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MINERAL INVESTIGATIONS IN THE NORTHUMBERLAND TROUGH: PART 3, ECCLEFECHAN-WATERBECK AREA

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INTRODUCTION

Background

Two of the most important criteria for the formation of major SEDEX Irish-style deposits, the presence of syn-depositional faulting in a Lower Dinantian basin and a geothermal system over a zone of high heat flow in the crust, are fulfilled along the northern margin of the Solway-Northumberland basin. Recognition of the broad similarities in the geological and tectonic history of the sedimentary basins of east-central Ireland and northern England/southern Scotland prompted Mineral Reconnaissance Programme (MRP) interest in the Solway-Northumberland basin in the 1970's soon after discovery of the world-class Navan Zn-Pb deposit in Ireland (Andrew, 1993).

Previous Research

Reconnaissance panned concentrate sampling by the MRP in the mid 1970's between Langholm and Ecclefechan identified anomalous concentrations of Pb and Zn extending intermittently over about 20 km of strike broadly coincident with the Lower Carboniferous / Lower Palaeozoic boundary (Gallagher et al., 1977).

Only the most prominent geochemical anomalies near Westwater [330500 582300] were followed up at that stage. Detailed investigations involving integrated geophysical and deep overburden surveys resulted in the discovery of minor vein and stratabound galena and sphalerite mineralisation over at least 4 km of Lower Carboniferous strike. Shallow diamond drilling (13 holes to depths of 20 to 60 m), revealed the presence of sporadic Pb-Zn-Cu mineralisation with combined grades of 0.1-0.3% over 1-2 m of thickness. Sulphides (galena and sphalerite) occur in disseminations and dolomitic veins in porous sandstones and cementstones, usually in close proximity to the contact of the basal Carboniferous Birrenswark lavas and the overlying 'cementstone' facies of the Lower Border Group. Mineralised breccia zones within the lavas carry chalcopyrite and pyrite, and both styles of mineralisation appear to be emplaced along north-easterly trending normal faults and cross faults.

In the period 1981-85 systematic stream sediment surveys in southern Scotland, carried out as part of the BGS Geochemical Baseline Survey of the Environment (G-BASE), confirmed the regional pattern of anomalous base-metal concentrations close to the basin margin (BGS, 1993a), although the stream sediment data exhibit generally poorer geochemical contrast in comparison with panned concentrates, especially in areas of subdued relief and thick drift to the south-west of Langholm.

A multidisciplinary study into the analysis of spatially-related (geochemical, geophysical and geological) datasets and mineral deposit modelling for carbonate-hosted mineral deposits in northern England (Plant and Jones, 1991; Jones et al., 1994) also emphasised the high base-metal prospectivity of the Solway-Northumberland basin. The report suggests that particularly favourable sites for mineralisation occur where the northern basin-margin synsedimentary faults cut Courceyan-Chadian rocks at <0.5 km depth. Zones of fault intersection can result in areas of dilation and structural disruption which may provide potential pathways for mineralising fluids.

Selection of project area

Based on these concepts and the high incidence of base-metal geochemical anomalies a new MRP project aimed at stimulating mineral exploration interest in the northern margin of the Northumberland-Solway basin was initiated in 1992. Four principal targets areas considered

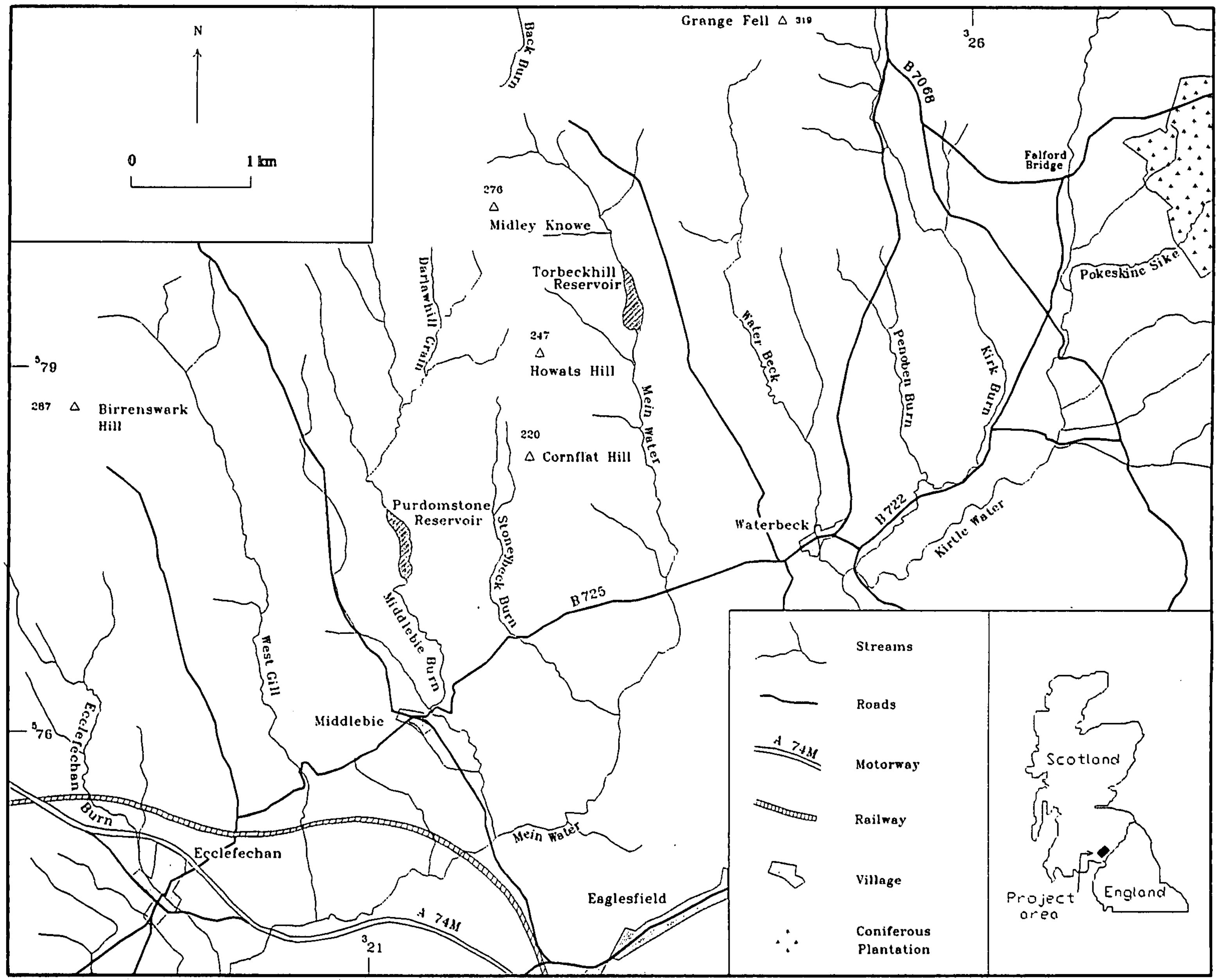


Figure 1 Locational and drainage network map of the survey area

prospective for stratabound (Irish-style) and/or epigenetic (Pennine-style) base-metal mineralisation were examined. This report describes the results of mineral reconnaissance investigations between Falford (2.5 km south-west of Westwater) and Ecclefechan, covering a total strike length of about 12 km and an across-strike width of 8 km (Figure 1). The principal follow-up targets in the project area were the Lower Carboniferous sedimentary and basic rocks in the vicinity of the major north-east trending Waterbeck Fault, one of a system of en echelon structures marking the northern edge of the Northumberland-Solway Basin. In addition, reconnaissance geochemical data are also presented for the area lying immediately north of the Lower Carboniferous where anomalous concentrations of Cu, Ba (+ minor Pb and Zn) occur in streams cutting the unconformable or faulted Silurian-Upper Old Red Sandstone boundary.

PHYSIOGRAPHY

The area which occupies about 60 km^2 lies partly in the foothills of the Southern Uplands and is characterised by smooth, rounded grass and heather clad hills rising to a maximum of 319 m OD on Grange Fell near the northern margin of the study area (Figure 1). Relief and elevation decrease in a generally southwards direction although the Birrenswark lavas form a distinct line of hills, 200-250 m OD, through the central part of the area. A marked break of slope coincides approximately with the lava-sediment boundary, to the south of which the land is gently undulating or flat-lying with an average elevation of <100 m OD.

Over the higher ground, the principal drainage direction is south-south-east, most tributaries flowing in moderately deeply incised valleys orthogonal to the regional strike until they cross the lava-sediment boundary, where they drain into the broad south-west meandering courses of Mein Water and Kirtle Water. Due to an almost continuous cover of glacial deposits (including lodgement and ablation tills) which thicken southward, rock outcrop over the Border Group sedimentary rocks is very scarce except in the most deeply incised stream sections. The Birrenswark lavas are better exposed especially in the steep sided gorges cut by Ecclefechan Burn, West Gill and Middlebie Burn (Figure 1), and in a few small disused quarries which have provided hard core for farm roads and local tracks. Much of the higher ground in the north-eastern part of the area is covered by blanket peat up to 3 m thick in places especially in the poorly drained upper reaches of Water Beck and Mein Water.

Apart from the villages of Ecclefechan, Middlebie and Waterbeck the area is relatively sparsely populated. Much of the valley and marginal hill land is utilised for arable and pastoral farming, but the highest ground supports only thin grass cover and consequently is used mainly for sheep grazing. A small coniferous plantation is located in the north-east corner of the area (Figure 1).

PLANNING AND DEVELOPMENT FRAMEWORK

The area is located about 25 km north-west of Carlisle and the same distance east of Dumfries. Communications are good with a network of minor roads and the A 74M motorway, and west coast railway providing easy access to Glasgow and London (Figure 1). The market town of Annan, 10 km to the south, is a small port on the Solway estuary supporting several established industries and, on the outskirts, the Chapel Cross nuclear power station. There are no known conservation areas likely to effect mineral extraction either within or in close proximity to the study area.

GEOLOGY

Lower Carboniferous sedimentary rocks which form the northern margin of the Northumberland basin underlie the southern part of the district (Figure 2). They are underlain by lavas of the Birrenswark Volcanic Formation which rest on rocks assigned to the Upper Old Red Sandstone. These in turn, rest with marked unconformity upon an irregular Lower Palaeozoic surface. The stratigraphical succession is summarised in Table 1.

Silurian: Riccarton Group

The oldest rocks of the area crop out only in the far north-west (Stockbridgehill [3199 5795]) and north-east (Grange Fell [3244 5819]*) corners of the district. They belong to the the Riccarton Group of Silurian (Wenlock) age. These rocks comprise a thick sequence of steeply dipping, east-north-east striking, turbidite sandstones, shales and mudstones deposited in a subsiding foreland basin following the closure of the Iapetus Ocean (Stone et al., 1987). The succession is folded, faulted and affected by low-grade metamorphism which accompanied end-Caledonian tectonic events. Petrographical and lithological studies (Lumsden et al., 1967) indicate that quartz is the predominant mineral in the greywackes accompanied by subsidiary amounts of feldspar, chlorite (derived from earlier ferromagnesian minerals), muscovite and accessory amounts of apatite, zircon and tourmaline.

? Devonian - Carboniferous: Upper Old Red Sandstone

Overlying the Silurian with marked angular unconformity is a thin sequence of strata of Upper Old Red Sandstone (UORS) facies. The rocks comprise red sandstones, conglomerates and siltstones with locally developed thin horizons of concretionary carbonate nodules (cornstones) and, near the top of the sequence, thicker bands of pedogenic carbonates (Leeder, 1974; 1976). The strata are of probable Upper Devonian age although Lumsden et al., (1967) suggested that they may represent a distinctive reddened facies of the Lower Carboniferous. The succeeding basalt lavas of the Kelso and Birrenswark Volcanic formations have given K-Ar whole rock radiometric ages of 361 +/- 7 Ma, indicating that eruption probably straddled the Devonian - Carboniferous boundary (De Souza, 1982).

The rocks occupy low ground around the summit of Burnswark Hill and upper reaches of the Middlebie Burn, Mein Water, Water Beck, Penoben Burn, Kirk Burn and Kirtle Water (Figures 1 and 2). Both to the south-west and northeast of the district Leeder (1976) has recorded well developed pedogenic carbonates (which represent palaeosol horizons) in the top few metres of the successions, particularly where they are associated with lithic-rich sandstones. The carbonate profiles include nodular, massive, cylindroid and irregular morphoplogies and the carbonate phase is usually ferroan dolomite sparrite (Leeder, 1976). Stringers and nodules of chert are also present. Locally, as at Cowdens Quarry [3165 5771] west of the district, indurated and silicified sandstones are found immediately underlying the lavas.

Most of strata are of fluviatile origin and palaeogeographical evidence indicates that they were probably part of an interior alluvial braided drainage system with predominant current flow to the north-east (Leeder, 1973). The occurrence of palaeosols towards the top of the sequence suggests a period of crustal upwarp and stream incision related to partial melting of the upper mantle which gave rise to the eruption of the succeeding Birrenswark lavas.

* British National Grid Reference

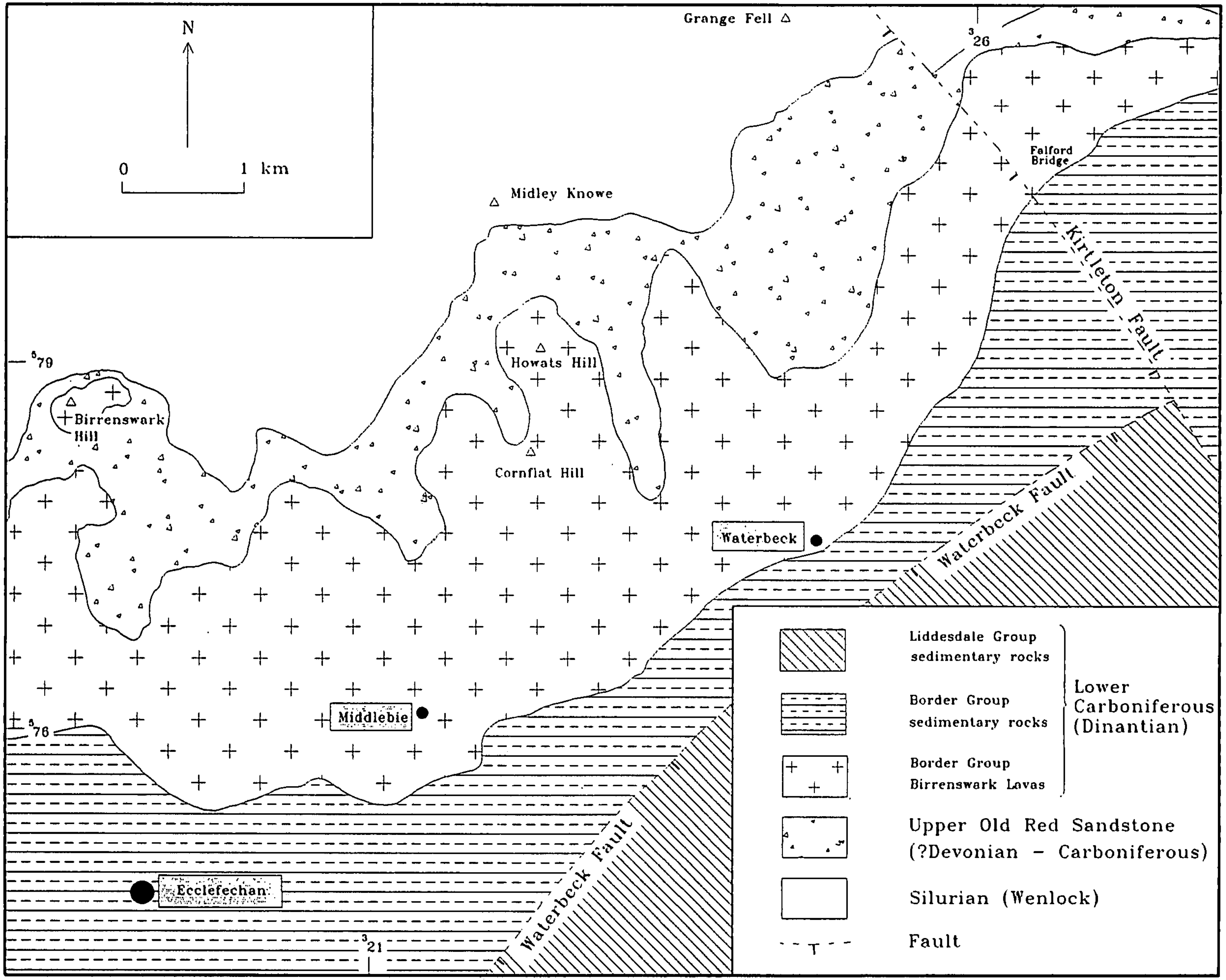


Figure 2 Geological map of the survey area

Table 1 Stratigraphical succession

SUPERFICIAL DEPOSITS		Thickness
RECENT	Peat	0.2 - 3 m
	Alluvium	<5 m
PLEISTOCENE	Glacial sand and gravel	<2 m
	Till	1.5 - 6 m
CARBONIFEROUS	*	
DINANTIAN — LIDDESDALE GROUP	limestone-dominated sequence at Eaglesfield & Blackwoodridge: lower part of Liddesdale Group (Asbian)	> 90 m
BORDER GROUP	Fell Sandstone Formation* (?Arundian - Asbian)	c.100 m
	Southerness Limestone Formation (Chadian - Arundian)	c. 50 m
	Kirkbean Cementstone Formation (Courceyan-Chadian)	c. 200 m
	Birrenswark Volcanic Formation (at base)	c. 80 m
?DEVONIAN- CARBONIFEROUS	Upper Old Red Sandstone	<50 m
	unconformity	
SILURIAN		
WENLOCK	Riccarton Group	>500 m

* = provisional lithostratigraphical formation

Carboniferous: Border Group

In the Langholm and Bewcastle areas Lumsden et al. (1967) and Day (1970) divided the Lower Carboniferous into a tripartite (Lower, Middle and Upper) Border Group and a bipartite (Lower and Upper) Liddesdale Group. These were primarily distinguished on biostratigraphical grounds with unit tops and bases defined by marker horizons. This report adopts a revised Border and Liddesdale Group lithostratigraphy (BGS, 1996) utilising the lithostratigraphical formations defined for the Solway coast (BGS, 1993b; McMillan in Lintern & Floyd, in preparation) and provisional formations and members to be proposed for Annandale (1: 50 000 Sheet 10W Lochmaben, BGS, in preparation).

The lowermost rocks of the Border Group in the area comprise the Birrenswark Volcanic Formation and these define the base of the Carboniferous system along the northern margin of the Northumberland - Solway Basin. These rocks, together with the succeeding Kirkbean Cementstone Formation and part of the Southerness Limestone Formation (BGS,1993b,1996; McMillan in Lintern & Floyd, in preparation), are of approximately the same biostratigraphical age as the Lower Border Group (Lumsden et al., 1967; Day, 1970). The top and base of the succeeding sandstone-dominated strata of the Fell Sandstone Formation (Fell Sandstone Group of Nairn, 1956) are probably diachronous: the formation is generally equivalent in age to the Middle to Upper Border Group (Lumsden et al., 1967; Day, 1970). Some beds including the sandstones contain a marine fauna. Strata of the Lawston Linn Coal Group (defined by Nairn, 1956) are taken to be facies variants of the Fell Sandstone Formation. Tuffs and lavas of the Glencartholm Volcanic Formation (Group of Nairn, 1956) die out to the east of the district at Allfornought. Strata of the lower part of the Liddesdale Group are present between Eaglesfield and High Muir.

Birrenswark Volcanic Formation

Extensional subsidence was very rapid during Courceyan-Chadian times, resulting in marked palaeogeographical changes and destruction of the internal UORS drainage system allowing the sea periodic access to the basins. Locally, alkali olivine-basalt extrusion accompanied rift-basin formation and tensional fracturing along the main basin faults (Leeder, 1974). The basalts and interbedded tuffs, which mark the base of the Lower Carboniferous succession, are known as the Birrenswark Volcanic Formation, named after Birrenswark (or Burnswark) Hill [35185 786]. The basalt petrography and mineralogy are described in detail by Pallister (1952) and Elliott (1960). The basalts are comparable with the Lower Carboniferous basalts of the Midland Valley of Scotland (MacDonald, 1975), being dominantly microporphyritic feldspar-rich types.

In the district, the lavas occupy the high ground of Burnswark Hill where they form an "outlier" in the Upper Old Red Sandstone. The main outcrop can be traced across south-facing slopes from Haregills to Middlebierig, extending northeastwards along the southern flanks of Howats Hill, Torbeckhill to Crowdieknowe Hill and Ley Hill (Figure 2). The total thickness of lavas in the district is estimated at about 80 m (Pallister, 1952). The rocks are vesicular and rich in amygdales particularly in the upper parts of flows, but their most striking feature is their alteration by deuteric activity and the effects of intense atmospheric weathering producing a distinctive spheroidal weathering surface. Hematite is commonly present, but pyrite and chalcopyrite, which were seen as common constituents of calcite-dolomite breccia veins and as patchy disseminations in lavas west of Langholm, have not been observed in the study area. Chloritisation and calcitisation are widespread, the former resulting from alteration of mafic silicates. Amygdales are commonly filled by calcite, accompanied by chlorite, clay minerals, quartz, and chalcedonic silica. Calcite also forms the matrix of breccia-veins. In Middlebie Burn, Pallister (1952) notes that the highest exposures of lava consist of a lava breccia cemented in a crystalline ankerite. Abundant sediment in vesicles and veins suggests that the lava were erupted contemporaneously with the onset of sedimentation.

Kirkbean Cementstone Formation

The earliest Lower Carboniferous sedimentary rocks of the area are represented by a sequence of up to 200 m of cementstone facies strata comprising thinly bedded, sparsely fossiliferous, muddy dolomitic limestones (cementstones), siltstones and sandstones. These rocks are referred to the Kirkbean Cementstone Formation (equivalent of most of the Cementstone Group of Nairn 1956). The sediments were deposited either in shallow channels or within mudflats in a predominantly estuarine environment. The cementstones probably formed as a result of frequent submergence of mudflats in semi-stagnant, saline water. In the district these rocks are thought to rest directly on the Birrenswark lavas. To the west in the Dalton area the cementstones are underlain by dark red fine-grained to conglomeratic sandstones assigned to the Annandale Sandstone Member (Annandale Sandstones of Nairn 1956). The eastern limit of these sandstones is probably near Hoddom although the BGS Hoddom Borehole No.2 (registered number NY17SE/3, 31641 57285) drilled in 1994 failed to penetrate the full cementstone sequence at 200 m below surface level (see Appendix). To the east of the district in the Langholm - Newcastleton area, up to 200 m of cementstones (referred to as the Black Burn Formation by Leeder, 1974) pass downwards into fine-grained, massive, fluviatile and deltaic distributary sandstones now collectively referred to the Whita Sandstone Member (after the Whita Sandstones of Peach and Horne, 1903, Nairn, 1956, 1958; Lumsden et al., 1967; Leeder, 1974; Smith and Walker, 1996).

Gypsum-anhydrite development in the Hoddom No.2 Borehole (NY17SE/3)

Throughout the sequence in BGS Hoddom No.2 Borehole (NY17SE/3), particularly in the cementstones and grey siltstones of the Kirkbean Cementstone Formation, fibrous gypsum (satin spar) bands, up to 4 cm thick are present. Normally the bands are sub-parallel or parallel to bedding. High angle and vertical veins of gypsum are also present. In addition, patches and bands of brecciated, massive anhydrite are developed in beds up to 1 m thick. Both anhydrite and gypsum can be formed subaqueously in shallow water and subaerially in coastal sabkhas (Tucker, 1988). Following burial to depths greater than a few hundred metres all $CaSO_4$ is preserved as anhydrite. Secondary gypsum forms during erosion and uplift. Although it is thought that the fibrous gypsum probably grew under pressure in water-filled veins induced by hydraulic fracture (Shearman et al., 1972), its source can be attributed either to anhydrite hydration or to residual sulphate-rich pore fluids.

Southerness Limestone Formation

At Southerness on the Solway coast the well exposed coastal section of marine limestones, sandstones, mudstones and algal beds was described in detail by Craig (1956) and Deegan (1970). The sequence includes the *Syringothyris Limestone* which Craig (1956) considered to be the biostratigraphical equivalent of the Harden Beds at the base of the Middle Border Group at Langholm (Lumsden et al 1967). The Southerness beds are presumed to overlie the Kirkbean Cementstone Formation, only exposed inland, and have been assigned to the Southerness Limestone Formation (BGS 1993b, 1996; McMillan in Lintern & Floyd, in preparation). In the Ecclefechan area exposure of these rocks is very poor and as a consequence their extent and thickness is poorly known. Probably in the order of 50 m of thinly-bedded marine strata are present in the area. In the Ecclefechan Burn a limestone with a marine fauna including *Syringothyris cuspidata* was recorded by Nairn (1956) in his Cementstone Group. More recently a section excavated for a pipeline north of Allfornought Hill [33200 57870] immediately to the east of the district also revealed a Harden Beds faunal assemblage (Brand, 1992a). It is possible that representatives of the Southerness Limestone Formation are present in the BGS Hoddom Borehole No.2 (NY17SE/3) but interpretation awaits detailed biostratigraphical collection and analysis. In the interim, the top c 100 m of sandstone-dominated strata resting on the cementstones are provisionally assigned to the Fell Sandstone Formation.

Fell Sandstone Formation

South-west of the district, BGS Hoddom Boreholes Nos. 1 (NY17SE/2, 31641 57258) and 2 reveal up to 100 m of medium to coarse pink and white sandstone with seatearth and siltstone and subordinate mudstone. Some sandstones are conglomeratic with pebbles predominantly of quartz. These strata are provisionally assigned to the Fell Sandstone Formation (Group of Nairn 1956). Some bands are fossiliferous and although these have yet to be examined, a section in a pebbly sandstone exposed in the River Annan at Hallguards immediately up-dip and to the west of the borehole site yielded a fauna indicative of a Middle to Upper Border Group age (Brand, 1992b). Sandstone-dominated strata of the Fell Sandstone Formation are patchily exposed in the River Annan downstream from Hoddom to Brydekirk and may be part of the thick sequence of interbedded sandstones and seatrocks which form Repentance Hill, Woodcock Air and Pennersaughs Hill. Fossiliferous marine sandstones are found in the River Annan north of Brydekirk Mains [31872 57132] and in a recently exposed M74 motorway section at Pennersaughs [32105 57411]. Both faunal assemblages are indicative of Middle to Upper Border Group ages (Brand, 1992b; Dean, 1995).

The Fell Sandstone Formation may also be exposed in the Kirtle Water near Blackwoodridge where a succession of alternating red marls and conglomeratic sandstones overlying a fossiliferous mudstone were referred to top of the Lawston Linn Coal Group by Nairn (1956). He noted typical lithologies of the group from sections further east in the River Esk as comprising yellow-brown, micaceous, sandstones (locally fossiliferous) with subordinate fossiliferous marine mudstones, muddy limestones and thin coals. Nairn (1956) placed the Lawston Linn strata above tuffs of the Glencartholm Volcanic Formation which attain their maximum thickness in the River Esk but die out westwards. In the Ecclefechan area, the Glencartholm volcanic rocks are absent and the Kirtle Water sedimentary succession is provisionally subsumed in the Fell Sandstone Formation, on the grounds that it may simply be a facies variant which represents changing conditions of sedimentation.

Carboniferous: Liddesdale Group

A sequence with thick limestones, formerly extensively worked at Blackwoodridge, Eaglesfield and Kelhead fall within the Lower Limestone Group (Nairn, 1956) and are biostratigraphical equivalents of part of the Lower Liddesdale Group (Lumsden et al., 1967). In this report, the strata remain unnamed but are placed near the base of the Liddesdale Group (undivided). In the district the sedimentary rocks are downthrown to the south-east by the Waterbeck Fault. The strata are characterised by rhythmical sequences of thick, massive limestones, mudstones, sandstones and thin coals. Biostratigraphical evidence indicates the strata to be of Asbian age (Brand, 1992a). In the Blackwoodridge-Eaglesfield area, Nairn (1956) estimated the sequence to be at least 90 m thick.

Volcanic Vents

Several small volcanic plugs containing agglomerate and/or intrusive material occur to the east of the district in the Black Burn and Hartsgarth Burn catchments (Smith and Walker, 1996). While no direct genetic link has been established, it is likely that the vents acted as feeders for the Birrenswark lavas or the Glencartholm volcanic beds (the latter are not represented in the project area). Blocks and fragments of sedimentary debris in the agglomerate-filled necks include dolomite and chert of probable Upper Old Red Sandstone age, The principal igneous component is olivine-basalt, but unusually a block of carbonated, serpentinized peridotite has been recorded in the Black Burn-Rough Gill vent (Lumsden et al., 1967). Apart from small amounts of pyrite, no sulphide mineralisation has been noted in or at the margins of the vents.

Structure

The regional structure of the post-Silurian strata is dominated by a north-easterly strike, dip to the south-east, a few folds with mainly north-northeast-south-southwest orientation and a system of normal, *en echelon* north-easterly faults downthrowing predominantly to the south-east. A system of cross-cutting, north-westerly trending normal faults is also present. This structural pattern, which is largely the result of deformation during the end-Carboniferous to early Permian, Variscan Orogeny, probably reflects reactivation of older Caledonian structures within the underlying basement (Chadwick and Holliday, 1991).

Recent seismic interpretation and outcrop studies (Chadwick et al., 1993; 1995) in the Solway Basin have indicated that normal faulting near the basin margins was the result of rapid extensional subsidence during the early Dinantian, and that continuing movement on these syn-depositional faults accompanied deposition of the Border Group.

A major north-easterly fault, the Waterbeck Fault crosses the project area (Figure 2). This fault, one of several postulated along the northern margin of the Solway Basin, downthrows Liddesdale Group strata to the south-east and cuts out parts of the Border Group to the north. The north-westerly trending, south-westerly throwing Kirtleton Fault (Figure 2) and associated structures of similar trend to the west of the project area probably acted as block faults, accounting for the presence of Liddesdale Group strata in the High Muir to Eaglesfield area.

Abrupt transitions from relatively flat lying to tightly folded strata is a feature of the Border and Liddesdale Group strata in the district. This pattern is particularly well observed in the Fell Sandstone Formation of the River Annan. Lack of exposure over much of the district precludes a detailed structural analysis, but the structural pattern may be analagous to that observed in the Lower Carboniferous rocks of Berwickshire, where zones of steeply dipping, folded and thrust strata are believed to have formed during late Carboniferous times in response to regional compression (Shiells, 1963). The rapid disappearance to the north of tightly folded limestones at Eaglesfield and Blackwoodridge may be attributed to displacement along the line of the Waterbeck Fault.

The structures display no obvious sequence of events, although folding, which shows evidence of truncation by the major faults, probably took place prior to, or at the latest, contemporaneously with, the faulting.

DRAINAGE GEOCHEMISTRY

Geochemical sampling of panned concentrates in the Ecclefechan-Waterbeck area was originally undertaken in 1976 as part of a more extensive MRP reconnaissance survey at the northern margin of the Solway-Northumberland Basin. The results of this work are presented together with additional panned concentrate data collected in 1995 to confirm and improve sample density in the vicinity of anomalies discovered in the earlier reconnaissance survey. Visual inspection of the panned concentrates identified small amounts of sulphide minerals, pyromorphite, abundant baryte and hematite, and relatively coarse particles of gold in up to 15% of the samples indicating that many of the geochemical anomalies are related to mineralisation. However, mineralogical examination carried out on a selection of the anomalous concentrates showed that a high proportion of the streams close to habitation and roads were contaminated. The most common particulate contaminants recognised were fragments of lead-metal (often cerrusitised), glass, lead shot, pieces of rusty metal and wire (some with copper coating), accounting for the high levels of Pb, Sn and Sb seen in the most contaminated samples. Although Sn anomalies (>15 ppm) are a reliable indicator of contamination, high levels of Pb and Sb are also generated by mineralisation and the mineralogical data often indicate the presence of sulphides and contaminant grains in the same samples (Table 4a).

Sampling and analysis

Heavy mineral concentrates were obtained by wet screening an initial volume of 4 litres of -2 mm stream sediment and panning to a final volume of about 25-30 ml. Analysis for Cu, Zn, Pb, Ba, Ni, Fe, Sn, Sb and Mn was performed on 12 g of milled sample by X -Ray fluorescence spectrometry (XRF) at the BGS Geochemical Division laboratories in London (1976 reconnaissance samples, n=73, Table 2) and Keyworth (1995 follow-up samples, n=61, Table 3). The results of optical examination of the remaining unground excess material and of semi-quantitative XRF/electron microprobe analysis on separated grains from a selection of the anomalous samples (1995 survey) are given in Table 4a and 4b respectively.

Distribution of panned concentrate anomalies

Copper

Copper values in panned concentrates show a wide range of concentration (0 - 801 ppm) (Tables 2 and 3; Figure 3), average values over the Border Group being comparable or slightly higher than in the Newcastleton (Smith and Walker, 1996) and Arnton Fell areas (Smith et al., 1996).

Many of the anomalous Cu_p* values (>60 ppm) occur over the outcrop of the Birrenswark lavas or in streams draining across the lava-sediment boundary. Cupriferous pyrite and rare grains of chalcopyrite are minor but widespread constituents of panned concentrates in these streams, although the highest value of the dataset from Penoben Burn (801 ppm at [325430 578700]) is caused by contamination from fragments of oxidising Cu-coated wire. However, there may also be a local source of Cu mineralisation beneath the drift, since at the next site, only 300 m upstream, a high Cu value of 144 ppm at [325360 579020] is associated with small amounts of oxidising pyrite and one or two grains of ?chalcopyrite. A similar mineral association accounts for the Cu anomalies (113-124 ppm) north of Middlebie and close to the lava-sediment boundary south-west of Waterbeck (158 ppm at [323320 576580]). An unusually high value of 686 ppm Cu in Stoneybeck Burn at [322205 576802] may be related to a local source(s) of mineralisation as there was no evidence of contamination at the site and samples of deep till collected 400 m to the north contain over 2500 ppm Cu and visible chalcopyrite and copper secondary minerals (see section on Deep Overburden Sampling and Figures 7 and 11).

Over the Border Group sedimentary rocks anomalous Cu values are recorded to the west of Ecclefechan (187 ppm at [318700 574140]) and in upper Kirtle Water and its west draining tributaries (e.g. 66 ppm at [326800 579470]). At the former site a few grains of chalcopyrite and sphalerite were mineralogically confirmed (Table 4b), but some Cu-contaminants were also detected (Table 4a).

* subscripts denote sample type, p=panned concentrate, u=panned till, t=sieved till

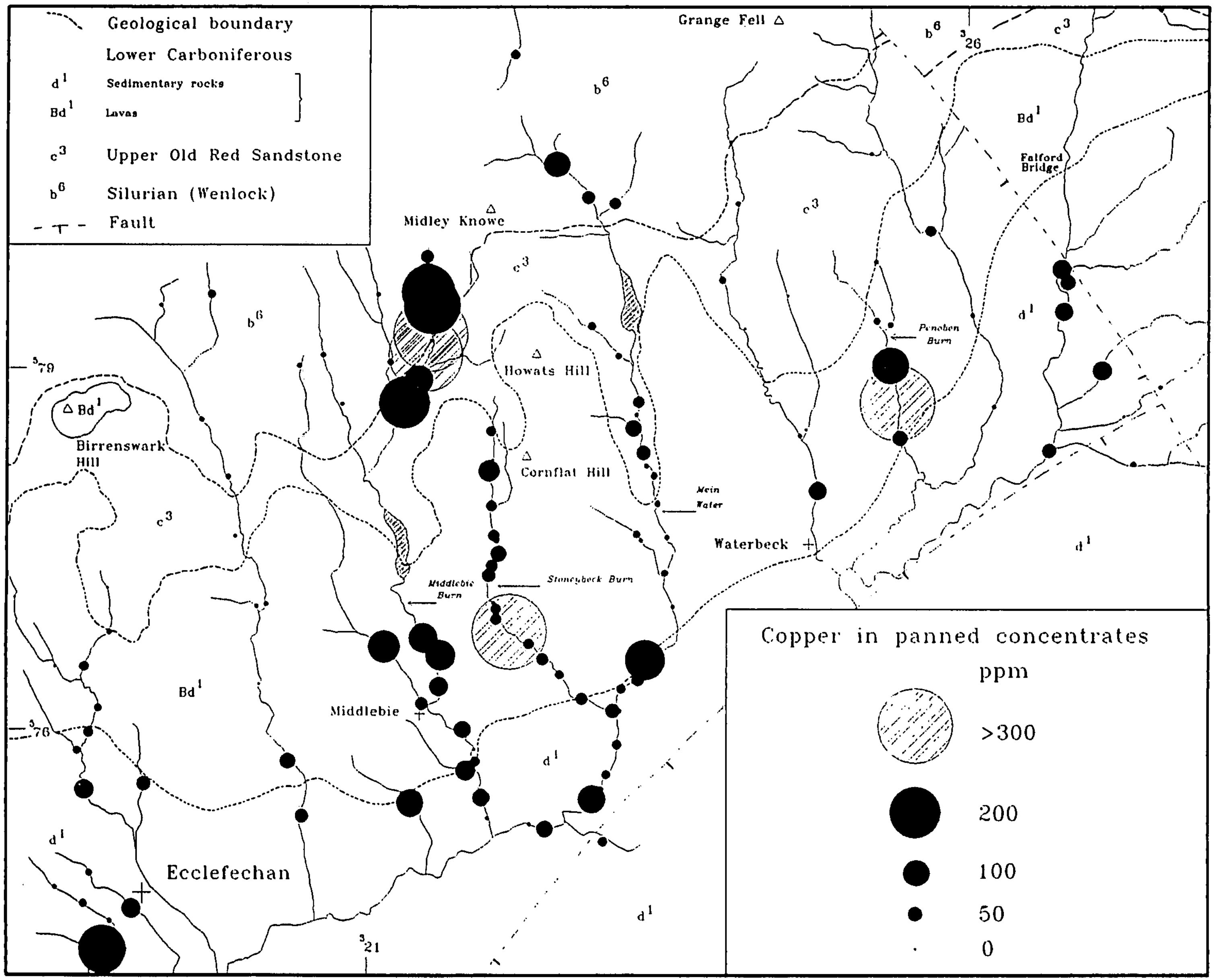


Figure 3 Copper in panned concentrate samples

The most conspicuous group of high Cu values occur in six consecutive samples collected from the headwaters of Darlawhill Grain, south-west of Midley Knowe (Figure 3). At least two of the sites lie within the Silurian, but maximum values of 371 and 301 ppm are associated with the Silurian-Upper Old Red Sandstone boundary. The panned concentrates contain abundant hematite and baryte and, in one sample, a coarse grain of gold. In the area of the anomaly float boulders of carbonate-veined, brecciated, strongly haematised greywacke and grey sandstone were noted over several hundred metres of stream channel indicating the presence of an unexposed fault structure possibly forming the boundary between the Silurian and Upper Old Red Sandstone. Similar occurrences north-eastwards along strike, are associated with the unconformable or faulted Silurian-Upper Old Red Sandstone boundary (Colman et al., 1995), and in the Arnton Fell area Cu, Ba, and Au anomalies have been reported from a comparable hematised breccia close to the faulted Silurian-Lower Carboniferous boundary (Smith et al., 1996).

Lead

The pattern of high Pb_p values (Tables 2 and 3) is broadly similar to Cu_p, forming a distinct cluster in the two adjacent catchments of Middlebie Burn and Stoneybeck Burn (Figure 4), with scattered high values over the Lower Carboniferous sedimentary rocks around Ecclefechan and south of Middlebie. In contrast with other parts of the Solway-Northumberland Basin (Smith and Walker, 1996; Smith et al., 1996) where high Pb_p values tend to be patchily developed, the project area contains more coherent and higher amplitude anomalies.

Mineralogical studies showed that, in addition to primary lead minerals, many of the Pb-anomalous samples contain a variety of contaminant materials, the most frequently encountered being flattened fragments of pale grey Pb-metal sometimes coated by white cerussitic overgrowths. This form of contamination accounts entirely for the high Pb_p values reported from Penoben Burn {1900 ppm at [325430 578700]) and from a small stream south of Middlebie (564 ppm at [321365 575400]). In both samples, Sn_p and Sb_p values are also enhanced and no Pb-minerals were detected.

The maximum Pb_p value of the dataset (4300 ppm), recorded in Stoneybeck Burn about 200 m upstream of the B-road intersection [322080 576915], is caused by abundant bright green fragments and euhedral grains of pyromorphite. One or two grains show a cubic habit suggesting derivation by low temperature alteration of galena. Detailed follow-up sampling in Stoneybeck Burn revealed highly anomalous Pb_p extending over a distance of 600 m with an apparent cut-off about 100 m upstream of the major anomaly. Unusually abundant hematite and magnetite, resulting in total Fe_2O_3 contents of up to 58 % (Table 2), accompany the pyromorphite together with small amounts of baryte. Systematic downstream decrease of the anomaly is evident as far as the confluence of Stoneybeck Burn with Mein Water, although relatively high Pb_p values (200-300 ppm) continue for nearly 1 km below the confluence suggesting a contribution from other sources of Pb-mineralisation.

Many of the high Pb_p values in Middlebie Burn and its west bank tributary, Smithy Cleuch, have been traced to the presence of small amounts of galena (Table 4a), although some contribution from metallic lead and dark grey fragments of contaminant slaggy material with microbotryoidal surfaces is evident. In several samples from this catchment and from West Gill [320343 575743], rare anhedral fragments of grey, waxy, secondary-Pb phases of the plumbogummite-beudantite group were identified. Occasional grains of these minerals are quite widely dispersed over the mineralised Lower Carboniferous rocks in the Westwater and Newcastleton areas (Gallagher et al., 1977; Smith and Walker, 1996). The exact nature of the primary phase from which they have developed is, however, difficult to establish, although one fragment from the West Gill site showed good cubic cleavage which may indicate that it is an alteration product after galena.

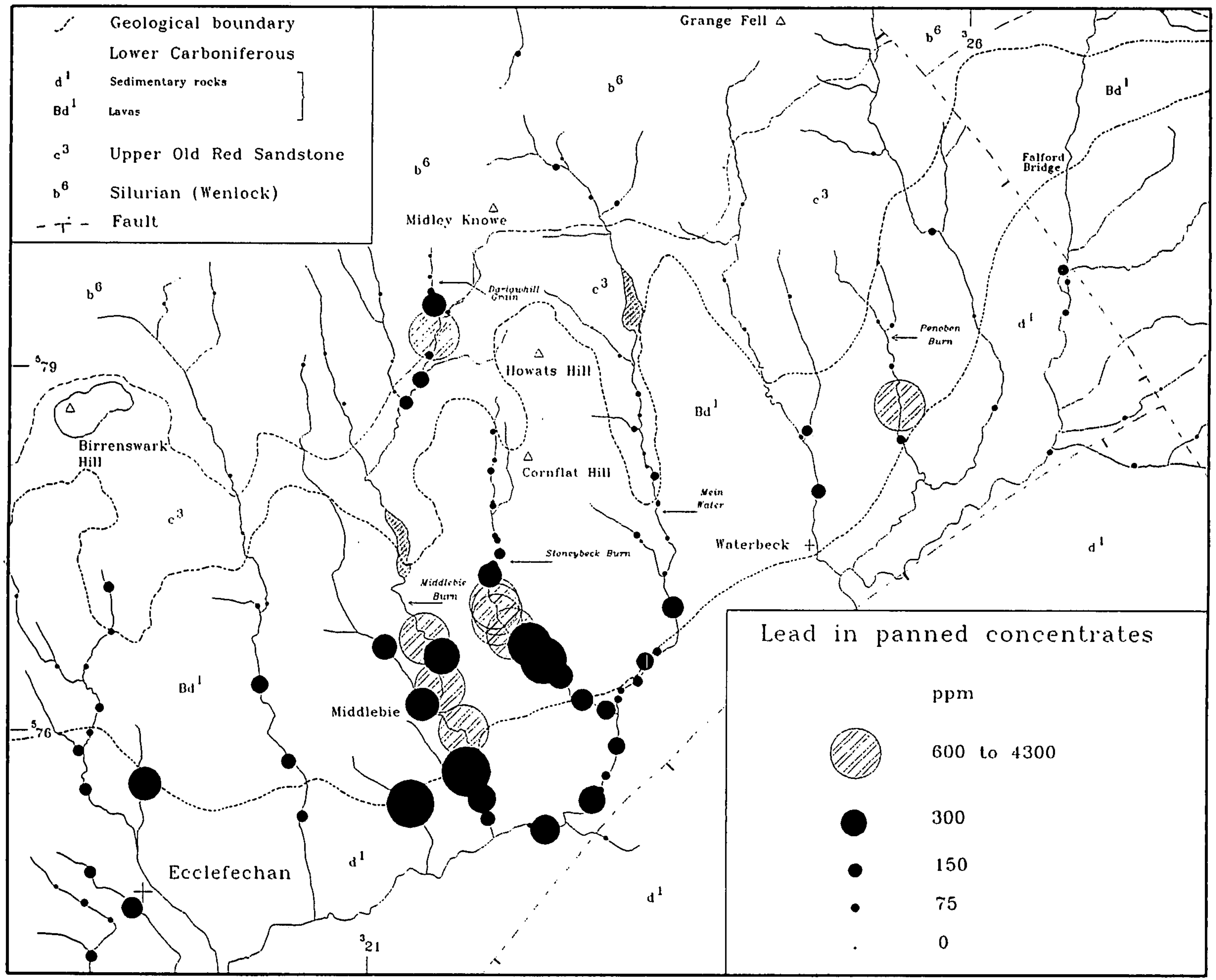


Figure 4 Lead in panned concentrates

Several high Pb_p values (maximum 772 ppm at [321540 579270]) also define the zone of haematised fault breccia in upper Darlawhill Grain. Despite the presence of sphalerite, cupriferous pyrite, and baryte in the panned concentrate, no Pb minerals were observed and it is therefore likely that Pb is concentrated by adsorption onto the iron oxides. A heavily fractured and intensely reddened float boulder at the above site contained mainly dolomite with sandstone bands. The red colour is due to limonitic granules possibly after pyrite, but no fresh sulphides were seen. Within the carbonate matrix small quartz lenses and irregular hair veinlets contain minor amounts of carbonate and radiating fringes of bladed hematite.

Zinc

In sharp contrast with the very high levels of Zn_p which characterise the Border Group north-east of Langholm, especially in the Newcastleton area (Smith and Walker, 1996) where approximately 10% of values exceed 500 ppm, those of the project area are much lower (Tables 2 and 3; Figure 5). Only one very high value of 2373 ppm is reported, the remainder all falling below 400 ppm. The pattern of weakly anomalous Zn_p values (>200 ppm), however, is closely related to the distribution of Pb_p and to a lesser extent Cu_p, showing a distinct cluster in Stoneybeck Burn, Middlebie Burn, and West Gill. Most of these anomalies are clearly related to the sub-outcrop of the Birrenswark Lavas, although around Ecclefechan the Border Group cementstones appear to exert greater influence with the highest value of the dataset 2373 ppm at [319145 575555] occurring very close to the inferred lava-sediment contact. Mineralogical examination of this sample revealed moderately abundant, relatively coarse-grained (mostly >500 μm), yellow-orange grains of resinous sphalerite (Table 4a) which are typical of the sphalerites separated from panned concentrates along most of the northern basin margin, north-east of the project area. In many instances the source of panned concentrate anomalies in the Westwater, Newcastleton and Arnton Fell areas has been traced to minor fracture-bound sphalerite-pyrite mineralisation concentrated in narrow carbonate veins in limestones and cementstones (Gallagher et al., 1977; Smith et al., 1996; Smith and Walker, 1996). Since comparable carbonate facies rocks (Kirkbean Cementstone Formation) are present in the project area, it is likely that the observation of widespread, but scarce, sphalerite grains in panned concentrates is related to similar weak epigenetic mineralisation. Very little Zn was found in contaminant grains.

The only notable Zn_p concentrations in the northern part of the area are related to the zone of strongly haematised and carbonate-veined Silurian close to the unconformable or faulted Upper Old Red Sandstone boundary in the upper reaches of Darlawhill Grain and Grainhall Burn. Maximum Zn concentrations of 398 ppm at [321190 579050] are insufficient to suggest significant Zn mineralisation, however from the high concentrations of Fe recorded in this stream much of the Zn is likely to be adsorbed onto secondary iron oxides.

Barium

The distribution of high Ba_p values (>5000 ppm) (Tables 2 and 3) shows a similar pattern to that of Zn_p and Pb_p in being strongly enriched over the Birrenswark lavas in Stoneybeck Burn and Middlebie Burn (Figure 6). Abundant coarse white grains of baryte with well developed fracture surfaces and slightly reddened surface coatings were recognised in most samples from these catchments. The anomalies are probably due to baryte vein mineralisation which is relatively common in the Birrenswark lavas in the Westwater and Newcastleton areas (Gallagher et al., 1977; Smith and Walker, 1996). The best example, at Mine Sike near Westwater [32926 58174], is a 0.7 m wide vein breccia containing about 10% baryte and abundant coarse-grained galena and sphalerite. Other veins and occurrences of vesicles infilled by baryte were discovered in diamond drill cores from the lavas

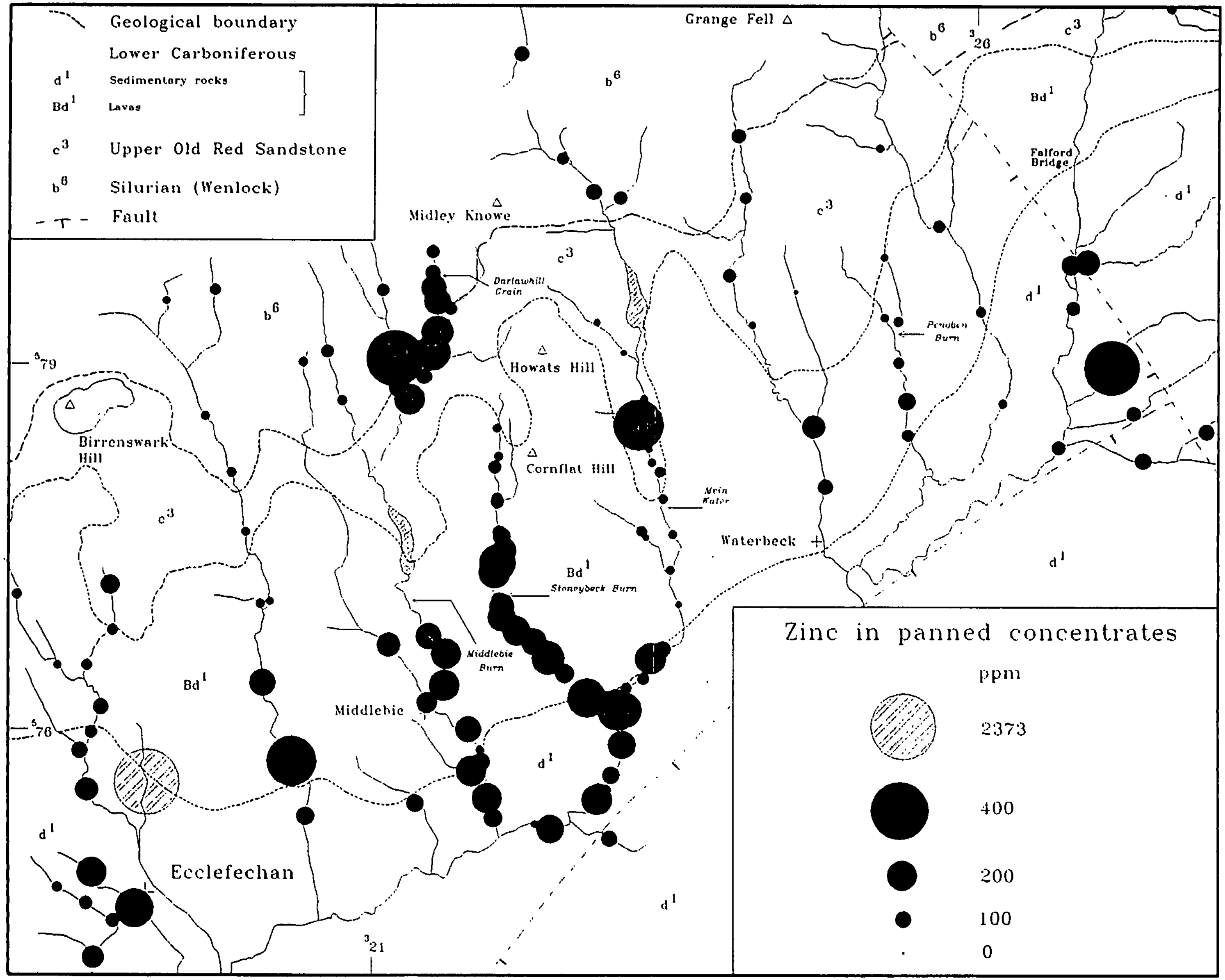


Figure 5 Zinc in panned concentrates

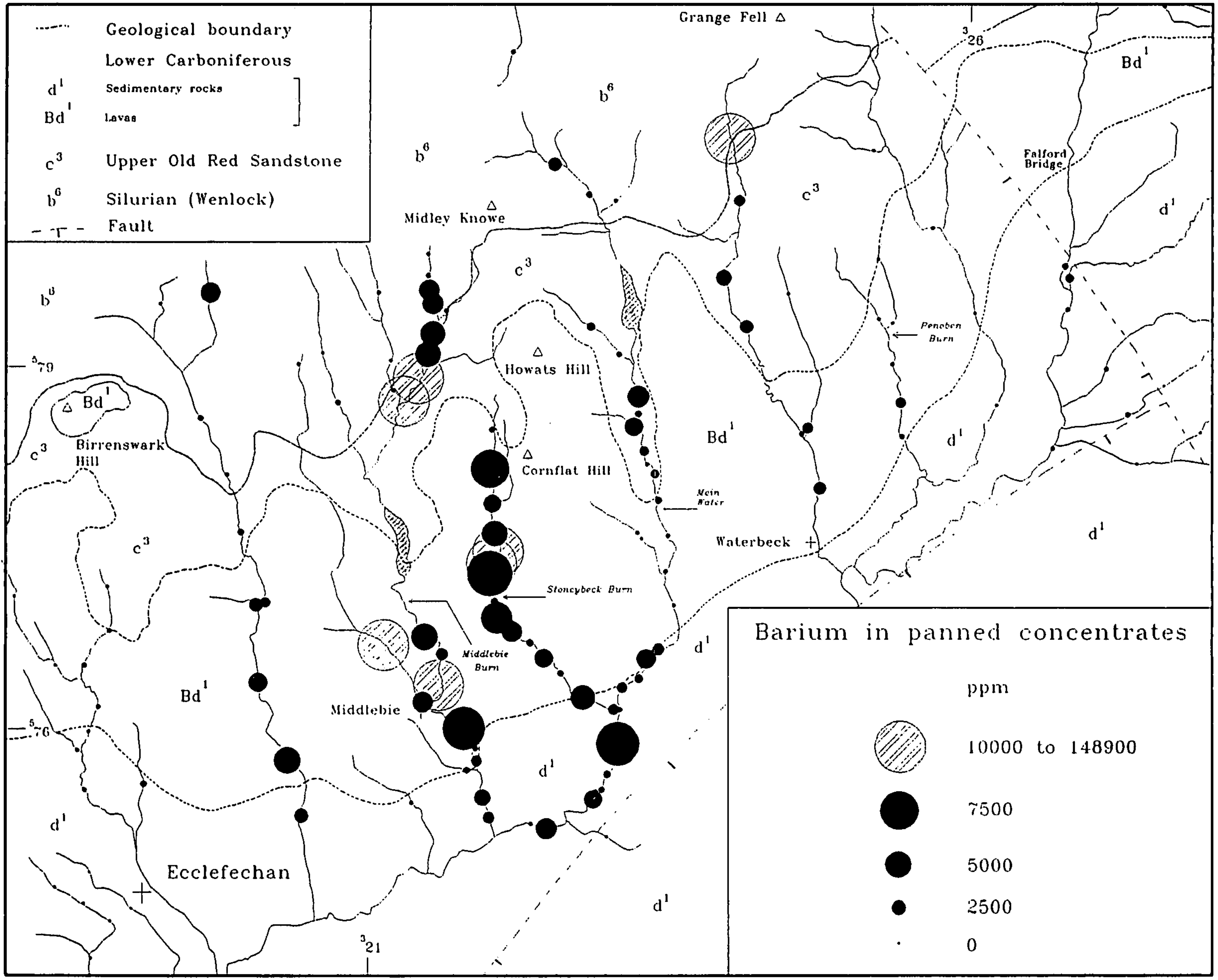


Figure 6 Barium in panned concentrates

over a strike length of nearly 1.5 km between Mine Sike and Megsfield [32760 58100], close to the north-eastern edge of the project area.

Outside of the Birrenswark lavas the most prominent anomalies are located in streams intersecting the unconformable or faulted Silurian-Upper Old Red Sandstone boundary. Barium anomalies and coarse baryte accompany enhanced Pb, Cu and moderate Zn levels in panned concentrates from the headwaters of Darlawhill Grain, but in the geologically similar environment in the headwaters of Water Beck to the east, a major Ba_p anomaly of 14.9% is not associated with other metals.

Other than a few high Ba_p values in Mein Water south of its confluence with Stoneybeck Burn, which are attributed to possible baryte veins within the lavas, there is no evidence of Ba enrichment associated with the Lower Carboniferous sedimentary rocks.

Gold observations

Visible gold grains were recorded in panned concentrates from 13 sites (Table 7) in the area. Most grains were relatively coarse (0.5-1.0 mm), flattened, and irregular or subrounded in shape, and their spatial distribution, mainly from Stoneybeck Burn, Middlebie Burn and Ecclefechan Burn, strongly suggests a source within the Birrenswark lavas. The largest number of grains was recovered from Middlebie Burn, in samples containing the highest coincident As and Sb values (e.g. BFP 7725 at [321960 575443]). Other gold sites in lower Mein Water, containing weakly anomalous As and Sb values, probably reflect downstream dispersion from a source area in Stoneybeck Burn. One gold observation from the headwaters of Darlawhill Grain may be associated with the zone of haematisation and carbonate-quartz veining in the Silurian near to its contact with the Upper Old Red Sandstone. Evidence of the southern dispersal of till deduced from the abundance of greywacke clasts in the upper parts of tills overlying the Birrenswark lavas, suggests that some gold, at least, may have its origin in the Silurian rocks.

OVERBURDEN GEOCHEMISTRY

Sampling and analysis

Because outcrop is negligible over the Border Group and the stream network poorly developed and heavily contaminated, reconnaissance deep overburden sampling was undertaken at intervals of 200-400 m randomly located to intersect the lava-sediment boundary over a strike length of 9 km. The primary objective of this work was to look for evidence of base-metal concentration over the inferred surface trace of the Waterbeck Fault and to clarify the source of drainage anomalies in the Stoneybeck Burn-Middlebie Burn catchments. 51 bulk till samples were collected using a portable mechanical auger to sample as close to the till-bedrock interface as possible (Figures 7-14). The average penetration depth of the power auger at 51 sites was 4.8 m (1.8 to 11.5 m), (Tables 5 and 6).

At each site 8-10 litres of till, collected from the basal 1-2 m of the hole, was wet screened to remove clay and fine silt, and the remaining -2 mm fraction (normally 0.5-1.5 litres) reduced by panning to yield a concentrate of about 30 ml (BFU samples in Table 5). Additionally a sample of till from the maximum attainable depth was collected at each site and after drying and dissaggregation, sieved at 150 µm to produce a fine-fraction for chemical analysis (BFT samples in Table 6). The lithology and morphology of clasts recovered during the wet screening operation was recorded to provide an indication of provenance and transport distance. Samples were analysed by XRF for the same range of elements as the drainage concentrates.

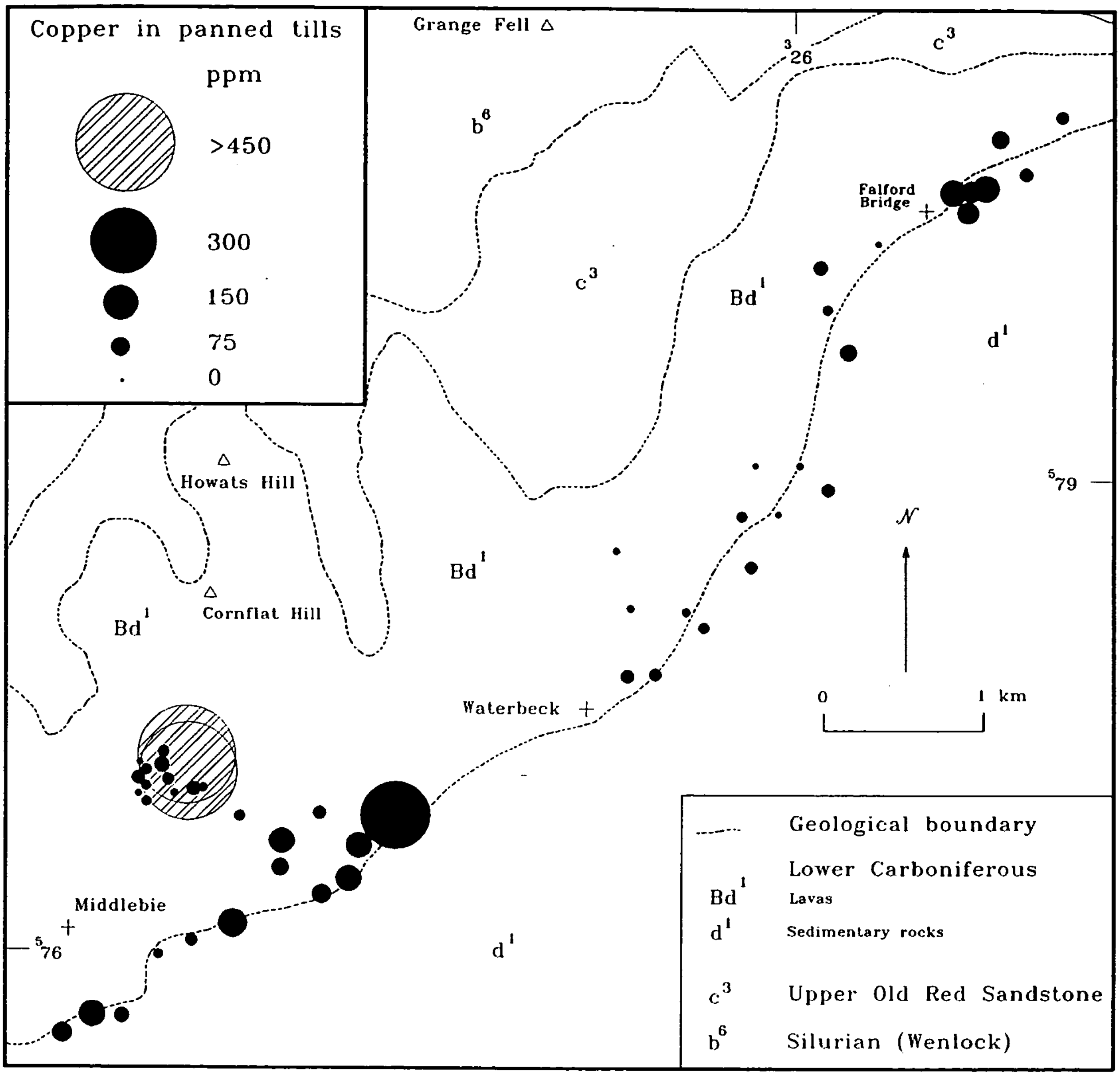


Figure 7 Copper in panned tills

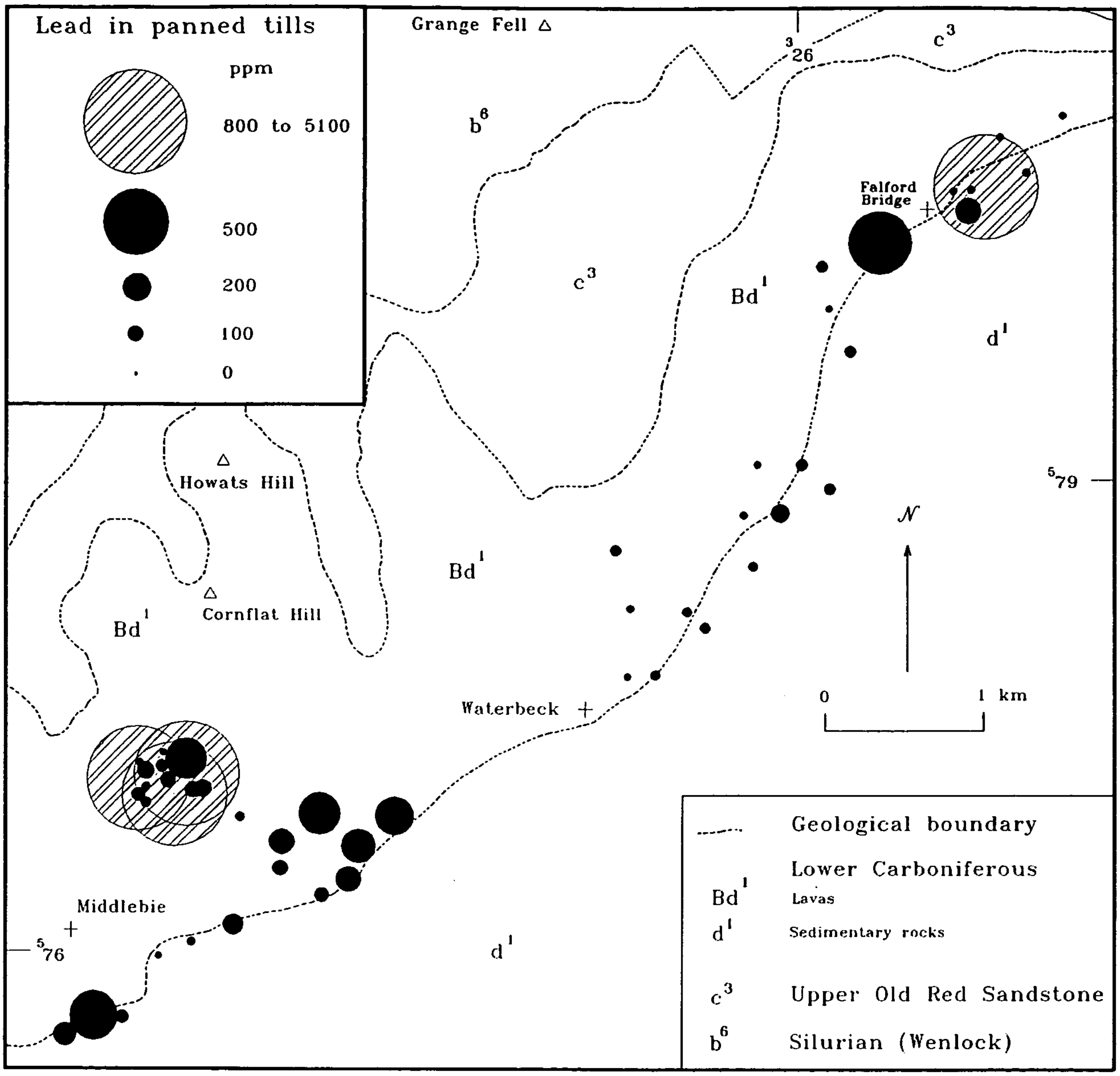


Figure 8 Lead in panned tills

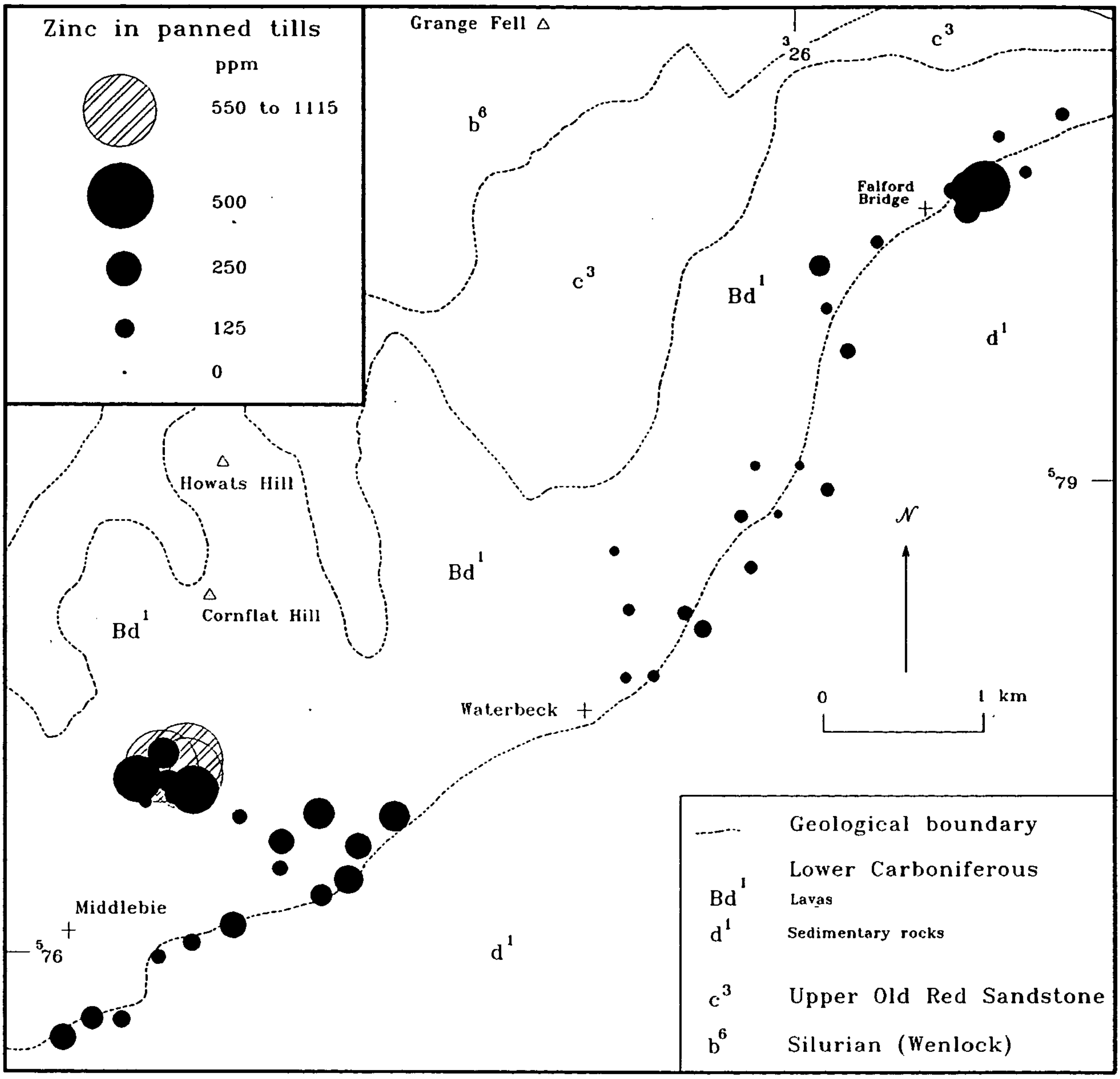


Figure 9 Zinc in panned tills

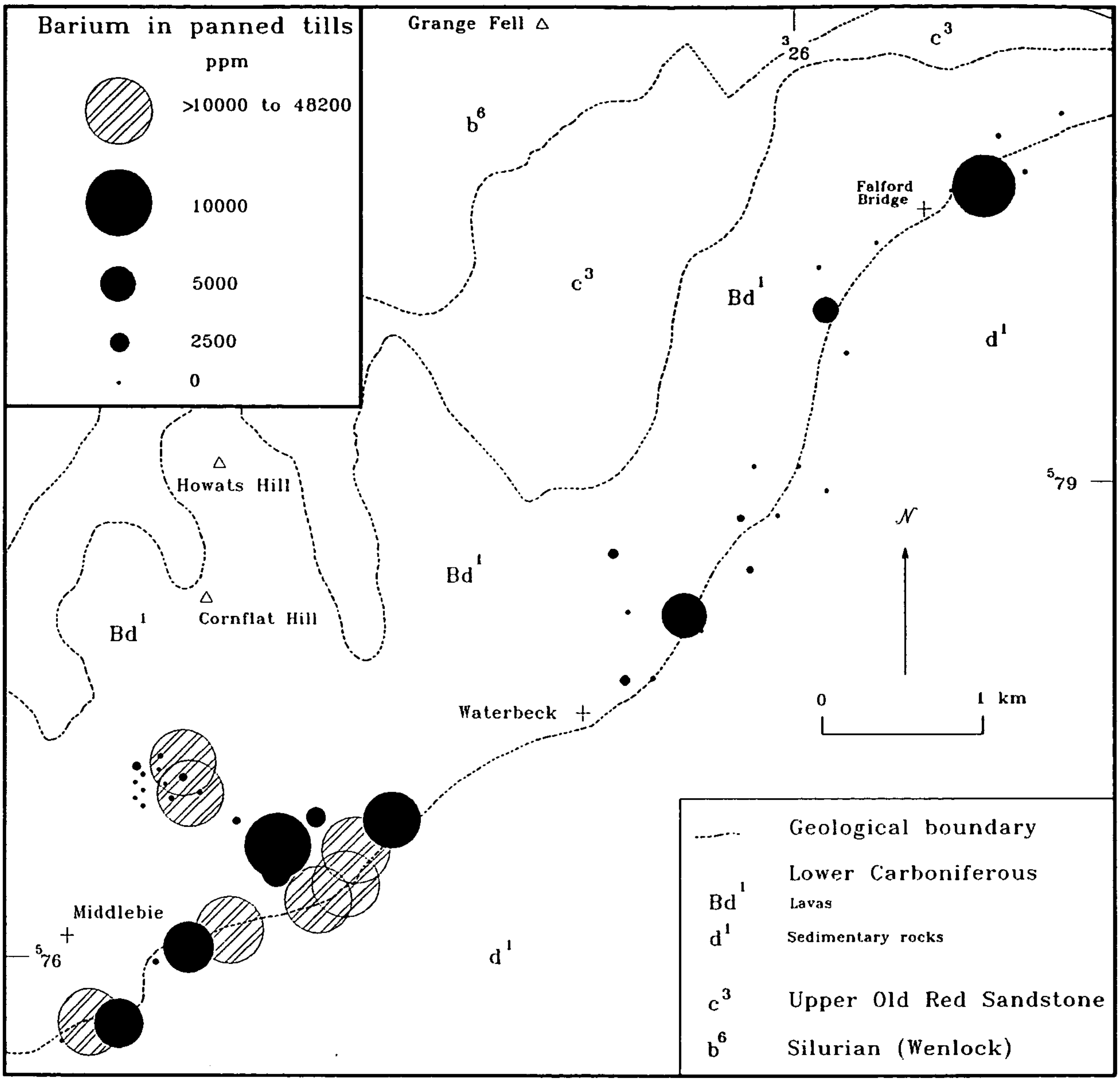


Figure 10 Barium in panned tills

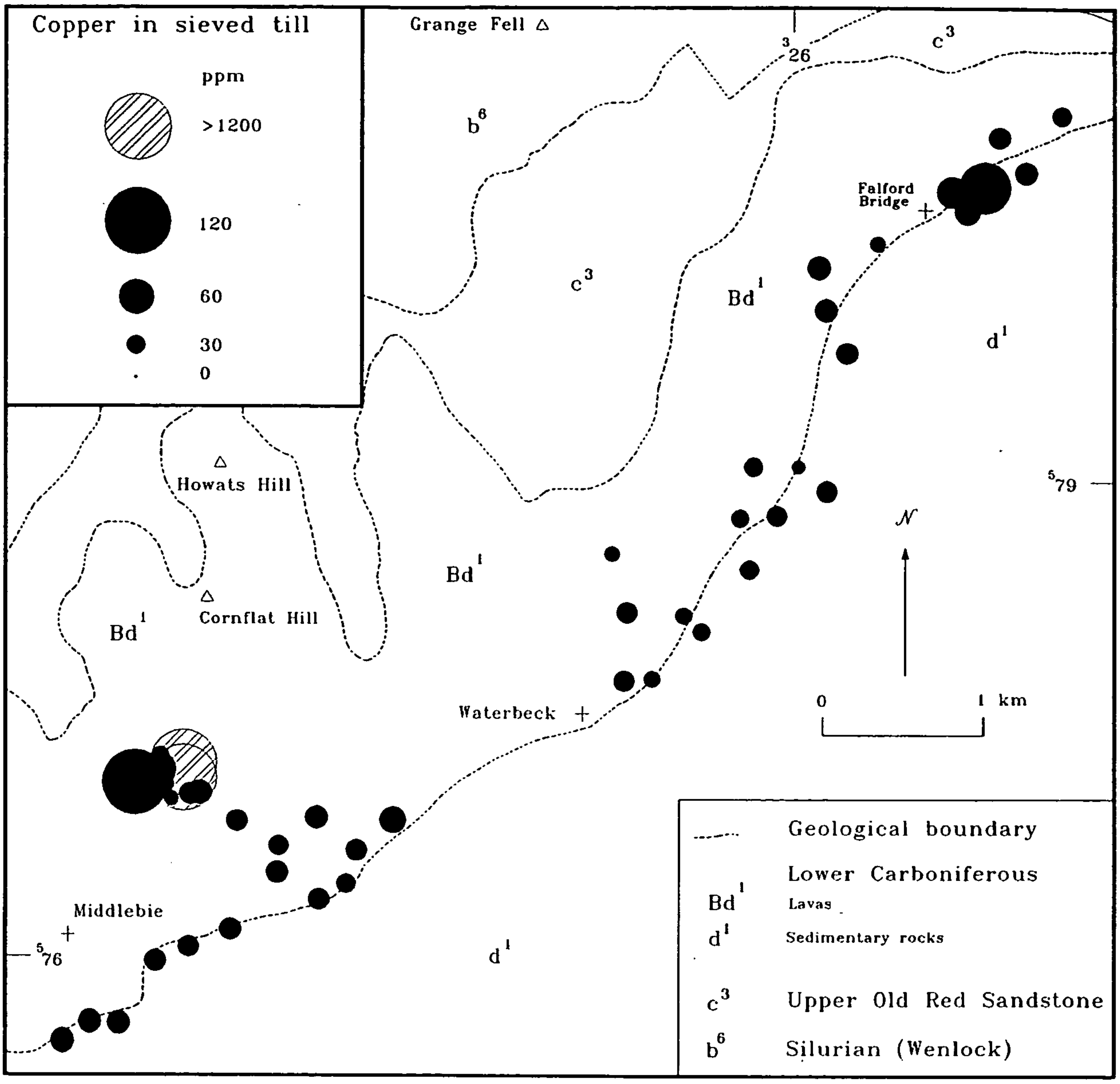


Figure 11 Copper in sieved tills

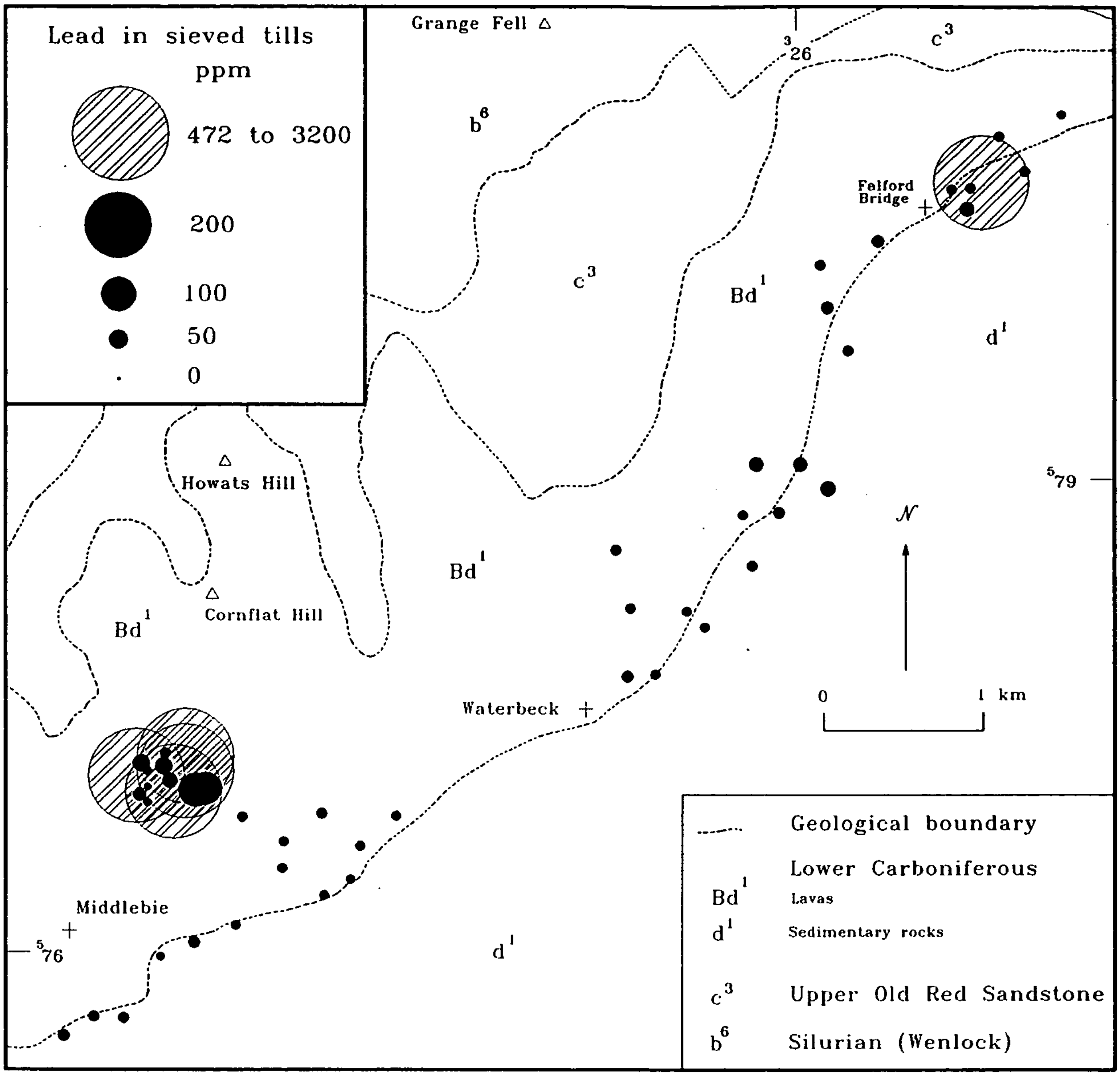


Figure 12 Lead in sieved tills

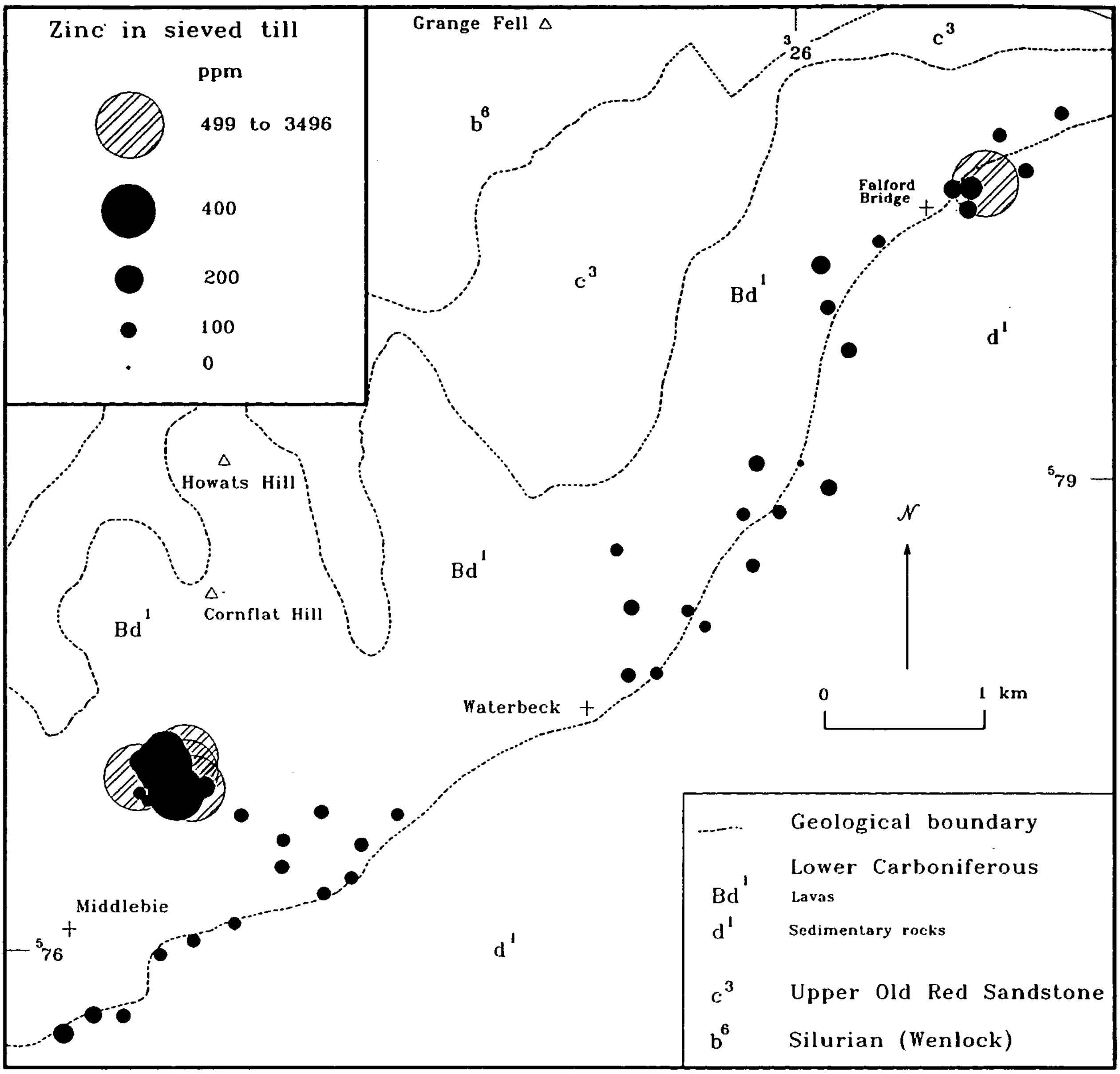


Figure 13 Zinc in sieved tills

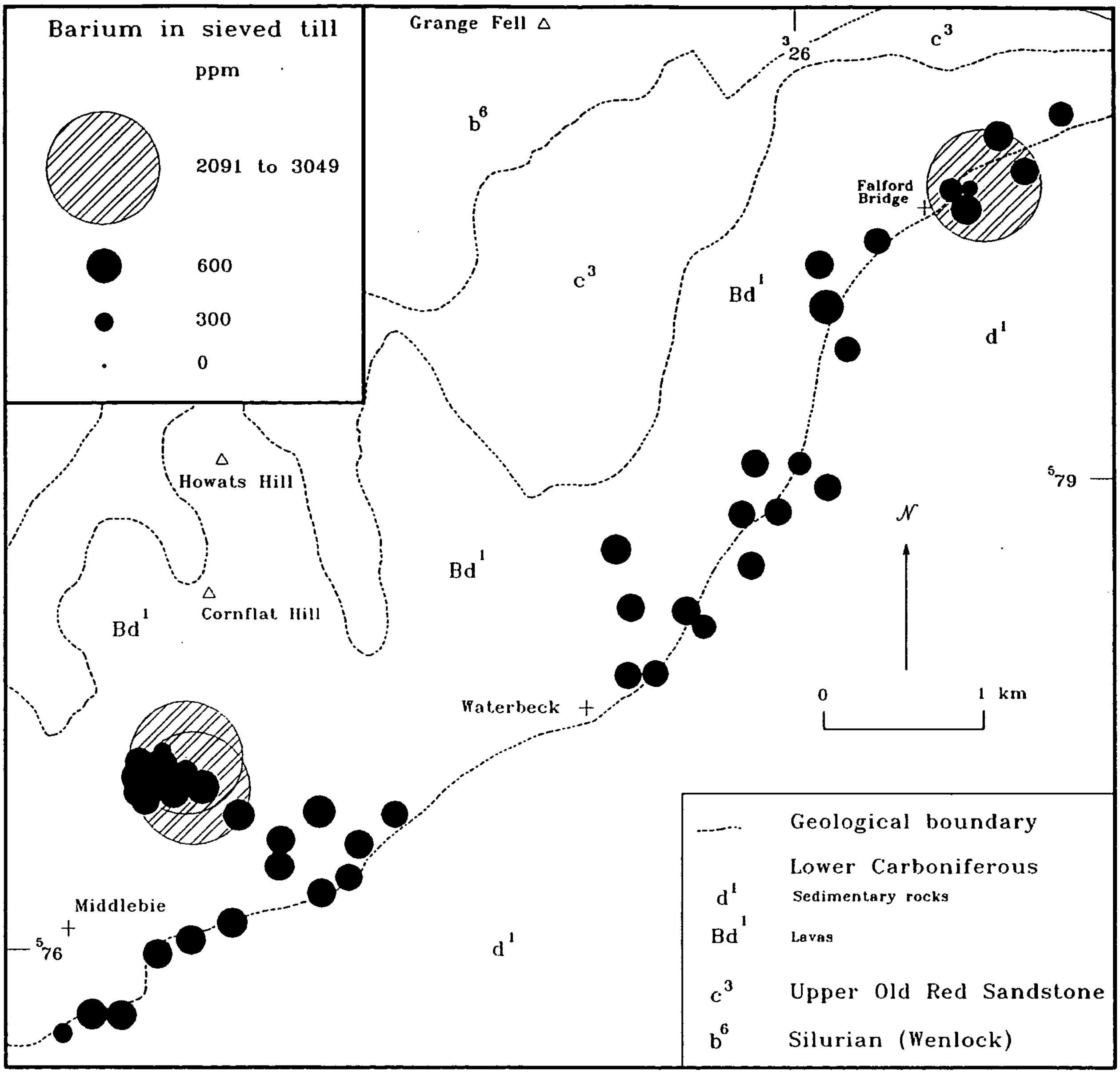


Figure 14 Barium in sieved tills

Compositionally the till over the Border Group sedimentary rocks is a very compact grey or grey-brown clay or silty clay, containing in the lower part of profiles, numerous large boulders and pebbles of mainly local provenance. Ice meltout deposits comprising thick lenses of sand and gravel overlying till were encountered south of the road between Waterbeck and Middlebie. A distinct colour change to darker brown or red-brown till coincident with a marked increase in the abundance of basalt clasts occurs over the Birrenswark lavas, although in the upper parts of profiles farther travelled material derived from the Silurian and Upper Old Red Sandstone to the north is common.

Most of the till concentrates collected over the Border Group sedimentary rocks are characterised by pale-coloured, sandy compositions containing a relatively small heavy mineral component (samples containing <10 % Fe_2O_{3t} in Table 5). Magnetite, zircon, hematite and rutile are the principal phases in decreasing order of abundance. Concentrate samples collected over the Birrenswark lavas are readily distinguished by their dark brown appearance, and a significantly higher proportion of iron ores and ferromagnesian minerals (samples containing >15 % Fe_2O_{3t} in Table 5).

Geochemical data for till samples

The geochemical data for panned and sieved tills are presented in Tables 5 and 6 respectively and the spatial distribution for Pb, Zn, Cu and Ba in the panned till shown in Figures 7 - 10, and sieved till in Figures 11 - 14. For conciseness in the text, results for the two sample types are differentiated by the subscripts u and t respectively after the symbol of the element concerned, for example Zn in panned till is abbreviated to Zn_u.

Three principal areas of coincident base-metal anomalies are evident near Falford Bridge, south-west of Waterbeck and in the Stoneybeck Burn catchment (Figures 7-14). At the north-eastern end of the area, near Falford Bridge, Pb shows strong enrichment in both the sieved and concentrate fractions (Pb_t = 1093 ppm and Pb_u = 844 ppm), together with modest enrichment of Zn, Cu and Ba (Tables 5 and 6) at a site located about 100 m south of the assumed lava-sediment boundary (BF 7804). Coarse grains of fresh sulphides noted in the panned concentrate were mineralogically confirmed as galena (with lesser amounts of pyrite, baryte and pyromorphite) (Tables 4a and 4b), indicating close proximity to a mineralised bedrock source. At a site situated about 800 m to the south-west (BF 7806) the concentrate sample contained high Pb (474 ppm) caused by galena and pyromorphite, although only background concentrations of Pb and other ore metals were recorded in the fine fraction.

Weak enhancement of Cu_u, Pb_u and Zn_u (Figures 7-9) was recorded from three additional auger holes (BF 7849, 7850, and 7851) drilled a short distance to the south-west of site BF 7804 in an attempt to define the extent of the base-metal anomaly. This pattern and the absence of high values in the fine-till fraction could be the result of a clastic dispersion train, either from a single relatively large mineralised source in the vicinity of BF 7804, or from a number of small localised occurrences.

The second, and most coherent anomalous base-metal zone extends more or less continuously from 1.3 km south-west of Waterbeck to the south of Middlebie, the intervening ground between Falford and Waterbeck containing only one or two scattered high Ba_u values (Figure 10). Within the anomalous zone Cu_u, Pb_u and Zn_u show very similar patterns of enrichment, although individual values are of insufficient magnitude to indicate the presence of major suboutcropping mineralisation in the near vicinity. There are no discernible base-metal or Ba anomalies in the sieved till fraction, and little spatial variation of any consequence (Figures 11-14). These results indicate a low degree of dispersion by chemical weathering, probably because of the predominantly alkaline nature of the drift and the diluent effect of the clay-rich tills.

Mineralogical work identified fresh chalcopyrite, galena, baryte and pyrite from a sample (BFU 7823, Table 4a) located very close to the mapped lava-sediment junction, but no sphalerite was seen either in this or in other samples containing anomalous Zn_u values. Highly altered and brecciated lavas close to faulted lava-sediment contacts in the Westwater district, 2 km east of the project area, contain a major proportion of their anomalous Zn and Pb content in the Fe-oxide (mainly hematite) constituents of the rock (Gallagher et al., 1977), suggesting that primary sulphides which are occasionally observed in dolomitic veins and breccias in less altered lavas, may have undergone oxidation and localised redistribution.

Many of the base-metal anomalies are accompanied by very high Ba_u values, several in excess of 1%, reflecting the presence of appreciable amounts of coarse baryte. Since relatively abundant baryte (and Ba_u anomalies) was also noted in some samples (e.g. BFU 7826 and 7848) with no corresponding base-metal anomaly, it is likely that additional sources of baryte mineralisation, not associated with sulphides, also exist within this zone. The style of mineralisation is probably similar to the vein and vesicle-filling baryte occurrences reported from the faulted margin of the Birrenswark lavas in the Westwater and Newcastleton districts (Gallagher et al., 1977; Smith and Walker, 1996).

A brief follow-up investigation of the drainage anomalies in the Stoneybeck Burn catchment was undertaken involving close interval overburden sampling at 15 sites spaced approximately 100 m north-south and 200 m east-west. The results, (sample sites BF 7829-42, Tables 5 and 6) reveal the highest combined concentrations of Cu_u, Pb_u and Zn_u so far reported in panned tills from the Solway-Northumberland Basin and clearly identify suboutcropping mineralisation near two adjacent sites (BFU 7834 and 7835), about 200 m east of Stoneybeck Burn. These occur immediately east of the upstream cut-off in anomalous Pb_p values and undoubtedly represent a major contribution to the persistant downstream dispersion of Pb over at least 800 m of stream section. Mineralogical examination of BFU 7835 identified moderately abundant galena and larger amounts of bright green pyromorphite, mainly in the -500µm fraction (Table 4a and 4b). Although the majority of till clasts are composed of basalt, several of the highly anomalous samples also contained substantial amounts of sedimentary material including sandstone and siltstone. It is therefore possible that the lavas are locally intercalated with sedimentary rocks as observed in several of the MRP diamond drill holes into the lavas near Westwater (Gallagher et al., 1977).

About 250 m due west, additional sources of mineralisation are indicated by substantial Pb_u, and Zn_u, anomalies at two adjacent sites (BF 7838 and 7839). The presence of As and Sb anomalies associated with high Pb and Ni is evident in several of the follow-up till concentrates (e.g. 7830 and 7839), confirming that the high levels of these elements recorded in drainage concentrates (Tables 2 and 3) from the Stoneybeck Burn, Middlebie Burn and West Gill catchments, are the result of mineralisation rather than contamination. This element association is considered to be indicative of hydrothermal alteration, a phenonema not hitherto recognised in MRP surveys over other parts of the Birrenswark lavas. In this context it is interesting to note that gold was observed in all of the anomalous Pb-As-Sb catchments, strongly suggesting a common source of sulphides and precious metal mineralisation within the lavas.

MINERAL OCCURRENCES AND ROCK GEOCHEMISTRY

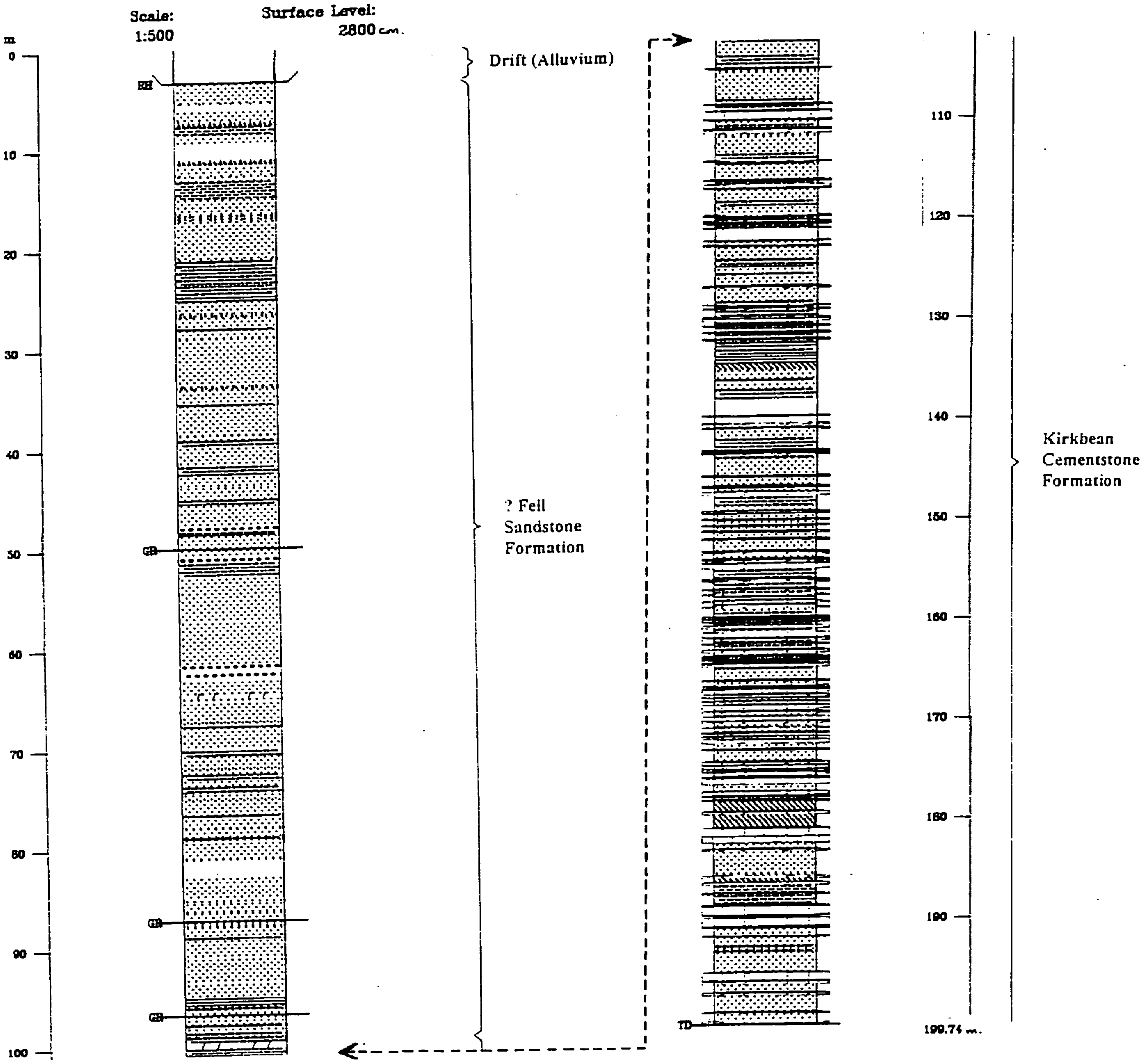
There is no history of metalliferous mining and only one recorded occurrence of mineralisation within the project area. The latter is represented by a reference to an 'Old Mine (Copper)' on the original, 1874, six inch to one mile geological field slip (sheet 52) at Old Torbeckhill [323400 579242]. A visit to the site revealed an unsuccessful exploration adit extending for about 10 m into Birrenswark lavas on the steep eastern side of Mein Water. A little minor haematisation and a few bright green patches of chloritic material was noted in the roof of the adit, but otherwise the lava appeared to be relatively unaltered and unmineralised. A sample (BFR 7915, Table 8) from the portal contained only slightly elevated Cu and Zn values, and from the low tenor of Cu_p in Mein Water downstream of the adit, a major source of Cu-mineralisation within the catchment is considered unlikely.

Detailed inspection of available outcrop and float material was routinely undertaken during the drainage survey leading to the collection of a further 14 samples (12 stream boulders and 2 outcrop samples) which showed evidence of either alteration, veining or possible mineralisation. The samples were analysed by X-ray fluorescence (XRF) for the same range of elements as the drainage and till samples (see Sample Preparation and Analysis, p 3). Geochemical data for the rock samples are presented in Table 8 and petrographic notes for two samples of basalt, based on the inspection of polished thin sections, are given in the Appendix.

The analytical data indicates that the carbonate veining seen in 4 stream clast samples of Border Group sedimentary rocks, are essentially barren of base-metals. All except two of the 11 basalt samples however, contain moderately anomalous concentrations of one or more metalliferous elements (Cu, Pb, Zn, Ba, Ni, As, Sb). They also exhibit strong pervasive alteration to clay/chlorite with patches and veins of carbonate and hydrothermal quartz, and show various shades of red and brown colouration due to secondary iron oxide formation.

Several basalt samples also contain massive patches and vesicle infillings of fine-grained, vivid green chlorite, which can easily be mis-identified in the field as copper secondary minerals (BFR 7910, 7914 and 7915, Table 8). In contrast to the drainage and till data, in which the concentration of Pb and Cu generally exceeds that of Zn, several of the basalts contain relatively high Zn, probably due to adsorption by chlorite and hematite. Apart from pyrite, seen in a sample of carbonate-veined basalt (BFR 7911), no sulphides were observed in hand specimen or thin section. This again may be accounted for by the intense alteration, particularly apparent in the highly amygdaloidal basalts, in which sulphide minerals are unlikely to survive oxidation. All of the 'mineralised' samples were collected in Stoneybeck or Middlebie burns, and BFR 7904 containing the highest Pb content of this suite of rocks, was a sample from a large angular boulder collected 400 m upstream from the northernmost Pb_p anomaly. An unusual rock type encountered in several large boulders in the lower reaches of Middlebie Burn (BFR 7912), had the appearance in the field of a strongly reddened glassy basalt. Thin section examination (Appendix) however, revealed the main component to be an iron-stained micritic carbonate containing basalt clasts and a network of microfissures filled with quartz. Although no sulphides were seen, the analytical data suggests the presence of Zn mineralisation (1422 ppm Zn).

In summary it is evident that the basalts are, at least locally, highly altered. They are associated with a broad zone of baryte and sulphide mineralisation, and possibly also with gold mineralisation, extending over a potential strike length of about 1 km. Assessment of both the style of mineralisation and its economic significance in the most prospective area between Stoneybeck Burn and Middlebie Burn would require drilling because of the lack of outcrop in proximity to the major drainage and till anomalies.



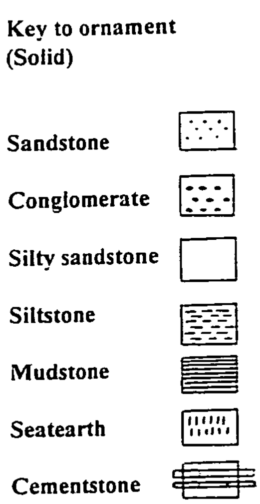


Figure 15 Summary lithological log of the Hoddom No. 2 Borehole core (NY17SE BJ)

Hoddom borehole core analysis

A summary lithological log of the Hoddom No. 2 borehole core, drilled in 1994 at Hoddom Bridge, about 2 km south-west of the the project area, is presented for the first time in this report (Figure 15). A brief inspection of the core for the presence of ore minerals revealed an essentially barren sequence of Lower Carboniferous sedimentary rocks apart from a few weak disseminations of pyrite within mainly dark, fine-grained sandstones and siltstones. The most economically interesting feature of the core is the presence of gypsum-anhydrite in veins, breccias and massive beds, most strongly developed over the lowermost 100 m of the hole (see section, *Gypsum - anhydrite development in the Hoddom No.2 Borehole (NY17SE/3))*. Comparable thicknesses of anhydrite in the lower sections of the 1200 m deep Easton 1 borehole, 10 km west of Bewcastle, suggest the widespread development of an evaporitic facies in the Solway-Northumberland basin (Colman et al., 1995).

Analytical data for 12 samples of split core taken from the most promising intersections of carbonate-veined cementstone, iron sulphide enriched siltstones/sandstones/cementstones and gypsum-anhydrite veins/breccias in the Hoddom borehole confirm the absence of base-metal mineralisation (Table 9). Uniformly low metal values of the carbonate-veined cementstones contrast with lithologically similar rocks in the Langholm and Newcastleton areas which frequently contain weak, but widespread sphalerite-pyrite (± galena) in carbonate veins (Gallagher et al., 1977; Smith et al., 1996; Smith and Walker, 1996). However, primary dispersion haloes of base-metals are often very restricted, around MVT (Mississippi Valley Type) deposits, where ore metal concentrations typically decrease to background levels over distances of only 10's to 100's of centimetres (Jones, 1988).

Several major Pb-Zn deposits including the major MVT Pine Point deposits (Thiede and Cameron, 1978) are associated with underlying evaporitic sequences or, in the case of the Gays River deposit, with an overlying evaporitic seal or cap rock (Ravenhurst et al., 1989). Thus the existence of a substantial thickness of evaporites in the Solway-Northumberland Basin could provide a highly soluble and potentially permeable medium for metalliferous fluids migrating up deep syn-sedimentary faults, such as the Waterbeck Fault, or at higher levels, provide an effective seal to fluid expulsion.

CONCLUSIONS AND RECOMMENDATIONS

1. Drainage panned concentrate data indicate a substantial zone of coherent Cu-Pb-Ba (and minor Zn) anomalies over the Birrenswark Volcanic Formation in the Stoneybeck Burn, Middlebie Burn and West Gill catchments. A second anomalous group is apparent close to the Silurian-Upper Old Red Sandstone boundary in Darlawhill Grain associated with a haematised fault breccia. Other, more scattered anomalies occur in the vicinity of the lava-sediment boundary or related to cementstones to the south-west of Ecclefechan.

2. The geochemical data for Pb, and to a lesser extent Cu and Sb, are affected by extensive and widespread contamination. Where very extensive contamination is present, such as in the lower reaches of Middlebie Burn, detailed mineralogical examination was necessary to discriminate contaminant grains from ore mineral phases in the drainage concentrates.

3. Major Pb_p anomalies in Stoneybeck Burn are caused by abundant bright green pyromorphite and small amounts of galena accompanied by coarse baryte, chalcopyrite, and hematite. The anomaly dispersion train can be traced over at least 1.8 km of the stream section with maximum values located about 1 km north of the inferred lava-sediment contact.

4. Gold grains and coincident As, Sb anomalies were identified at 13 sites mostly associated with, or dispersed a short distance downstream of, those containing base-metal anomalies.

5. Because of the thickness and almost continous cover of glacial deposits, follow-up investigations relied mainly upon deep overburden sampling. Reconnaissance-scale sampling along the lava-sediment boundary identified sources of base-metal and baryte mineralisation beneath drift in the area east of Falford Bridge, and over a 1.5 km strike-parallel zone between Stoneybeck Burn and west of Middlebie village. Close interval sampling around the major Pb anomaly in Stoneybeck Burn yielded major coincident Cu, Pb concentrations at levels far in excess of those so far reported from recent MRP surveys at the northern basin margin (Gallagher et al., 1977; Smith et al., 1996; Smith and Walker, 1996). Enhanced As, Sb values are also associated with the highest Pb, Zn concentrations on the west side of Stoneybeck Burn, indicating a possible genetic association between gold and base-metal mineralisation.

6. The prospectivity of the northern basin margin is enhanced by the recent discovery of a thick evaporite sequence in the Hoddom borehole. Although no associated base-metal enrichment was detected, drilling was terminated within the anhydrite-bearing rocks and consequently their true thickness and the composition of the underlying sedimentary sequence is not known.

7. On the basis of the very encouraging geochemical data, further deep overburden sampling is merited to the south-west, over the remaining 9 km of lava-sediment suboutcrop between Ecclefechan and Dalton [3115 5740]. Diamond drilling to investigate the bedrock source of the principal overburden anomalies is also recommended.

ACKNOWLEDGEMENTS

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APPENDIX Petrographic notes on two polished thin sections from the Middlebie area.

1) Sample BFR7911

Olivine-basalt, sparsely porphyritic, with euhedral olivine phenocrysts (<=2 mm) and tabular plagioclase microphenocrysts, hosted in holocrystalline groundmass rich in slender tabular plagioclase crystals. The matrix of the groundmass is subopaque due to alteration and the formation of hematite, minute grains of which are apparent under reflected light. The olivine crystals have been completely replaced by pseudomorphs consisting of very fine-grained green chlorite, crystals of carbonate and, in many cases, slender rims of possible prehnite.

The rock is highly vesicular. Vesicles range from <1 mm to several mm in size, including irregular vesicular fissures which traverse the thin section. Vesicles are occupied by amygdaloidal fills which in many cases consists of a fine-grained polygonal carbonate mosaic, while other examples consist of 'clay' margins surrounding a central pocket of carbonate mosaic, or contain massive patches of very fine-grained vivid green chlorite with opaque microgranules. However, across the centre of the thin section runs a fissure filled by fine- to very fine-grained quartz mosaic which hosts in its margins patches of iron-stained rhombic carbonate as well as isolated patches of chlorite.

No sulphide or other ore minerals were seen in the thin section.

2) Sample BFR7912

Micritic carbonate rock in which clasts of pumiceous olivine-basalt are embedded.

The main component of the micrite is the massive, very fine-grained carbonate component. However, this hosts numerous 1-3 mm pockets of cherty quartz, very fine-grained (almost cryptogranular) or forming a <0.2 mm grain-size polygonal mosaic. The cherty quartz itself hosts isolated iron-stained rhombic carbonate crystals <=0.1 mm in size (possibly ankerite or siderite), and similar rhombic carbonate also forms fringes surrounding the silica pockets. In addition, the host micrite contains, in some areas, a network of delicate intercommunicating microfissures filled by more cherty quartz. Traces of dark "smudgy" staining of the micrite and of opaque coatings to some carbonate rhombs may indicate the presence of relict hydrocarbon in the rock.

The basalt clasts vary from c 0.2 mm in size to one several mm wide which forms almost half of the thin section. They appear to be unbroken fragments which may have become incorporated by simply dropping as pyroclastic particles into the unconsolidated lime mud. They now consist of an opaque glassy basalt groundmass surrounding innumerable ovoid vesicles up to mm scale in size, filled by cherty very fine-grained quartz and very fine-grained brown iron-stained carbonate. The groundmass appears brick red to the naked eye, and under reflected light numerous hematite-like grains are clearly present.

No sulphide or other ore minerals were found in the thin section.

Table 2 Ecclefechan Panned Concentrate Data (Reconnaissance Survey, 1976)

Sample Ref. No.	Easting	Northing	Cu (ppm)	Pb (ppm)	Zn (ppm)	Ba (ppm)	Ni (ppm)	As (ppm)	Sn (ppm)	Sb (ppm)	Fe_2O_3t (ppm)
BFP2017	326820	579780	54	39	164	1241	40	nd	6	0	13.82
BFP2018	326780	579820	68	102	122	827	81	nd	14	0	19.17
BFP2366	327600	581980	10	14	48	207	27	nd	1	11	6.43
BFP2590	320430	579020	12	18	53	429	38	nd	0	4	8.94
BFP2591	320630	579110	13	14	79	221	50	nd	4	8	6.35
BFP2592	321210	578800	29	8	107	394	40	nd	1	0	6.69
BFP2593	320790	578700	9	12	58	698	31	nd	0	4	6.88
BFP2608	325200	580780	8	26	43	228	31	nd	42	4	7.19
BFP2610	325690	580130	35	65	73	398	32	nd	35	6	9.72
BFP2611	325240	579880	9	7	39	207	18	nd	7	4	4.10
BFP2613	324510	579600	0	17	17	255	9	nd	1	0	4.65
BFP2614	324760	577990	66	152	95	2197	46	nd	2	6	24.18
BFP2615	324610	578440	9	23	30	654	23	nd	1	0	7.23
BFP2616	324660	578490	0	106	151	1737	60	nd	8	15	36.26
BFP2617	324150	579330	0	17	39	2339	24	nd	8	9	10.52
BFP2618	323960	579730	22	14	82	2784	20	nd	3	8	9.22
BFP2619	324090	580360	12	17	69	1845	35	nd	0	5	6.99
BFP2620	324030	580880	4	0	89	148906	27	nd	0	0	2.13
BFP2621	322870	579350	25	0	37	1299	11	nd	1	2	3.82
BFP2622	323090	579100	17	12	31	706	14	nd	2	3	7.43
BFP2623	321310	578710	204	143	208	18425	41	nd	1	3	10.87
BFP2624	321650	579460	36	21	75	456	33	nd	2	3	8.92
BFP2625	321510	579630	216	68	166	3837	52	nd	0	6	11.58
BFP2626	321090	579610	9	11	75	461	32	nd	0	3	5.38
BFP2627	321190	579050	15	3	398	303	22	nd	0	0	3.86
BFP2634	318840	577170	0	106	123	281	40	nd	11	9	20.95
BFP2635	318070	577090	0	15	58	150	16	nd	8	6	6.21
BFP2636	318410	576520	3	24	42	186	15	nd	0	1	6.05
BFP2648	319700	579610	25	11	66	3672	53	nd	1	0	7.59
BFP2649	319290	579520	9	11	40	280	36	nd	3	8	6.58
BFP2658	326800	579470	66	53	81	545	45	nd	14	0	10.67
BFP2659	327300	578600	0	30	88	573	23	nd	2	0	4.89
BFP2660	327380	578210	15	40	105	153	28	nd	18	5	9.84
BFP2661	326680	578320	49	45	84	474	42	nd	27	3	10.28
BFP2662	326220	578680	9	47	50	278	30	nd	22	5	6.85
BFP2663	326040	579440	10	17	59	247	42	nd	3	0	5.99
BFP2665	323420	577880	15	28	46	662	26	nd	4	6	11.57
BFP2666	323300	578300	50	15	39	1535	23	nd	4	5	11.04
BFP2667	323240	578610	6	18	46	1049	31	nd	0	8	9.89
BFP2668	323280	577570	8	10	34	229	28	nd	0	0	6.03
BFP2669	322060	577050	8	3061	99	1164	43	nd	1	7	20.46
BFP2670	322000	577280	7	58	91	1024	49	nd	42	4	17.23
BFP2671	322060	577610	38	50	87	4807	44	nd	3	4	10.41
BFP2672	322040	577890	10	19	66	438	38	nd	1	2	7.29
BFP2673	322050	578240	1	31	51	706	29	nd	3	0	11.07
BFP2674	321900	575840	4	47	42	648	29	nd	10	5	13.94
BFP2675	322010	575280	6	155	120	1840	64	nd	16	19	44.29
BFP2676	322360	575230	7	27	38	383	27	nd	2	2	9.32

Table 2 Continued

Sample Ref. No.	Easting	Northing	Cu (ppm)	Pb (ppm)	Zn (ppm)	Ba (ppm)	Ni (ppm)	As (ppm)	Sn (ppm)	Sb (ppm)	Fe_2O_3t (ppm)
BFP2677	322950	575510	16	64	66	806	36	nd	4	0	16.79
BFP2679	323120	576340	29	47	64	1738	39	nd	0	3	18.14
BFP2680	323420	576660	29	73	100	2039	50	nd	26	7	24.02
BFP2681	323550	577020	8	242	34	338	24	nd	0	9	8.86
BFP2682	319620	578570	12	12	47	753	32	nd	1	0	5.56
BFP2683	319840	578100	13	21	55	435	39	nd	8	1	5.98
BFP2684	319900	577600	8	9	48	854	34	nd	0	7	4.90
BFP2685	320080	577020	10	34	49	2287	33	nd	9	3	9.21
BFP2686	320160	577040	11	19	40	1597	34	nd	0	4	8.56
BFP2687	320100	576380	0	188	175	3435	82	nd	10	19	43.84
BFP2694	322210	581610	28	46	95	554	33	nd	12	2	5.78
BFP2715	327900	578450	0	13	99	91	22	nd	0	6	10.79
BFP2716	327600	578840	8	6	0	33	4	nd	0	3	2.39
BFP2717	327120	578980	70	1850	385	494	45	nd	188	16	27.88
BFP2772	323390	578110	20	80	62	1395	29	nd	2	7	18.90
BFP2843	323060	580360	39	37	83	465	59	nd	31	6	9.62
BFP2844	322840	580410	46	26	104	905	45	nd	2	4	7.63
BFP2845	322600	580730	3	7	15	100	11	nd	0	0	2.37
BFP2846	322580	580690	100	60	70	2362	49	nd	10	4	8.65
BFP4995	321500	579920	44	6	81	358	29	nd	0	0	4.85
BFP4996	321500	579750	108	18	95	577	31	nd	0	2	7.04
BFP4997	321540	579520	230	271	176	3928	36	nd	4	11	11.73
BFP4998	321540	579270	371	772	218	4785	44	nd	1	15	20.79
BFP4999	321500	579100	301	68	249	4823	41	nd	9	4	14.61
BFP5000	321430	578900	112	179	101	13021	36	nd	0	0	11.27

Table 3 Ecclefechan Panned Concentrate Data (Follow-up Survey, 1995)

Sample Ref. No.	Easting	Northing	Cu (ppm)	Pb (ppm)	Zn (ppm)	Ba (ppm)	Ni (ppm)	As (ppm)	Sn (ppm)	Sb (ppm)	Fe_2O_3t (ppm)
BFP7701	322205	576802	686	1700	192	3835	79	89	25	15	55.89
BFP7702	322080	576915	37	4300	189	6000	68	40	101	17	41.53
BFP7703	322080	577000	35	668	167	1272	71	64	14	10	34.90
BFP7704	322020	577280	47	271	216	8900	78	50	24	<5	40.08
BFP7705	322100	577460	58	113	163	10900	67	37	18	<5	29.53
BFP7706	322045	577360	40	101	250	30900	59	43	10	6	32.28
BFP7707	322080	577575	20	58	115	2813	32	28	<5	<5	15.86
BFP7708	322040	577860	35	49	81	3226	38	15	6	<5	20.59
BFP7709	322020	57850	79	62	81	7500	34	17	6	<5	21.61
BFP7710	322035	578475	31	41	46	769	23	21	23	<5	7.23
BFP7711	322355	576712	34	519	174	1018	72	53	35	12	42.10
BFP7712	322470	576585	40	555	227	3451	75	96	73	16	54.26
BFP7713	322610	576458	27	292	122	837	55	46	23	14	32.02
BFP7714	322795	576260	40	249	262	4619	90	133	31	16	52.15
BFP7715	323050	576160	51	208	275	1789	86	114	8	14	49.49
BFP7716	325440	578420	53	77	71	632	44	41	8	5	21.78
BFP7717	325430	578700	801	1900	111	1715	50	44	87	41	25.08
BFP7718	325360	579020	144	33	64	460	28	22	<5	<5	11.92
BFP7719	325359	579361	14	29	57	185	41	39	<5	<5	11.27
BFP7720	325245	579392	20	13	45	351	32	9	<5	<5	6.40
BFP7721	323105	576160	10	70	236	504	31	17	39	<5	12.32
BFP7722	323260	576415	43	95	69	1278	37	23	8	<5	13.64
BFP7723	323320	576580	158	190	209	3606	78	104	24	15	39.62
BFP7724	321365	575400	104	564	112	449	68	51	90	8	32.20
BFP7725	321960	575443	62	329	202	2948	100	147	22	18	58.82
BFP7726	321830	575665	73	587	203	916	77	124	265	15	53.60
BFP7727	321910	575740	31	205	116	1678	52	45	25	9	28.64
BFP7728	321805	576005	61	648	172	8400	94	109	101	9	56.72
BFP7729	321460	576220	43	389	132	3739	66	81	33	11	36.13
BFP7730	322490	575190	59	337	186	3864	86	91	78	30	56.91
BFP7731	322970	575090	29	24	98	196	28	9	37	6	6.68
BFP7732	322880	575430	106	312	206	3267	99	89	26	14	51.45
BFP7733	322895	575490	39	154	120	702	56	43	9	7	29.64
BFP7734	322995	575632	27	77	108	1059	46	41	16	7	22.61
BFP7735	323085	575880	29	189	184	8500	71	99	15	15	37.37
BFP7736	321145	576690	124	284	156	15600	63	84	10	15	27.26
BFP7737	321475	576760	113	694	170	5084	72	93	148	15	41.74
BFP7738	321620	576617	116	424	200	2049	90	79	111	23	34.38
BFP7739	321605	576360	69	1600	206	30200	101	124	133	21	48.08
BFP7740	320458	575295	46	108	115	2410	72	57	16	<5	29.77
BFP7741	320343	575743	56	160	344	5005	87	139	28	23	48.81
BFP7742	318860	576805	13	49	65	484	25	10	<5	<5	9.76
BFP7743	318650	576520	30	34	64	624	37	7	<5	<5	9.01
BFP7744	318765	576180	24	75	97	546	48	40	8	6	28.15
BFP7745	318685	575975	31	56	73	341	44	42	<5	<5	21.43
BFP7746	318590	575825	23	109	102	454	43	22	<5	<5	17.91
BFP7747	318650	575505	69	122	150	581	46	37	21	<5	27.67
BFP7748	319145	575555	49	385	2373	891	54	58	22	<5	18.70

Table 3 Continued

Sample Ref. No.	Easting	Northing	Cu (ppm)	Pb (ppm)	Zn (ppm)	Ba (ppm)	Ni (ppm)	As (ppm)	Sn (ppm)	Sb (ppm)	Fe_2O_3t (ppm)
BFP7749	318700	574140	187	112	143	143	18	14	388	13	7.35
BFP7750	318860	574440	11	36	80	92	17	14	68	<5	6.35
BFP7751	318640	574580	23	64	79	153	22	19	3871	294	7.27
BFP7752	318405	574710	10	21	57	128	15	5	130	<5	3.05
BFP7753	318690	574830	17	120	198	91	30	14	206	<5	13.10
BFP7754	319040	574540	70	234	260	85	30	19	330	8	14.84
BFP7755	323260	578715	38	39	44	4110	30	43	<5	8	20.61
BFP7756	323215	578500	59	45	347	3398	49	30	89	7	19.41
BFP7757	323325	578190	11	14	46	424	25	15	<5	<5	5.54
BFP7758	323420	577890	11	32	50	1027	26	18	8	<5	10.07
BFP7759	323480	577300	20	29	48	473	23	16	5	<5	8.55
BFP7760	323245	577620	23	55	62	469	34	16	15	<5	17.58
BFP7761	323500	577595	12	27	51	546	27	16	43	<5	8.87

Table 4a Electron microprobe identification of selected grains in panned tills (BFU) and panned concentrates (BFP), from the Ecclefechan area

Sample No	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
BFU7804	Pyro	Pyro	Pyro (Ca)	Gal	Gal	Bar	Bar										
BFU7806	Gal	Gal	Vanad	Pyro (Ca)	Py	**Copper**	Py	Pyro	Rut	Sil	Sil	Sil	Ortho	Ortho	Pyrox	Titanite	Gal
BFU7821	Alum	Bar	Bar	Rut	Py	Py	Chalco	Rut	Rut	Chlor	Amph	Rut					
BFU7823	Gal	Gal	Gal	Bar	Bar	Py	Py	Py+Cu	Chalco	Chalco	Sil	Sil	Chalco				
BFU7835	Gal	Gal	Pyro (Ca)	Pyro (Ca)	Bar	Qtz/Ortho	Gal	Gal	Gal	Sil	Sil	Sil	Sil	Sil	Sil		
BFP7701	Bar	Bar	Calcite	Pyro (Ca)	Pyro	Pyro	Sil	Sil	Sil								
BFP7702	Qtz	Qtz	Pyro	Pyro	Titanite	Pyro	Pyro	Qtz	Siderite	Topaz	Sil	Pyrox	Sil				
BFP7711	Pyro	Pyro	Bar	Pyro (Ca)	Siderite	Sil	Chlor	Gal									
BFP7713	Qtz	Qtz	Pyro (Ca)	Pyro	Dol	Dol	Dol	Qtz	Sil	Pyrox	Pyrox	Sil					
BFP7724	Rut	Sil	Sil	Sil	Sil	Plag											
BFP7726	Py	Py	Pyro (Ca)	Pyrox	Pyrox	Pyrox	Bar										
BFP7727	Qtz	Gal	**Pb,Sn**	Bar	Bar	Topaz	Gal	Rut	Pyrox	Sil	Sil	Qtz					
BFP7728	Pyro (Ca)	Bar	Bar	Gal	Qtz	Chlor	Chlor	Gal									
BFP7730	Pyro	Pyro	Pyro	Bar	Bar	Qtz	Rut	Chlor	Chlor								
BFP7735	Sphal	Qtz	Py	Bar	Dol/Pyrox	Rut	Chalco	Chlor	Chlor	**P,Ag,Ca**							
BFP7748	Py	Py	Bar	Bar	Gal	Gal	Gal	Gal	Sphal	Sphal	Sphal	Py	Chlor	Chlor			
BFP7749	?Chlor	Chlor	**Cu,S ?O**	**CuS**	Py	Py	**Cu-ox**	**Cu-ox**	**Pb,Sn,Ca**	Chlor	Albite						

Pyro=Pyromorphite	Cu-ox=Copper oxide
Gal=Galena	Sil=Silicate
Bar=Baryte	Dol=Dolomite
Sphal=Sphalerite	Qtz=Quartz
Py=Pyrite	Rut=Rutile
Chalco=Chalcopyrite	Pyrox=Pyroxene
Vanad=Vanadinite	Chlor=Chlorite

Probable contaminants in bold text

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Table 4b Mineralogical Examination of -500μm and +500μm superpanned fraction of heavy mineral concentrates prepared from panned till (BFU) and panned stream sediment (BFP)

	-500μm						+500μm					
Sample No	Barite	Chalco.	Sphalerite	Galena	Other	Contaminants	Barite	Chalco.	Sphalerite	Galena	Other	Contaminants
BFU7804	Abun		Mod (small)	Several	Mod pyromorphite		2			1		
BFU7806				Few	Sev pyrite+pyromor.	Cu shard						
BFU7821	Abun						Several					
BFU7823	Abun	Few		Few	Sev pyrite		Mod				Sev. pyrite	
BFU7835	Mod			Mod	Abun pyromorphite							
BFP7701	Abun				Abun pyromorphite	Pb shot	Abun					
BFP7702	Abun				Abun pyromorphite	Pb metal	Several					
BFP7711	Mod				Mod pyromorphite		Abun					
BFP7713	Mod				Few pyromorphite							Pb metal
BFP7724						Pb metal	Mod					Pb metal
BFP7726						Pb metal						
BFP7727	Mod		1	1	1 pyrite		Mod					
BFP7728	Mod					Pb metal	Mod			1 (cerussitised)		
BFP7730	Mod				Few pyromorphite	Pb metal	Mod					
BFP7735	Mod											
BFP7748	Mod		Few	Few			Mod		Mod			
BFP7749	Mod	Few					Mod	1			1	

Estimated number of grains
Abun = >100
Mod = 20-100
Few = up to 20
Several = 3 to 10

Table 5 Ecclefechan Panned Till Data

Sample Ref. No.	Easting	Northing	Depth (metres)	Cu (ppm)	Pb (ppm)	Zn (ppm)	Ba (ppm)	Ni (ppm)	As (ppm)	Sn (ppm)	Sb (ppm)	Fe_2O_{3t} %
BFU7801	327670	581320	3.00	45	35	79	185	59	31	<5	8	13.81
BFU7802	327280	581180	4.00	70	32	67	275	53	26	<5	<5	11.2
BFU7803	327445	580955	2.00	50	40	71	264	53	29	<5	<5	14.08
BFU7804	327190	580865	3.00	112	844	379	9300	161	33	12	<5	28.72
BFU7805	326160	580360	4.50	53	71	141	222	83	19	<5	<5	14.31
BFU7806	326520	580510	2.00	15	474	78	45	32	30	11	11	19.8
BFU7807	326204	580090	3.80	34	33	69	3594	45	15	<5	<5	6.93
BFU7808	326335	579820	4.10	66	69	97	228	65	22	<5	<5	18.22
BFU7809	326210	578945	3.10	49	66	87	193	47	14	<5	<5	9.7
BFU7810	326035	579100	1.80	20	72	50	167	35	9	<5	<5	6.46
BFU7811	325755	579100	3.50	15	37	53	247	32	19	<5	<5	8.59
BFU7812	325900	578790	4.50	17	125	46	260	28	8	6	<5	4.42
BFU7813	325730	578450	3.60	46	50	77	626	42	25	7	<5	14.24
BFU7814	325670	578775	3.20	36	37	78	716	46	16	<5	<5	10.54
BFU7815	325430	578060	4.20	37	60	115	47	49	24	<5	<5	20.44
BFU7816	325320	578160	6.00	28	53	90	6600	48	21	5	6	17.32
BFU7817	325125	577760	3.50	46	52	69	321	38	13	6	<5	10.58
BFU7818	324874	578550	6.80	21	62	55	1110	40	14	5	<5	12.68
BFU7819	324968	578180	4.00	25	39	71	258	48	13	<5	<5	10.04
BFU7820	324949	577748	4.40	51	34	63	1072	42	18	<5	7	9.51
BFU7821	323015	576880	3.60	48	310	225	2634	114	117	10	14	35.31
BFU7822	323262	576672	9.00	109	247	182	17600	57	41	9	<5	25.08
BFU7823	323487	576864	10.50	310	280	217	8400	56	21	<5	<5	10.55
BFU7824	322520	576858	2.90	37	50	92	750	52	21	<5	<5	15.92
BFU7825	322779	576700	5.40	107	177	175	9900	77	35	12	<5	28.17
BFU7826	322770	576530	5.40	68	98	99	4056	41	23	9	<5	17.06
BFU7827	323030	576360	5.50	77	94	147	10600	52	18	<5	5	16.84
BFU7828	323200	576460	11.50	109	178	204	11100	68	48	11	<5	29.82
BFU7829	322290	577038	4.50	30	110	230	308	155	26	12	12	34.5
BFU7830	322110	577000	4.50	24	808	132	333	65	60	5	29	43.75
BFU7831	322070	577090	6.60	43	102	154	124	70	38	8	9	32.63
BFU7832	322030	577180	2.90	59	77	556	50	120	41	9	12	50.49
BFU7833	322040	577265	2.70	40	32	220	307	164	9	7	<5	14.61
BFU7834	322185	577225	7.10	2759	296	664	10100	210	27	6	6	13.61
BFU7835	322185	577130	5.80	452	5100	1115	823	155	25	8	19	15.98
BFU7836	322230	577030	5.40	52	99	328	48200	187	26	6	<5	21.55
BFU7837	321890	577200	6.60	17	38	67	883	36	12	8	6	11.48
BFU7838	321930	577150	7.10	38	113	120	279	57	50	10	10	28.19
BFU7839	321880	577100	4.60	49	802	431	230	161	189	9	48	39.26
BFU7840	321930	577050	10.20	14	32	32	229	19	7	11	<5	10.94
BFU7841	321880	577000	3.20	20	82	69	92	39	22	7	8	22.78
BFU7842	321930	576950	3.60	32	59	68	204	55	13	<5	<5	17.95
BFU7843	322220	576060	4.70	44	45	114	7600	44	17	<5	6	11.41
BFU7844	322480	576170	5.50	122	140	182	31000	69	43	9	7	20.74
BFU7845	322010	575970	1.80	32	35	89	472	43	13	<5	<5	9.53
BFU7846	321595	575588	6.40	110	369	155	14200	105	51	9	<5	33.54
BFU7847	321408	575468	6.10	80	159	184	76	101	52	10	7	43.57
BFU7848	321780	575580	5.10	59	84	112	7200	57	24	9	<5	20

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Table 5 Continued

Sample Ref. No.	Easting	Northing	Depth (metres)	Cu (ppm)	Pb (ppm)	Zn (ppm)	Ba (ppm)	Ni (ppm)	As (ppm)	Sn (ppm)	Sb (ppm)	Fe_2O_{3t} %
BFU7849	327100	580847	2.80	87	39	279	50	178	10	9	8	25.49
BFU7850	326985	580838	3.70	110	33	102	37	194	17	10	9	31.3
BFU7851	327080	580712	2.60	88	182	180	50	128	31	6	<5	26.98
BFU7853	322230	577030	5.40	52	105	362	30300	215	23	13	5	22.96
BFU7854	321930	577150	7.10	14	38	61	282	32	18	9	<5	10.56
BFU7855	321880	577100	4.60	50	851	353	184	147	130	<5	36	37.14
BFU7856	321930	577050	10.20	30	46	55	171	19	28	<5	<5	15.31
BFU7857	321930	576950	3.60	17	25	54	208	37	6	<5	<5	7.33

Table 6 Ecclefechan Sieved Till Data

Sample Ref. No.	Easting	Northing	Depth (metres)	Cu (ppm)	Pb (ppm)	Zn (ppm)	Ba (ppm)	Ni (ppm)	As (ppm)	Sb (ppm)	MnO %	Fe_2O_{3t} %
BFT7801	327670	581320	3.00	32	19	87	411	72	8	<5	0.099	7.46
BFT7802	327280	581180	4.00	35	22	86	506	75	12	<5	0.087	7.34
BFT7803	327445	580955	2.00	37	22	95	466	91	9	<5	0.109	7.97
BFT7804	327190	580865	3.00	91	1093	776	2091	163	15	<5	0.129	10.84
BFT7805	326160	580360	4.50	39	25	123	485	84	6	<5	0.091	7.53
BFT7806	326520	580510	2.00	24	30	75	434	48	3	<5	0.026	5.45
BFT7807	326204	580090	3.80	38	31	94	593	81	10	<5	0.1	7.24
BFT7808	326335	579820	4.10	35	25	101	430	79	8	<5	0.09	7.34
BFT7809	326210	578945	3.10	35	39	106	460	76	9	<5	0.084	6.97
BFT7810	326035	579100	1.80	20	35	27	383	30	7	<5	0.031	3.69
BFT7811	325755	579100	3.50	31	36	105	473	69	10	<5	0.08	6.87
BFT7812	325900	578790	4.50	33	28	89	455	71	15	<5	0.079	6.90
BFT7813	325730	578450	3.60	31	24	86	469	65	9	<5	0.074	6.71
BFT7814	325670	578775	3.20	29	22	82	463	66	8	<5	0.068	6.78
BFT7815	325430	578060	4.20	28	22	67	402	52	10	<5	0.055	6.15
BFT7816	325320	578160	6.00	26	21	76	491	64	8	<5	0.095	6.82
BFT7817	325125	577760	3.50	26	22	77	446	58	10	<5	0.094	6.22
BFT7818	324874	578550	6.80	24	25	80	520	66	8	<5	0.091	6.95
BFT7819	324968	578180	4.00	34	24	103	484	78	9	<5	0.088	7.69
BFT7820	324949	577748	4.40	34	29	89	466	68	9	<5	0.082	6.85
BFT7821	323015	576880	3.60	38	24	89	556	82	16	<5	0.106	7.59
BFT7822	323262	576672	9.00	35	23	90	489	75	12	<5	0.09	7.33
BFT7823	323487	576864	10.50	45	21	75	454	70	13	<5	0.092	7.09
BFT7824	322520	576858	2.90	35	23	88	531	78	8	<5	0.096	7.57
BFT7825	322779	576700	5.40	32	22	83	480	71	10	<5	0.086	6.98
BFT7826	322770	576530	5.40	37	22	90	495	78	9	<5	0.089	7.44
BFT7827	323030	576360	5.50	35	21	85	490	72	9	<5	0.094	7.16
BFT7828	323200	576460	11.50	31	20	82	462	67	8	<5	0.091	6.78
BFT7829	322290	577038	4.50	40	94	141	591	111	15	<5	0.144	8.93
BFT7830	322110	577000	4.50	23	719	416	521	137	22	8	0.183	13.41
BFT7831	322070	577090	6.60	28	38	188	420	149	9	<5	0.11	10.10
BFT7832	322030	577180	2.90	61	44	421	544	137	16	<5	0.211	14.27
BFT7833	322040	577265	2.70	30	23	294	270	236	7	<5	0.214	11.80
BFT7834	322185	577225	7.10	1624	475	1714	3049	265	38	<5	0.964	14.59
BFT7835	322185	577130	5.80	1225	3200	3496	404	442	28	15	0.727	12.33
BFT7836	322230	577030	5.40	36	98	499	2963	251	15	<5	0.131	13.35
BFT7837	321890	577200	6.60	34	44	155	464	85	10	<5	0.046	7.41
BFT7838	321930	577150	7.10	17	19	50	477	34	8	<5	0.062	3.99
BFT7839	321880	577100	4.60	118	472	580	549	164	11	<5	0.217	9.97
BFT7840	321930	577050	10.20	11	14	38	474	28	9	<5	0.058	3.71
BFT7841	321880	577000	3.20	21	31	74	459	53	10	<5	0.141	5.98
BFT7842	321930	576950	3.60	23	17	68	487	64	8	<5	0.081	6.54
BFT7843	322220	576060	4.70	34	27	84	511	71	12	<5	0.092	7.23
BFT7844	322480	576170	5.50	36	21	79	518	71	8	<5	0.094	7.24
BFT7845	322010	575970	1.80	36	19	79	504	69	12	<5	0.077	7.23
BFT7846	321595	575588	6.40	40	25	112	526	88	12	<5	0.106	7.80
BFT7847	321408	575468	6.10	42	28	133	315	107	12	<5	0.063	9.19

Table 6 Continued

Sample Ref. No.	Easting	Northing	Depth (metres)	Cu (ppm)	Pb (ppm)	Zn (ppm)	Ba (ppm)	Ni (ppm)	As (ppm)	Sb (ppm)	MnO %	Fe_2O_{3t} %
BFT7848	321780	575580	5.10	38	25	90	508	81	10	<5	0.092	7.48
BFT7849	327100	580847	2.80	55	22	153	233	149	7	<5	0.079	10.99
BFT7850	326985	580838	3.70	54	22	121	378	133	6	<5	0.088	9.65
BFT7851	327080	580712	2.60	43	36	118	515	89	7	<5	0.077	8.00

Table 7 Ecclefechan Panned Concentrate Gold Observations

Sample Ref. No.	Easting	Northing	Number of Gold grains	Location	Lithostratigraphy
BFP4998	321540	579270	1	Darlawhill Grain	Silurian/UORS unconform.
BFP7711	322355	576712	1	Stoneybeck Burn	Birrenswark Lava Fmn.
BFP7713	322610	576458	1	Stoneybeck Burn	Birrenswark Lava Fmn.
BFP7725	321960	575443	2	Middlebie Burn	Border Gp Cementstones
BFP7726	321830	575665	1	Minor W trib. Middlebie Burn	Birrenswark Lava Fmn.
BFP7727	321910	575740	3	Middlebie Burn	Birrenswark Lava Fmn.
BFP7728	321805	576005	2	Middlebie Burn	Birrenswark Lava Fmn.
BFP7730	322490	575190	1	Lower Mein Water	Border Gp Cementstones
BFP7732	322880	575430	1	Lower Mein Water	Border Gp Cementstones
BFP7735	323085	575880	1	Lower Mein Water	Border Gp Cementstones
BFP7743	318650	576520	1	Upper Ecclefechan Burn	Birrenswark Lava Fmn.
BFP7744	318765	576180	1	Upper Ecclefechan Burn	Birrenswark Lava Fmn.
BFP7749	318700	574140	1	Small stream SW of Ecclefechan	Border Gp Cementstones

Table 8 Ecclefechan Surface Rock Data

Sample Ref. No.	Easting	Northing	Rock Type/Samp Typ.	Mineralisation Style	Minerals	Cu ppm	Pb ppm	Zn ppm	Ba ppm	Ni ppm	As ppm	Sb ppm	Fe2O3t %	MnO %
BFR7904	322120	577880	Basalt/clast	Vein	Carbonate, Hematite	10	401	781	195	32	16	17	7.06	0.406
BFR7905	325415	578710	Sandstone/clast	Vein	Carbonate, Hematite	11	4	47	1795	5	<5	<5	2.21	0.224
BFR7906	325480	578385	Cementstone/clast	Vein	Carbonate	30	<3	18	239	16	<5	<5	5.76	0.303
BFR7907	325420	578520	Siltstone/clast	Vein	Carbonate	17	9	35	91	33	7	<5	7.23	0.382
BFR7908	321475	576760	Basalt/clast	Vein	Carbonate	9	37	308	192	59	<5	<5	4.42	0.328
BFR7909	321981	575365	Basalt/clast	Dissem.	Carbonate	16	28	82	119	27	8	<5	6.59	0.356
BFR7910	321981	575365	Basalt/clast	Dissem.	Copper secondaries?	51	22	104	445	237	21	<5	8.68	0.462
BFR7911	321981	575365	Basalt/clast	Vein	Carbonate, Pyrite, Hematite	802	144	385	1978	106	37	<5	8.03	0.304
BFR7912	321948	575443	(Micrite+basalt)/clast	Vein/Breccia	Hematite, Quartz, Carbonate	15	19	1422	152	20	6	<5	4.59	0.447
BFR7913	321365	575395	Siltstone/clast	Vein	Carbonate	18	9	49	195	36	<5	<5	5.06	0.139
BFR7914	321605	576360	Basalt/clast	Dissem.	Malachite	7	25	87	126	97	5	<5	14.06	0.119
BFR7915	323400	579242	Basalt/in situ	Dissem.	Malachite, Hematite	62	38	230	186	133	7	<5	11.46	0.167
BFR7916	322218	576798	(Vn. qtz.+ basalt)/clast	Vein	Hematite	5	5	5	25	3	<5	7	0.51	0.011
BFR7917	322218	576798	Basalt/in situ	Pod	Carbonate/?Baryte	29	86	229	274	347	15	<5	14.34	0.064
BFR7918	322224	576760	Basalt/in situ	Vein	Hematite	11	18	1297	206	33	<5	<5	5.55	0.408

Table 9 Lithology and chemical analysis of Hoddom borehole core samples

Sample Ref. No.	Intersection m	Lithology	Cu ppm	Pb ppm	Zn pm	Ba ppm	Ni pm	Cd pm	MnO %	Fe_2O_3 %
BFD 7920	21.65 - 21.69	Pink massive siltstone with fine calcite veinlets	8	4	23	131	39	<5	0.185	2.60
BFD 7921	36.40 - 36.50	Grey-pink mottled fine sandstone with FeS disseminations and in calcite veinlets	<2	<2	8	143	33	<5	0.273	1.39
BFD 7922	39.35 - 39.41	Sandy siltstone with soft orange dolomitic patches	9	4	32	139	43	<5	0.091	3.65
BFD 7923	42.97 - 43.06	Pink sandstone with dolomitic patches and fine ox. clusters of FeS	10	5	18	172	24	<5	0.061	3.65
BFD 7924	48.90 - 49.07	Red-pink sandstone with numerous calc. vnlts and patches of fine sulphide (upto 1cm)	8	6	36	139	34	<5	0.128	2.70
BFD 7925	61.03 - 61.08	Pink sandstone containing a few coarse clasts; thin band of FeS parallel to bedding	5	8	27	87	52	<5	0.208	4.45
BFD 7926	87.52 - 87.60	Fine grained pink sandstone with oxidised FeS in veinlets upto 0.2 cm wide.	4	3	21	107	28	<5	0.149	2.85
BFD 7927	118.82 - 118.89	Pink cementstone with 0.2 cm crystal ?PbS	3	<2	17	90	18	<5	0.063	1.23
BFD 7928	131.96 - 132.02	Dark grey siltstone with numerous bands of gypsum/anhydrite (0.2 - 2 cm) generally par. to bedding	53	<2	7	10	8	<5	0.003	0.18
BFD 7929	162.63 - 162.68	Grey fine-grained sandstone with coarse clasts and thin silty bands, dissem coarse patches FeS	5	11	14	82	21	<5	0.002	1.83
BFD 7930	163.08 - 163.15	Grey banded siltstone, gypsum in veins and thin beds; coarse patches (0.3 cm) of dissem.FeS	9	11	13	137	21	<5	0.040	1.89
BFD 7931	175.75 - 175.78	Grey fine-grained sandstone with minor FeS	17	11	15	237	20	<5	0.020	2.38