1004 was collected from the small dumps at Westwater lead trial at the head of Mine Sike and the remaining samples listed in Table VI are from stream exposures and a small lava quarry (see Fig. 4). Further to the east near Westwater farm, outcrops in Glentenmont Burn immediately below the confluence of Green Burn, and in Green Burn itself provided mineralised cementstones and other rocks for study (see Table VII). Geochemical analyses of channel samples taken at the stream confluence and also from the two exposures drilled in depth at Boreholes 4 and 5 (see Fig. 1) are listed in Tables VIII, IX and X respectively. A final table (XI) incorporates observations on scattered rock samples from outcrops and mineralised stream boulders east of Westwater on St Brides Hill, in Logan Water and Wauchope Water, and on Catfield Rig.

APPENDIX III TABLE 1

Lithology and mineralogy of Birrenswark Lavas sampled from the Frigg Pipeline trench NW of the B7068.

Sample No. BFR	NGR (35)	Distance (m) NW of B7068 road	Lithology and Petrography	Mineralisation
3564	2708 8154	672	Brecciated basalt in jasperoid material	Calcite, quartz, malachite,
3563	2711 8152	640	Highly amygdaloidal lava with red silty intercalations	Calcite,
3562	2714 8150	606	Amygdaloidal zeolitic lava	Calcite
3561	2718 8184	551	Weathered lava with amygdales	Calcite
3560	2724 8144	494	Relatively fresh, medium grained lava	
3559	2725 8143	487	Red siltstone with lava fragments	
3558	2728 8141	454	Sparsely amygdaloidal lava with calcite veins	Calcite
3557	2730 8139	420	Red siltstone with angular lava fragments	
3556	2730 8139	420	Amygdaloidal lava with xenoliths	Calcite
3555	2731 8139	409	Amygdaloidal, zeolitic lava	Calcite
3554	2733 8138	380	Amygdaloidal, zeolitic lava	

APPENDIX III TABLE II

Lithology, mineralogy and geochemical analysis of Birrenswark Lavas sampled from Frigg Pipeline trench SE of Megsfield, some 8 km WSW of Langholm.

Sample No. BFR	NGR (35)	Distance (m) SE of B 7068 road	Lithology and petrography	Mineralisation	ppm Cu	ppm Zn	ppm Ag	ppm Pb
3519	2773 8103	140.6	Altered basalt in a matrix of vein material	Quartz, calcite, baryte, pyrite	20	60	2	40
3518	2772 8104	140	Altered basalt clasts, green and brown	Calcite, pyrite, baryte				
3517	2772 8105	134	Weakly vesicular brown basalt, brecciated and veined	Quartz, calcite, pyrite and (?) sphalerite in veins, baryte.	35	120	2	30
3515	2770 8106	108	Basalt lava with elongated vesicles	Traces of pyrite	20	230	2	20
3513	2769 8107	95	Basalt lava, moderately vesicular with mineral segregations	Quartz, calcite, pyrite sphalerite, baryte segregations, malachite				
3512	2769 8108	85	Basalt lava, moderately vesicular, weathered	Traces of pyrite in vesicles	170	280	2	30
3578	2773 8103	140	Slaggy amygdaloidal lava	Baryte		n.a.		
3579	2773 8103	c141	Cementstone with argillaceous laminae.	Calcite, hematite		n.a.		
3580	2773 8103	c141	Medium grained dolomitic cementstone	Calcite, pyrite, galena, sphalerite		n.a.		

Appendix III, Table II continued.

3581	2773 8103	c141	Veined cementstone	Calcite, dolomite, pyrite, marcasite, sphalerite, galena		n.a.		
3582	2773 8103	c141	Grey cementstone	Calcite, dolomite, marcasite, galena, baryte.		n.a.		
3520	2773 8103	140.6	Cementstone block	Galena on joint	20	50	2	760
3521	2773 8103	142	Weakly banded cementstone block with sandstone and silty cementstone bands, and dolomitic areas	Calcite-quartz-pyrite-galena hematite-magmatite with rare sphalerite and marcasite				
3522	2733 8103	142.8	Banded cementstone block	Calcite-pyrite-galena veinlets	15	240	3	650
3529	2773 8103	149	Micaceous siltstone block	Pyrite veinlets, galena coatings	10	280	1	120
3524	2773 8102	155	Large cementstone block	Marcasite-sphalerite veinlets	20	1300	2	160
3525	2775 8102	167	Strongly veined medium grained doleritic dyke rock	Calcite		n.a.		
3526	2775 8102	169.5	Limonitic block of porphyritic basalt.	Limonite		n.a.		
3528	2776 8100	192	Porphyritic dolerite	Limonite		n.a.		

APPENDIX III, TABLE III

Lithology, mineralogy and geochemical analysis of Lower Carboniferous sediments sampled from Frigg Pipeline trench SE of Megsfield, some 8 km WSW of Langholm.

Sample No. BFR	NGR (35)	Distance (m) SE of B 7068 road	Lithology	ppm Cu	Zn	Ag	Pb
3533[1]	2800 8078	523	Peloidal dolomite boulder with rounded siltstone clasts		n.a.		
3548	2800 8005	1650	Sandstone with shale clasts, ferruginous concretions and green reduction bands	5	20	0	10
3584	2903 7985	1895	Fine-grained sandstone				
3502	2918 7972	2095	Mudstone, brown to red	320	40	1	20
3504	2932 7956	2300	Coarse sandstone with limonitic patches	25	10	0	10
3506	2935 7953	2340	Sandstone with carbonaceous films and rootlets, (?) ganister	75	10	0	10
3507	2942 7944	2460	Dark, (?) ashy sandstone	60	20	1	20
3508	2945 7941	2500	Yellow siltstone with abundant rootlets	60	10	1	10
3511	2961 7926	2725	Sandstone, fine-grained and spotted	10	10	0	10

[1]Sphalerite disseminated, galena-calcite veinlets common.

APPENDIX III, TABLE IV

Lithology, mineralogy and geochemical analysis of Lower Carboniferous sediments sampled from upper Pokeskine Sike.

Sample No. BFR	NGR (35)	Lithology	Mineralisation
1000[1]	2875 8182	White calcareous sandstone	Galena, sphalerite, pyrite
1001	2870 8163	Veined cementstone	Galena, sphalerite, pyrite, marcasite, smithsonite
1003[2]	2870 8163	Sandstone containing micritic intraclasts.	Galena, sphalerite, pyrite
1049[3]	2869 8160	Black cementstone rich in rounded cavities	Sphalerite, galena
3400	2871 8159	Dark cementstone rich in rounded cavities	Gypsum
3573	2875 8182	White calcareous sandstone	Galena
3574	2874 8180	Dolomite rock with plant remains	Galena, pyrite
3575	2870 8158	Bedded cementstone with small cavities	
3594	2873 8194	Dolomite rock	

1 - duplicate sample BFR 1002 contains 0 ppm Cu, 0 ppm Zn, 1 ppm Ag and 1.2% Pb.

2 - the galena contains 230 $\pm$ 10 ppm Ag and about 75 ppm Sb.

3 - the sample contains 20 ppm Cu, 2300 ppm Zn, 4 ppm Ag and 70 ppm Pb.

APPENDIX III, TABLE V Lithology, mineralogy and geochemical analysis of Lower Carboniferous sediments sampled from lower Pokeskine Sike.

Sample No. BFR	NGR (35)	Lithology	Mineralisation	ppm Cu	ppm Zn	ppm Ag	ppm Pb
1007	2852 8121	Iron-stained sandstone	Galena, sphalerite				
1008	2713 7989	Cementstone with sandstone bands	Sphalerite, pyrite, galena, marcasite.	10	6300	5	100
1009	2722 7985	Veined fossiliferous cementstone	Galena, pyrite, sphalerite, cerussite.	10	3000	4	7200
1010	2730 7987	Cementstone	Galena, sphalerite, pyrite.				
1012	2812 8060	Fossiliferous cementstone	Sphalerite, pyrite marcasite, galena.				
1013	2850 8107	Fossiliferous cementstone	Galena, sphalerite, pyrite.				
1014	2827 8075	Partly dolomitised cementstone	Galena, sphalerite, pyrite,	10	3500	5	1.01%

APPENDIX III, TABLE VI

Lithology and mineralisation of rock samples from the Mine Sike district.

Sample No. BFR	NGR (35)	Lithology	Mineralisation
1004	2931 8184	Mineral vein rock	Sphalerite (66%), galena (18%), baryte (6%), hematite, goethite, marcasite, calcite.
3572	2928 8189	Amygdaloidal doleritic lava	Calcite
3576	2927 8189	Amygdaloidal aphyric lava	Dolomite, calcite, marcasite, galena, sphalerite, pyrite, chalcopyrite.
3595	2911 8191	Red sandstone	-
3596	2911 8190	Fossiliferous dolomite rock	Calcite, chalcopyrite.
3597	2966 8194	Friable white sandstone	-
3598	2929 8180	Sandstone with micritic cement.	-
3599	2955 8142	Amygdaloidal lava fragments set in coarse dolomite cement	Calcite

APPENDIX III, TABLE VII

Lithology and mineralisation of rock samples from Glentenmont Burn (3568-3616) and Green Burn (1005-3626).

Sample No. BFR	NGR (35)	Lithology	Mineralisation
3568	3044 8248	Cementstone	Pyrite, marcasite, (?) chalcopyrite.
3610[1]	3045 8248	Cementstone	Galena, pyrite
3612[1]	3045 8248	Cementstone	Sphalerite, galena, pyrite
3613[1]	3045 8248	Interbanded siltstone and sandstone	Pyrite, (chalcopyrite)
3616[1]	3045 8248	Cementstone with muddy laminae	Pyrite, marcasite
1005	3032 8264	Cementstone	Dolomite, Galena, pyrite
1006	3020 8252	Friable limonitic sandstone	Galena (approx. 8%), sphalerite
3565	3037 8251	Yellow calcareous sandstone	Galena
3566	3034 8251	Cementstone	Dolomite, galena, pyrite
3567	3029 8253	Fossiliferous cementstone	Galena, pyrite
3571	3003 8250	Amygdaloidal lava	
3621	3029 8253	Banded sandstone	
3623	3029 8253	Cementstone	Galena
3626	3029 8253	Fossiliferous cementstone	Galena

[1] - see also Table IX

APPENDIX III, TABLE VIII

Lithology and geochemical analyses of channel samples from Lower Carboniferous sediments exposed in Glentenmont Burn near Westwater (NGR 35.3045 8248); channel 10 cm wide running 115°.

Channel length, m	Lithology	Estimated true thickness m	Dip and direction of dip°	ppm Cu	Zn	Ag	Pb	Sample no. BFR
	LOWER CARBONIFEROUS SEDIMENTS							
0.62	Cementstone, dark grey, thin carbonate veinlets containing rare coarse galena and pyrite.	0.13	12/280	15	160	3	60	3610
2.5	Cementstone, grey, hard, thin carbonate veins contain pyrite, trace galena	0.43	10/290	10	180	3	150	3611
1.5	Cementstone, dark grey, irregular sparry calcite patches, fine grained disseminated pyrite, carbonate veins contain coarse sphalerite-galena-pyrite	0.31	12/290	20	170	3	190	3612
1.0	Siltstone interbedded with sandstone, both lithologies dominated by detrital quartz, discontinuous pyrite-chalcopyrite veinlets part-replaced by goethite	0.28	16/310	30	220	3	1460	3613
1.5		0.41	16/310	15	240	3	1460	3614
1.0	Cementstone, grey containing abundant calcite veinlets and patches.	0.24	14/300	25	1350	3	1600	3615

Appendix III, Table VIII contind.

Channel length, m	Lithology	Estimated true thickness m	Dip and direction of dip	ppm Cu	Zn	Ag	Pb	Sample no. BFR
2.2	Cementstone, dark grey, argillaceous laminations and intercalations which are offset by sparry calcite veins containing pyrite-marcasite. Patches and blebs of calcite contain fine galena and pyrite	0.53	14/330	25	70	4	80	3616
	Weighted average metal content of mineralised sediments	2.33		17	290	3	670	

Analyses by AAS

APPENDIX III, TABLE IX

Lithology and geochemical analysis of channel samples across the faulted contact of the Birrenswark Lavas and basal Lower Carboniferous sediments exposed in the east bank of Glentenmont Burn (NGR 35.3044 8263); channel 20 cm wide running 134°.

Channel Lenght, m.	Lithology	ppm Cu	Zn	Ag	Pb	Sample No. BFR
0.43	Birrenswark Lavas - brown rotted lava	170	1.2%	3	550	3602
0.43	Fault zone breccia - grey, weakly banded	25	1100	1	110	3603
0.39	Lower Carboniferous sediments - grey, rotten, brecciated	20	1040	1	50	3604
0.39	Lower Carboniferous sediments - rotten, brecciated, with brown clay	40	1200	1	100	3605
1.64	Weighted average metal content of mineralised fault zone	70	3970	2	340	

Analyses by AAS.

APPENDIX III TABLE X

Lithology and geochemical analysis of channel samples from basal Lower Carboniferous sediment exposed in Green Burn, near Westwater (NGR 35.3029 8253); channel 5 cm wide running 040°.

Channel length, m.	Lithology	Estimated true thickness, m	Dip and direction of dip°	Cu (ppm)	Zn (ppm)	Ag (ppm)	Pb (ppm)	Sample No. BFR
	LOWER CARBONIFEROUS SEDIMENTS							
	Sandstone, white in beds 0.1-0.4 m thick undisturbed	2+	50/120		n.a.			
	Sandstone, grey sheared	0.4	80/120		n.a.			
	Fault							
	Sandstone, grey, sheared, clay rich	0.08						
	Cementstone, iron stained with brown carbonate veinlets	0.11	56/105					
	Sandstone, white hard	0.03						
0.8	Clay gouge, grey, limonite stained	0.05		30	110	1	130	3620
	Sandstone, grey, clay rich, thinly laminated, orange stained (see also Table IX)	0.2						
	Cementstone, grey, hard with brown veinlets.	0.2	20/132					
1.3	Clay band, grey, limonite stained	0.08		30	230	2	1400	3621
	Clay, pale green	0.08						
	Sandstone, grey	0.22						
	(?) Calcareous siltstone, orange, clay rich with shaly partings	0.10						
1.4	Alternating orange sandy bands and dark grey clay bands	0.50		50	340	1	1040	3622

Appendix III Table X Contd.

Channel length, m	Lithology	Estimated true thickness, m	Dip and direction of dip°	Cu	Zn	Ag	Pb	Sample No. BFR
0.7	Cementstone, grey, hard with brown carbonate veins and <u>galena</u> on joint surfaces (see Table VIII)	0.3	52/110	10	320	3	8200	3623
	Cementstone, part of above unit, grading into calcareous sandstone also with brown carbonate veins then into green clay with shaly partings	0.35						
	Sandstone with shaly partings	0.10						
	Calcareous sandstone, orange, laminated and veined	0.05						
1.5	(?) Calcareous siltstone orange, banded with patch of cementstone containing brown carbonate veins	0.10		40	240	2	830	3624
1.0	(?) Siltstone, shaly			50	170	1	900	3625
1.7	Cementstone, massive, brecciated and intensely veined by brown carbonate, <u>galena</u> on joints (see also Table IX)	0.6	32/114	25	110	3	540	3626
1.0	Sandy siltstone and impure sandstone, rotten, green and grey	0.3		60	80	1	90	3627
	BIRRENSWARK LAVAS							
2.4	Lava, purplish-coloured vesicular, highly altered with 8 cm band of orange sandy clay at top	1	(?) 40/134	40	40	1	30	3628
	Weighted average metal content of mineralised sediments	3.5		30	200	2	1270	

n.a. - not analysed

Analyses by AAS

APPENDIX III, TABLE XI

Lithology and mineralisation of rock samples from St Brides Hill, Logan Water, Wauchope Water and Catfield Rig.

Sample No. BFR	NGR (35)	Lithology	Mineralisation
3570	3075 8252	Fine sandstone	Quartz, dolomite, pyrite
3569	3075 8253	Amygdaloidal lava, highly altered	Zinc and lead present in clay and/or limonitic material
3606[1]	3099 8291	Highly altered lava ('bole')	-
3591	3166 8221	Sandstone	Galena, pyrite
3592	3155 8252	Aphyric trachytoid basalt lava	-
2592[2]	3317 8233	Partly dolomitised cementstone (stream boulder)	Galena, pyrite, chalcopyrite
2593	3252 8165	Partly dolomitised cementstone	Pyrite
3593	3371 8259	Bedded cementstone part dolomitised	Pyrite, chalcopyrite, malachite, marcasite
2590	3326 8339	Brecciated cementstone set in carbonate cement	Marcasite, chalcopyrite

1 - sample contains 5 ppm Cu, 50 ppm Zn, 20 ppm Pb.

2 - sample contains 10 ppm Cu, 0.65% Zn, 3.3% Pb; also, sample BFR 2591 from the same site contains 170 ppm Cu, 30 ppm Zn and 180 ppm Pb.

APPENDIX IV TABLE I Results of till sampling along Frigg pipeline trench SW of Westwater

Sample No. BFS	NGR (35)	Distance (m) SE of B7068 Road	Cu	Pb ppm	Zn	Sample depth m.	Bedrock lithology	Basal till lithology
3514	27698107	95	50	20	220	2.0	Lava	Grey, leached
3516	27728105	125	65	30	190	2.5	Lava	Grey, clay rich
3523	27738103	146	60	620	190	2.0	Cementstone	Grey-brown stony
3527	27778101	188	80	40	150	3.2	Dolerite	Brown, stony, sand matrix.
3530	27918089	379	45	50	120	3.5	-	Brown, gleyed, clay rich
3531	27968084	454	50	40	150	3.5	-	Brown, many lava clasts.
3532	28008078	517	20	20	70	2.0	Sandstone	Grey-brown, sandy.
3534	28038076	554	55	40	160	3.0	Sandstone	Dark brown, clay rich
3535	28068075	604	40	40	120	3.0	?Sandstone	Dark brown, clay rich.
3536	28198062	787	45	40	100	3.0	?Sandstone	Brown, clay rich.
3537	28238058	837	40	60	140	3.0	Cementstone	Grey, clay rich.
3538	28288054	887	45	40	100	3.0	?Sandstone Cementstone	Dark grey, clay rich.
3539	28328050	950	40	80	170	3.0	?Siltstone Sandstone	Grey-brown, clay rich.
3540	28368046	1000	40	60	140	2.0	?Siltstone Sandstone	Grey-brown, clay rich.
3541	28408042	1050	40	90	180	2.0	?Sandstone	Red-brown, clay rich.
3542	28658038	1100	25	40	100	2.0	?Sandstone	Red-brown, clay rich.
3543	28688035	1150	20	50	110	2.0	?Sandstone	Red, clay rich.
3544	28528031	1200	5	10	30	2.0	Sandstone	Blue-grey, clay rich.
3545	28568028	1250	45	50	130	2.0	Siltstone	Grey and orange, gleyed.
3500	29227969	2175	75	20	20	2.5	Sandstone (ferruginous)	Grey, leached.
3501	29277965	2225	120	30	20	2.3	Shale-mudstone	Green, sandy
3503	29357953	2335	140	40	40	2.5	Sandstone	Grey-brown, sandy clay.
3505	29357953	2382	105	20	20	2.0	Sandstone with shale clasts	Brown, clay rich.
3509	29587930	2695	350	20	40	2.0	Sandstone (ferruginous)	Orange clay.

Significant anomalies underlined
?Sandstone - lithology deduced from examination of clasts at base of profile.
Analysis by AAS.

APPENDIX V TABLE II Mine Sike: Comparative metal content of 3 sample types

5m downstream of mineralization				300m downstream of mineralization			70m upstream of mineralization (area of till anomaly)		
Element	Concentrate ppm	Sediment ppm	Fines ppm	Concentrate	Sediment	Fines	Concentrate	Sediment	Fines
Ba	5%	818	615	3100	679	715	1425	793	725
Pb	340	70	126	86	60	81	350	40	50
Zn	2985	230	387	236	220	359	166	140	260
Cu	157	15	28	38	20	37	39	30	35
Ni	57	71	89	78	127	110	55	106	99
Fe	3.65%	3.27%	6.43%	8.64%	4.40%	7.50%	5.05%	4.60%	6.69%
Mn	290	945	1550	490	1445	2600	280	1675	2150

APPENDIX V TABLE III Green Burn: Comparative metal content of 2 sample types

Element	10m downstream of mineralization		100m downstream of mineralization		300m upstream of mineralization	
	Concentrate ppm	Sediment ppm	Concentrate	Sediment	Concentrate	Sediment
Ba	6339	650	5295	918	1111	757
Pb	1575	80	2160	100	149	70
Zn	182	160	214	160	193	192
Cu	87	40	122	35	143	30
Ni	109	108	100	125	94	99
Fe	22.25%	4.67%	22.56%	5.40%	19.04%	6.51%
Mn	970	1161	1050	1169	900	1766

APPENDIX V TABLE IVa Pokeskine Syke

Mineral	+1.0 mm	-1.0 mm +0.5 mm	-0.5 mm +0.25 mm	-0.25 mm +0.125 mm	-0.125 mm	Total
Sphalerite	4.25	16.21	19.85	8.30	3.1	51.77
Hematite	7.08	3.69	5.12	9.85	5.83	31.57
Galena	0.85	1.21	0.10	0.03	-	2.19
Garnet	-	0.10	0.09	2.82	2.93	5.94
Zircon	-	Tr	1.72	2.14	1.33	5.19
Pyrite	-	Tr	0.13	1.32	1.37	2.82
Tourmaline	-	Tr	-	-	-	-
Baryte	-	-	-	0.04	-	0.04
Total	12.18	21.21	27.01	24.50	14.62	100.00

APPENDIX V TABLE IVb Green Burn

Mineral	+1.0 mm	-1.0 mm +0.5 mm	-0.5 mm +0.25 mm	-0.25 mm +0.125 mm	-0.125 mm	Total
Baryte	-	0.20	0.11	0.25	0.18	0.74
Sphalerite	0.24	0.39	0.09	0.10	0.06	0.88
Hematite	39.66	38.89	15.34	3.90	0.47	98.26
Zircon	-	-	Tr	0.02	0.04	0.06
Tourmaline	-	-	-	Tr	Tr	-
Pyromorphite	-	-	Tr	Tr	Tr	-
Pyrite/ Chalcopyrite	-	-	Tr	Tr	Tr	-
Garnet	-	-	Tr	0.01	0.01	0.02
Galena	-	-	Tr	-	-	-
Total	39.90	39.48	15.54	4.28	0.75	100.00

APPENDIX V TABLE V Summary statistics of 27 concentrate-sediment pairs from drainage unaffected by mineralization

Element	CONCENTRATES			Correlation coefficient between sample types	SEDIMENTS		
	Mean ppm	Standard Deviation	Range		Mean ppm	Standard Deviation	Range
Ba	1446	1986	83-7692	-0.08	402	130	200-635
Pb	35	32	0-133	0.02	28	11	12-55
Zn	88	40	35-173	0.50	78	25	42-146
Cu	32	24	0-98	0.19	18	9.5	3-56
Ni	54	17	16-83	0.46	77	19.9	32-105
Fe	8.47%	4.7	1.48-21.5	0.06	3.71	0.83	1.86-5.11
Mn	330	149	80-690	0.04	772	604	274-2772

APPENDIX V TABLE VI Summary statistics of 25 concentrate-sediment pairs from drainage affected by mineralization

Element	CONCENTRATES			Correlation coefficient between sample types	SEDIMENTS		
	Mean ppm	Standard Deviation	Range		Mean ppm	Standard Deviation	Range
Ba	6729	13488	302-50000	-0.03	638	185	322-918
Pb	1160	2432	0-11320	0.94	69	53	8-253
Zn	1964	4156	74-14650	0.64	221	190	74-1012
Cu	61	66	0-286	0.54	22	9.1	6-41
Ni	66	27	24-123	0.47	99	32	34-161
Fe	10.96%	7.9	1.24-30.9	0.62	4.33	0.98	2.59-6.51
Mn	506	327	40-1310	0.001	1133	520	480-2943

APPENDIX V TABLE VII Summary statistics of 14 concentrate sediment pairs from drainage affected by contamination

Element	CONCENTRATES			Correlation coefficient between sample types	SEDIMENTS		
	Mean ppm	Standard Deviation	Range		Mean ppm	Standard Deviation	Range
Pb	301	519	7-1830	0.59	31	11	22-59
Sn	106	158	5-574	0.00	2	0.8	0.5
Zn	121	75	39-337	0.41	88	30	38-158
Cu	75	115	8-452	0.50	18	7.5	8-30
Ni	61	23	30-106	0.60	80	22	43-124

APPENDIX V TABLE VIII Summary statistics; 260 shallow soils from the area of Pokeskine Sike - Mine Sike, West of Langholm.

Element	$\bar{X}_A$ ppm	σ_A	$\bar{X}_L$ ppm	σ_L	$\sigma_L + \bar{X}_L$ ppm	Range, ppm
Cu	22	13	18	0.32	37	0-95
Pb	46	81	32	0.31	65	3-1050
Zn	100	122	73	0.31	150	10-1100

A denotes arithmetic data.

L denotes logarithmic.

APPENDIX V TABLE IX Summary statistics for 140 pairs of basal till minus 150 μm fraction and panned concentrate

ELEMENT	TILL CONCENTRATE					CORRELATION COEFFICIENT		MINUS 150 μm TILL FRACTION				
	MEAN		STANDARD DEVIATION		RANGE			MEAN		STANDARD DEVIATION		RANGE
	$\bar{X}A$	$\bar{X}$ LOG	σ	$LOG_{10}S$		ARITHMETIC	LOG_{10}	$\bar{X}A$	X LOG	σ	$LOG_{10}S$	
Pb	650	35	3270	0.9	2-31967	0.88	0.63	156	41	520	0.61	1-5008
Zn	237	98	662	0.47	11-6024	0.68	0.59	271	168	404	0.38	11-3054
Cu	36	14	72	0.64	1-677	0.57	0.21	35	23	38	0.45	1-265
Ni	79	48	75	0.49	2-458	0.77	0.66	90	77	61	0.23	23-402
Ba	4500	580	15627	0.62	100-83053	0.59	0.73	983	578	3407	0.28	110-38565
Fe	5.83	4.41	4.14	0.35	0.69-21.08	0.63	0.51	6.58	6.15	2.22	0.15	1.19-14.37

All element concentrations in ppm except Fe (%)

$\bar{X}_A$ Mean of arithmetic data

$\bar{X}_{LOG}$ Mean of logarithmic data

σ Standard deviation of arithmetic data

$Log_{10}S$ Standard deviation of logarithmic data

APPENDIX V TABLE X Summary statistics of 130 pH determinations subdivided into dominant lithology. Number of samples shown in parenthesis

Inferred bedrock lithology	$\bar{X}$ (pH)	$\bar{X}$ (Depth)	Range (pH)	Range (Depth) m.	Correlation coefficient
LAVA (30)	6.8	3.7	4.9-8.0	1.0-9.1	0.44
SANDSTONE (20)	7.1	2.5	4.9-7.9	1.3-6.2	0.25
MINERALIZATION (29)	6.6	2.4	4.5-8.0	0.2-6.2	0.68
MIXED CARBONIFEROUS (51)	6.8	2.8	4.0-8.4	0.2-7.3	0.55

APPENDIX V TABLE XI Summary statistics of pH determinations based on samples collected from till depths of >2 m

Inferred bedrock lithology	$\overline{X}$ (pH)	$\overline{X}$ (Depth)	Range (pH)	Range (Depth) m.	Correlation coefficient
LAVA (24)	7.0	4.2	5.5-7.9	2.2-9.0	0.44
SANDSTONE (10)	7.3	3.2	5.8-7.9	2.0-6.2	0.12
MINERALIZATION (17)	7.2	3.2	5.5-8.0	2.0-6.2	0.45
MIXED CARBONIFEROUS (33)	7.3	3.7	4.7-8.4	2.2-7.3	0.23

APPENDIX V TABLE XII Interelement correlations in tills

Element	- 150 µm till		Till Concentrate	
	Correlation significant at		Correlation	
	99-99.9%	99.9%	99-99.9%	99.9%
Pb	-	Cu,Ba,Zn	Cu,Ni	Ba,Zn
Zn	-	Cu,Pb	Ba	Cu,Fe,Ni,Pb
Cu	Ba,Zn	Fe,Pb,Ni	Pb	Ba,Zn,Ni,Fe
Ni	-	Cu,Fe	Ba,Pb	Cu,Zn,Fe
Ba	Cu	Pb	Zn,Ni	Pb,Cu