Natural Environment Research Council

Institute of Geological Sciences

Mineral Reconnaissance Programme Report

A report prepared for the Department of Industry

D. Ostle
Programme Manager
Institute of Geological Sciences
Nicker Hill, Keyworth,
Nottingham NG12 5GG

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Polymetallic mineralisation in Carboniferous rocks at Hilderston, near Bathgate, central Scotland

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Polymetallic mineralisation in Carboniferous rocks at Hilderston, near Bathgate, central Scotland

Geology
D. Stephenson, PhD

with contributions by
N. J. Fortey,PhD
M. J. Gallagher, PhD, MIMM

London 1983

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Bibliographic reference
Stephenson, D. and others, 1983. Polymetallic mineralisation in Carboniferous rocks at Hilderston, near Bathgate, central Scotland *Mineral Reconnaissance Programme Rep. Inst. Geol. Sci.*, No. 68

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SUMMARY

Five boreholes in the vicinity of the ancient Ag–Ni–Pb mine at Hilderston, near Bathgate have yielded new stratigraphic, mineralogical and geochemical information. These results, together with a critical re-examination of old records, are interpreted in relation to a palaeo-environment profile across a volcanic island with coastal lagoon and fringing reef deposits, as proposed by Jameson (1980).

Stratabound Zn–Pb mineralisation occurs in the lower, argillaceous part of the Petershill Limestone, which was deposited in an anaerobic lagoon on the edge of a volcanic landmass during the Lower Carboniferous Epoch (Lower Limestone Group, Viséan Stage). The best intersection shows 8 m of mineralised limestone, with underlying carbonaceous mudstone (1 m) and tuffaceous seat rock (2 m), having an average concentration of 0.14% Pb and 0.66% Zn and maximum values of 0.6% Pb and 3.1% Zn in the carbonaceous mudstone. Further drilling was subsequently carried out in order to investigate possible lateral extensions of the stratabound mineralisation and to test for mineralisation in similar lithologies and geological environments at other stratigraphic levels, and a report on the results will be available at Edinburgh.

Late-Carboniferous hydrothermal veins occur within the Petershill Limestone and in immediately overlying clastic sediments, where they are cut by E–W faults and quartz-dolerite dykes. At Hilderston Mine two assemblages are recognised in the vein: Ba–Fe–Ni–Co–Ag–As on a dyke margin adjacent to the clastic sediments and Fe-Pb–Zn–S at lower levels adjacent to the limestone. Zones of alteration in the dolerite dykes carry hydrocarbons and weak Ba–Fe–Cu–F mineralisation. No potentially-valuable vein deposits were discovered in the present investigation.

INTRODUCTION

SCOPE OF THE PRESENT INVESTIGATION

Hilderston Mine, which was worked at intervals from 1607 to 1898 for silver, lead and nickel, is one of a small number of worked metalliferous deposits occurring in the Midland Valley of Scotland. The nearest comparable deposit lies 20 km to the north-west in the Alva district. Although the country-rocks at Alva are Lower Devonian volcanics (Hall, Gallagher and others, 1982) rather than Lower Carboniferous sediments as at Hilderston, these localities are especially noteworthy because they are the only two in Scotland where native silver has been extracted (Dunham and others, 1978). Cobalt was also extracted at Alva and is present at Hilderston. The high commercial value of the metals recovered from Hilderston Mine and the paucity of evidence for the controls and genesis of the mineralisation prompted the present investigation.

Because of the many pipeline routes and other artifacts in the immediate area of Hilderston Mine, geochemical and electromagnetic geophysical studies were not carried out. Using the available 1:10 560 scale geological maps, supplemented by a structural interpretation based on aerial photographs and magnetometer traverses, borehole sites were selected to determine the incidence of metalliferous mineralisation in a Lower Carboniferous Limestone formation and associated clastic rocks, where they are intruded by late-Carboniferous quartz-dolerites and cut by E–W faults. The nature of the Hilderston vein has been determined from a reinterpretation of old records and examination of museum material.

Five boreholes of 55 m to 91 m rod-length (total meterage 365 m) were drilled at three locations in 1980. Core recovery of 99% or better was achieved by the contractor in the operation. Half-core samples were taken from appropriate sections for geochemical analysis and mineralogical study and the remaining material was stored in Edinburgh.

LOCATION

The Bathgate Hills comprise an area of 9 × 9 km within the Midland Valley of Scotland, between Linlithgow to the north and Bathgate to the south (Figure 1). Hilderston silver mine is situated in the highest ground (up to 312 m OD), 2 km ESE of Torphichen village and lies 300 m SE of Cairnpapple Hill at the eastern edge of the one-inch New Series Geological Sheet 31 (Airdrie).

GENERAL GEOLOGY OF THE BATHGATE HILLS

The first detailed description of the geology by Forsyth (1847) was followed by accounts in Geological Survey memoirs (Howell and Geikie, 1861; Geikie, 1879) all of which are valuable for their detailed descriptions of specific localities. These early works were summarised by Peach and others (1910) and this remains the definitive general work on the area. Further summaries are given in two Central Coalfield memoirs (Macgregor and Anderson, 1923; Macgregor and Haldane, 1933). Cadell (1925) gives a comprehensive account of the geology and also includes many interesting historical accounts of mining activities.

Sediments and volcanics of the Bathgate Hills are of Carboniferous age and range from the Upper Oil-Shale Group up to the Upper Limestone Group. A generalised succession for the southern part of the hills is shown in Table 1. Much of the succession consists of basaltic lavas and associated pyroclastic rocks which take the place of the normal sedimentary succession and thereby make correlation difficult with established successions north and south of the hills. Quartz-dolerite dykes and sills of late-Carboniferous age are widespread, forming prominent topographic features. The succession has a regional dip of

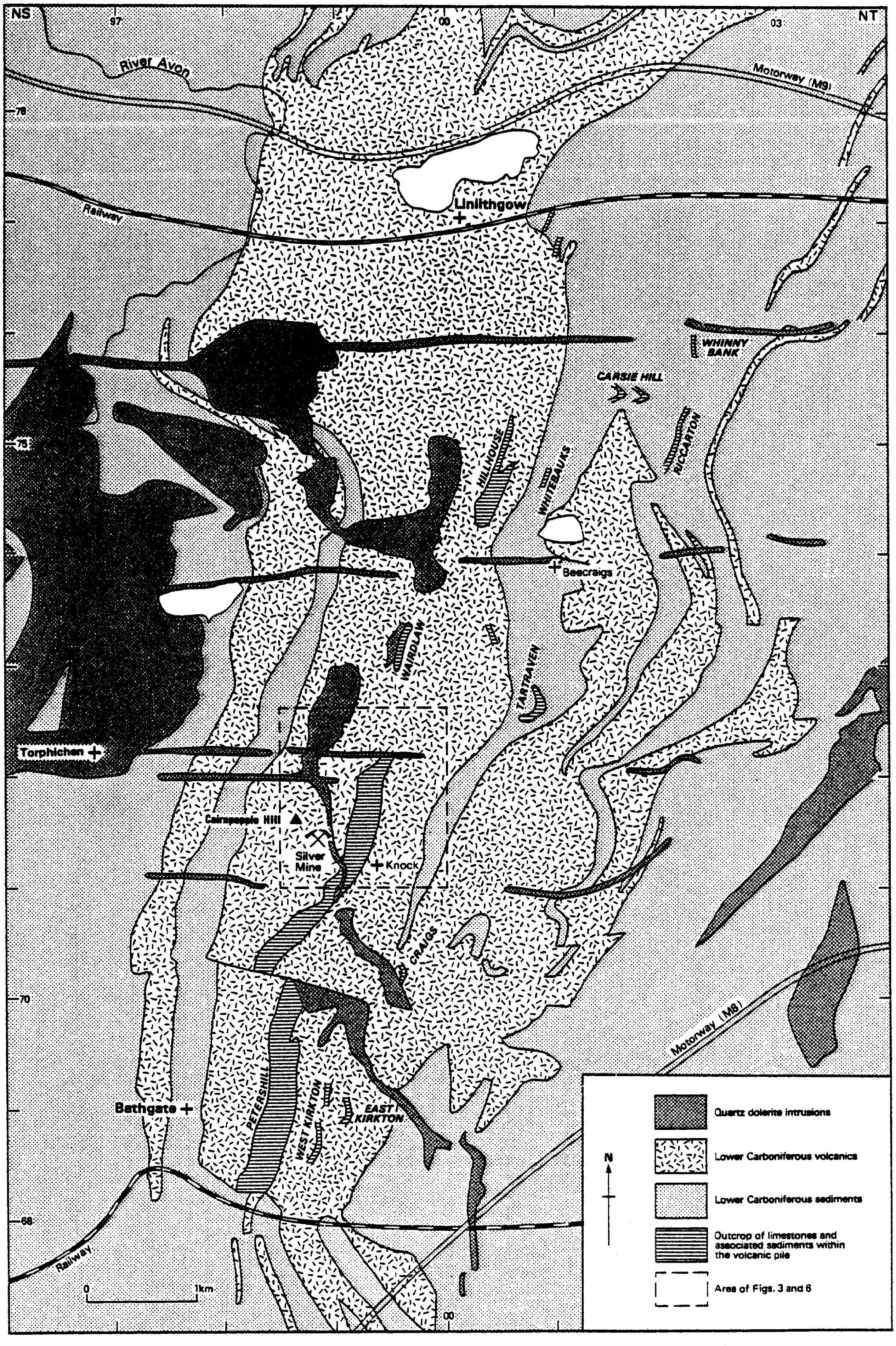


Fig. 1 Simplified geological map of the Bathgate Hills showing the area of the present investigation. Geological boundaries from published New Series one-inch

Table 1 Generalised succession in the southern part of the Bathgate Hills

	Upper Carboniferous (Namurian)	
	Upper Limestone Group:	
150 m	Sandstones, siltstone, mudstones with *Orchard, Calmy and Castlecary Limestones*	
40 m	Basalt lavas	
35 m	Mudstones, some sandstones	
1.5 m	*Index Limestone*	
	Limestone Coal Group:	
100 m	Sandstones and seat rocks with coals	
200–300 m	Basalt lavas	
	Lower Carboniferous (Viséan)	
	Lower Limestone Group:	
	Basalt lavas including *Wairdlaw Limestone* (4 m)	
16 m	Sandstone, siltstones, mudstones (Silvermine Member)	Petershill Formation
16–24 m	*Petershill Limestone* (Reservoir Member) locally may = Tartraven and Hillhouse Limestones regionally = Charlestown Main = Carriden No. 5 = Foul Hosie = Blackhall	
100 m	Tuffs with local basalt flows, more numerous towards base	
7.5 m	*West Kirkton Limestone* locally may = Whitebaulks Limestone. Regionally = Hurlet	
	Upper Oil Shale Group:	
80–100 m	Basalt lavas and tuffs	
4 m	*East Kirkton Limestone* (freshwater) locally may = Craigs Limestone	
over 100 m	Tuffs and basalt lavas	
300–800 m	Mudstones, sandstones, clays and tuffs with oil-shales	

about 18° to the northwest or west and is cut by E–W faults. The Bathgate Hills sequence is terminated in the south at the Heatherfield Fault, a major structure extending eastwards from the Central Coalfield with a throw of 50–150 m to the south. South of this fault the volcanics die out rapidly and the hills give way to lowlands.

UPPER OIL-SHALE GROUP

The group is assumed to underlie the whole of the area of present investigation and it is possible that the many thick seams of oil-shale present in the lower part of the group and in the underlying Lower Oil-Shale Group may have a genetic connection with the metalliferous mineralisation observed at higher stratigraphic levels.

The upper part of the group is exposed poorly in the east of the study area. Exposures are almost entirely of basaltic tuffs and agglomerates with localised basalt lava flows, which may be continuous through into the overlying Lower Limestone Group. A 1.8 to 4 m thick limestone, interbedded with tuffs and shales at East Kirkton quarry, is assigned to the Upper Oil-Shale Group because of its freshwater flora and fauna (Hibbert, 1836; Geikie, 1879; Peach and others, 1910). Banded cherts and irregular masses of silica within the limestone have been taken as indications of hot-spring activity.

LOWER LIMESTONE GROUP

The outcrop of this group extends north to south through the centre of the Bathgate Hills, including the Hilderston area. Much of the succession consists of volcanic rocks but one major and several minor sedimentary intercalations include limestones, sandstones, siltstones, mudstones, seatrocks and a few thin coals (Table 1). In general the lowest part of the group consists of a basal marine limestone (West Kirkton), followed by bedded tuffs and agglomerates with a few basalt flows and rare thin sandstones and limestones. The middle part consists of the Petershill Limestone and associated clastic sediments (the 'Petershill Formation' of Jameson, 1980). The upper part is a thick sequence of basalt lava flows passing upwards into the Limestone Coal Group. Within the upper unit, togographic hollows with no exposures may represent rubbly flow tops, pyroclastic horizons or thin intercalations of sediment and a local limestone lens is exposed at Wairdlaw.

LIMESTONE COAL GROUP

Above the basalts which overlie the Petershill Formation the sediments are of a different character. Shales, siltstones and cross-bedded sandstones occur in repeated sequences which include several worked coal seams. Exposure is poor within a 250 m wide, N–S band of negative relief corresponding to about 100 m of strata to the west of the Hilderston Hills.

UPPER LIMESTONE GROUP

The base of the group is marked by the Index Limestone which is exposed in a few quarries on the western edge of the Limestone Coal Group crop. The overlying 35 m of mainly argillaceous sediments are succeeded by about 40 m of basaltic lavas which constitute the youngest volcanic interlude of the area and which form a steep dip slope marking the western edge of the Bathgate Hills. Above the lavas a predominantly sandstone, siltstone, mudstone sequence includes three named limestones: the Orchard, Calmy and Castlecary. The latter two have been quarried and mined in the north-west of the Bathgate Hills at Carribber Glen and Bowdenhill.

QUARTZ-DOLERITE INTRUSIONS

The Bathgate Hills are cut by numerous dykes and sills of quartz-dolerite which form part of a widespread suite extending throughout central Scotland. The suite is believed to be of late-Carboniferous age and comprehensive general accounts are given elsewhere (Walker, 1935; Macgregor and MacGregor, 1948; Macdonald and others, 1981). Detailed field and petrographic descriptions of the Bathgate Hills intrusions are given by Falconer (1905, 1906) and Peach and others (1910).

The sills and dykes are petrologically, mineralogically and chemically similar and are without doubt comagmatic. Sills are particularly thick and widespread in the north-west of the Bathgate Hills where they often consist of several 'leaves' concordant with the sediments and lavas. Transgressive steps form dyke-like bodies, one of which may be the persistent N–S or NW–SE dyke which extends from the eastern edge of the major sill complex, southwards for 5 km through the Hilderston area, to Boghall on the eastern outskirts of Bathgate. This dyke averages 40 m in thickness and has a persistent dip to the east of about 60°. All other dykes have an E–W trend and commonly occupy fault planes which occur with a regular spacing of 250 m or 500 m across the area. The intrusions and faulting appear to be more or less contemporaneous.

STRUCTURE

The Bathgate Hills lie on the eastern limb of the major, NNE-trending Central Coalfield Syncline. Goodlet

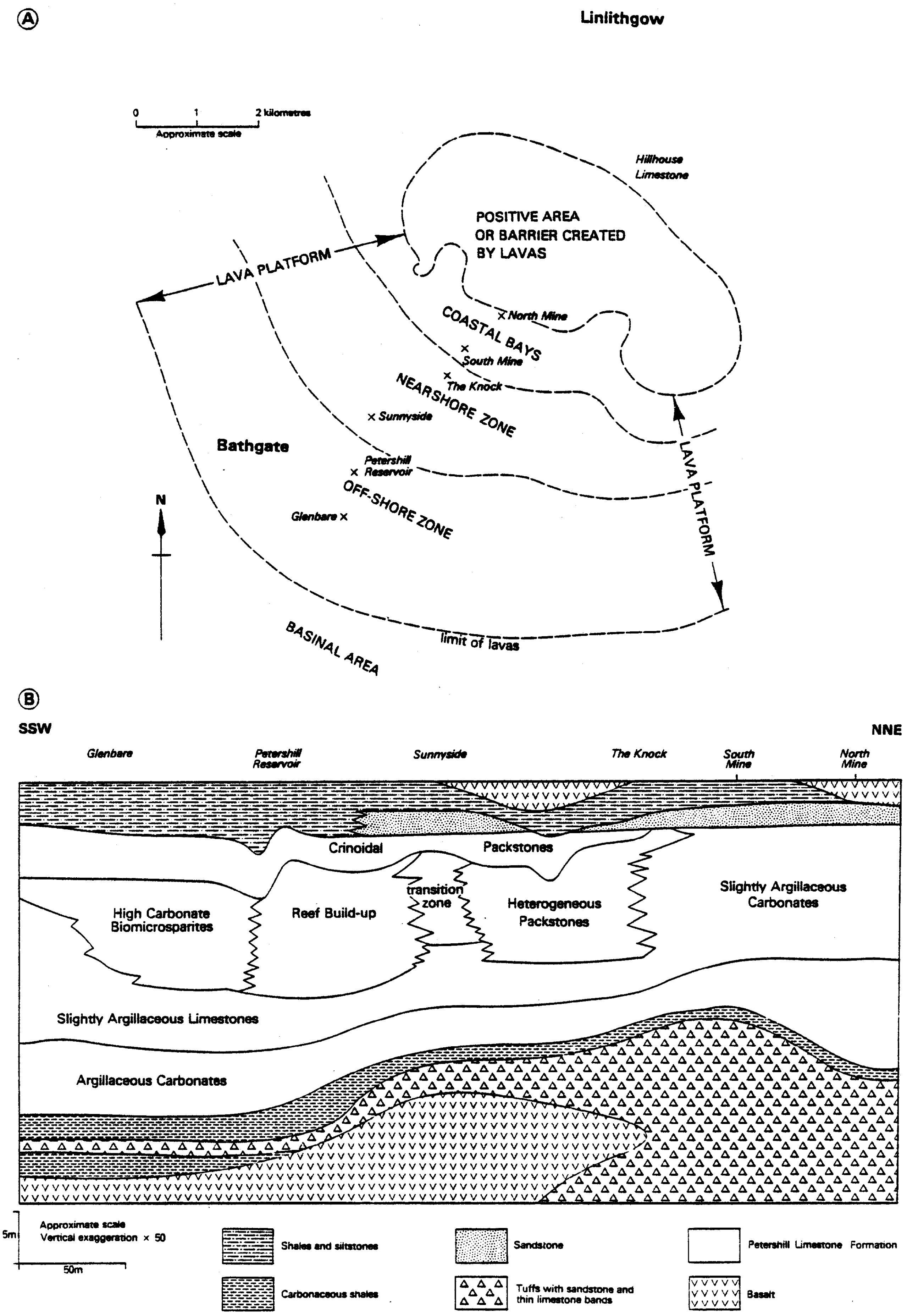


Fig.2 a: Palaeogeographic reconstruction of the Bathgate Hills area at the time of deposition of the Petershill Limestone, adapted from Jameson (1980).
b: Generalised cross-section of the Petershill Limestone facies (unshaded), adapted from Jameson (1980, Figs. A1 and 8.1) with additional information from Boreholes 2

(1959) and Francis (1965) have shown that they also coincide with a major thinning and facies change in the Carboniferous succession over the positive barrier of the 'Burntisland Arch' which separates the Central Coalfield basin of deposition from that of the Midlothian Coalfield. The Bathgate–Linlithgow volcanics are concentrated along the axis of this proposed barrier and presumably developed upon and contributed to a basin 'swell'. The aeromagnetic map of central Scotland (1:250 000 Sheet 11) shows a high-amplitude, steep-sided positive anomaly adjacent to the Bathgate Hills, suggesting a large igneous mass associated with the swell, but as yet this has not been investigated in detail.

The structure of the Bathgate Hills is relatively simple with a north or NNE strike and a westerly dip of 20° to 25°. The few changes of strike that are observed may be interpreted as flexures associated with movements along major E–W faults. This contrasts with the West Lothian Oil-Shale field to the east and the Central Coalfield to the west, where many minor structural domes and basins are superimposed upon the general north-south trend. Most of the movement within the Bathgate Hills is taken up by brittle fracture in the form of E–W faults. In general these seem to be high-angle normal faults with a tendency for northerly throws in the north and southerly throws in the southern part of the hills. Lateral movement could be present, but is difficult to evaluate owing to the scarcity of vertical features cut by the faults.

LIMESTONE CORRELATION

The results of this study indicate stratabound mineralisation, in addition to the previously-recognised mineral veins, within the Petershill Limestone and in immediately-overlying clastic sediments. It is therefore important to establish correlations for the limestones in the Bathgate Hills and to relate these to the Carboniferous succession elsewhere in central Scotland, as a stratigraphical base for further prospecting.

The base of the Lower Limestone Group in the Bathgate Hills has been taken as the earliest marine limestone, the 7.5 m thick West Kirkton Limestone. This has been correlated therefore with the Hurlet and Cobbinshaw Limestones elsewhere in central Scotland (Peach and others, 1910; MacNair, 1918; Cadell, 1925; Macgregor and Haldane, 1933; Mitchell and Mykura, 1962). Limestones at a similar stratigraphic level occur at Whitebaulks (3 to 3.5 m thick) and possibly Carsie Hill (4 m thick) (Figure 1).

The Petershill Limestone crops out 300 m west of the West Kirkton Limestone and has been assumed to occupy a position about 100 m above the base of the group. Most authors (*op. cit.*) have correlated it with the Charlestown Main and Carriden No. 5 Limestones to the north and with the Foul Hosie and Blackhall Limestones to the south, based upon similarities of stratigraphical position, thickness, lithology and fauna. Marker bands bearing a diagnostic macrofauna are lacking, but foraminifera indicate an Upper Viséan zone of V_3c and confirm the placing within the Lower Limestone Group (Jameson, 1980).

Within the Bathgate Hills, published geological maps group the limestones into four continuous bands; the East Kirkton–Craigs; the West Kirkton–Tartraven–Whitebaulks; the Petershill–Hillhouse; and the Wairdlaw. However there is no evidence, despite reasonable exposure in places, for the existence of limestone in the ground between the outcrops. There is therefore a justification in an alternative view that the limestones are localised lenses developed at various stratigraphic levels within a rapidly-developing volcanic/marine environment.

The upper part of the Petershill Limestone is exposed almost continuously in quarries from Glenbare Quarry, near Bathgate northwards for 3.5 km to North Mine Quarry, where the lower part contains stratabound mineralisation (BH3B). Farther north, there are no limestone exposures for 2.5 km until Hillhouse Quarries, where up to 9 m of limestone (c.f. 16 to 24 m of Petershill) is exposed over a strike length of 1 km at a stratigraphical level similar to that of the Petershill Limestone. The exposure gap between North Mine and Hillhouse coincides with the maximum development of volcanics in the centre of the Bathgate Hills. It is possible that the limestones may have developed on separate shelves on opposite sides of a positive barrier (Jameson, 1980) (Figure 2a) and hence may thin considerably or be absent from this area.

Other modifications to the accepted correlation include a suggestion that the Tartraven Limestone may be a continuation of the Petershill Limestone (rather than the West Kirkton), displaced 1100 m to the east-north-east by a swing of strike associated with a major E–W fault. The thickness of limestone formerly exposed in the Tartraven quarries is not accurately known (3.5 m seen) but it was undoubtedly less than that in North Mine Quarry, possibly reflecting an approach to the positive barrier.

GEOLOGY OF THE HILDERSTON AREA

THE PETERSHILL FORMATION

The formation is defined by Jameson (1980, pp. 37–43) as the sedimentary sequence between the lower and upper volcanics of the Lower Limestone Group in the southern Bathgate Hills. A predominantly carbonate 'Reservoir Member' (i.e. the Petershill Limestone), is overlain unconformably by the clastic 'Silvermine Member'. Figure 2b shows a cross section through the formation (after Jameson, 1980).

The uneven base of the formation appears to overlap the volcanics from south to north due to a variable thickness (2 to 25 m) of tuffs and sandstones in the south which become almost entirely tuffaceous in the north. The lowest laterally-persistent unit is a 0.75 to 2 m thick, carbonaceous mudstone with coals and marine shell bands, which usually rests upon rooty, tuffaceous seatrock (e.g. BHs 2 and 3B). This mudstone is a useful marker horizon and features prominently in the pattern of stratabound mineralisation to be described.

The lower part of the Petershill Limestone, consisting of nodular calcareous mudstones and argillaceous limestone, also forms a persistent unit throughout the crop. Thickness varies from 6 to 10 m, possibly due to an underlying topography (Figure 2b), and reaches a maximum at North Mine (BH 3B) where it contains stratabound mineralisation. The 10 to 12 m thick upper part of the limestone exhibits lateral facies changes which are interpreted as due to a change of environment from a volcanic land area in the centre of the Bathgate Hills, southwards across a marginal platform towards a basinal area (Jameson, 1980). The lower argillaceous limestones are overlain at North Mine (BH 3B) and Silver Mine (BH 2) by an upper unit of massive, slightly argillaceous limestone. Both units are interpreted as an organic-rich, restricted lagoon facies with a slow rate of sedimentation.

South of the Silver Mine the facies of the upper unit passes through a shallow, nearshore turbulent zone, possibly with barrier bars, into a calmer, deeper environment in which a reef development is recognised (Jameson, 1980). Farther south the limestones are characteristic of quieter, deeper, offshore waters. A clastic crinoidal limestone, forming the topmost unit of the Petershill Limestone in the south (Figure 2b) exhibits comparable facies changes. This passes northwards into a 2 to 3 m thick, massive fine-grained sandstone at the base of the Silvermine Member which continues the N–S, onshore-offshore profile. Above the sandstone the sequence coarsens upwards from carbonaceous shales through siltstones and interlaminated sandstones into bedded sandstones and is interpreted as an infilling of the coastal lagoon (Jameson, 1980). Sedimentation was terminated by renewed volcanic activity resulting in a thick, continuous sequence of sub-aerial basalt flows, the base of which rests on the basal sandstone of the Silvermine Member at North Mine (BH 3B) and rises to higher stratigraphic levels southwards.

VOLCANIC ROCKS

Detailed descriptions of the Bathgate Hills volcanics have been given by Falconer (1905, 1906) and Peach and others (1910).

Tuffs encountered in boreholes beneath the Petershill Limestone are usually green, grey-green or purple-brown with broad colour banding. Bedding is generally poor although sporadic graded bedding and lode casts suggest aqueous deposition. Clasts are poorly sorted and are usually sub-angular to sub-rounded, although bands of ellipsoidal lapilli are common, often with interstitial sparry calcite. Texture is variable and grain size varies widely from very fine-grained tuffaceous mudstones through to coarse tuffs and agglomerates with angular clasts up to 8 cm long. The clasts are almost entirely of fine-grained, aphyric basalt, often finely-amygdaloidal, or of reworked tuffs. Sedimentary clasts (sandstone or carbonaceous mudstone/siltstone) occur rarely. Harder bands show some evidence of secondary silicification. Numerous bands of soft, friable, pale green or cream, fine-grained tuff with a mossy or mottled texture are probably seatclays and sometimes contain plant rootlets. Leaching at such horizons just below the Petershill Limestone has resulted in slight metalliferous enrichment. It thus seems likely that the pyroclastic rocks accumulated in shallow water, with periodic sub-aerial exposure and possible development of coal-forming swampy conditions.

The lavas of the Bathgate Hills in general are alkali-olivine-basalts of remarkably uniform composition. They may be classified as Dalmeny type (olivine microphenocrysts) or Hillhouse type (olivine and clinopyroxene microphenocrysts) using the scheme of field classification devised for Scottish Carboniferous lavas (MacGregor, 1928). Many of the flows appear to be aphyric in hand specimen but usually prove to be of Dalmeny or Hillhouse type on microscopic examination. Analyses indicate that they are relatively primitive, silica-undersaturated alkali-olivine-basalts, often with sufficient normative nepheline (>5%) to warrant the name 'basanite' (Macdonald and others, 1977).

Field exposures are typically hard, compact and very fresh. Less-fresh, rubbly, vesicular and amygdaloidal material is present, but is less well-exposed. Freshly-broken surfaces are usually dark blue, lustrous and apparently finely-crystalline or occasionally glassy. Microphenocrysts of olivine and clinopyroxene up to 2 mm diameter are usually more apparent on weathered surfaces. Clusters of microphenocrysts forming olivine or augite nodules have been observed up to 2 cm in diameter but plagioclase phenocrysts are extremely rare.

There is no evidence to suggest sub-aqueous eruption, and the lavas are interpreted as an entirely sub-aerial accumulation, subsequent to the infilling of coastal lagoons by sedimentation and pyroclastic activity.

QUARTZ-DOLERITES

Typical quartz-dolerites of both dykes and sills consist of a coarse-grained equigranular aggregate of grey or pink plagioclase laths; dark green mafic minerals (mostly augite); black, lustrous iron-titanium oxides and disseminated pyrite. The rocks are truly 'tholeiitic' in character: olivine is present only in chilled margins; hypersthene and pigeonite are recognised in some samples; and a quartzo-feldspathic residuum is almost ubiquitous. The rock becomes finer grained towards margins, giving a dark, compact aphyric basalt, but glassy chills are not observed. Contacts are usually sharp but one contact between dolerite dyke and sandstone observed in BH 3A shows a remarkable, even gradation over a distance of 40 cm. Rare country rock xenoliths (e.g. sandstone) are observed close to the margins. Zones of dark green, glass-filled, 1–2 mm ocelli and larger, calcite-filled amygdales occur throughout the dykes but are particularly concentrated towards margins, which often have a spotted or mottled appearance.

Primary quartz is rarely observed in hand specimen but the silica-oversaturated nature of the magma is demonstrated by the acidic differentiates which occur in the central parts of sills and in the thicker dykes. Patches of micropegmatite (quartz–orthoclase intergrowths), which occur on a microscopic scale in the normal dolerite, increase in size in the coarse-grained centres of intrusions to form mottled pink patches up to 2 cm across which can form up to 50 per cent of the rock. Similar material is also filter-pressed out of the rock to form veinlets and veins up to 5 cm in width. Other pegmatitic patches are off-white and include blades of augite up to 15 mm long. These features are well seen in BHs 1A and 1B.

Contact alteration of country rocks is commonly observed and detailed occurrences are described by Peach and others (1910). In the present investigation, baked and bleached basalts are seen up to 1.5 m from dolerite margins in BHs 1A and 3B. Limestones and sandstones in BH 3A also show some baking and apparent bleaching.

Characteristic of quartz-dolerite throughout the area, are the zones of 'white whin' or 'white trap' in which the normal rock is transformed into a pale white, cream or yellowish-brown alteration product. The primary doleritic texture is preserved in all but the most extreme examples, but the constituent minerals are pseudomorphed. Plagioclase alters to white kaolinitic clay; pyroxene to a mixture of chlorite and leucoxene; and iron-titanium oxides to leucoxene. Secondary opaline or cryptocrystalline silica is widespread and carbonate may later replace all of the minerals and destroy the overall texture (Day, 1932). Such rocks are usually cut by thin veins of carbonate and silica. Samples of altered dolerite from the Hilderson Mine area have been described in detail by Gallagher (1958, pp. 319–328; 1964).

Most zones of 'white whin' are closely associated with fault planes and frequently show traces of mineralisation in the more brecciated zones. Calcite and pyrite with oc-

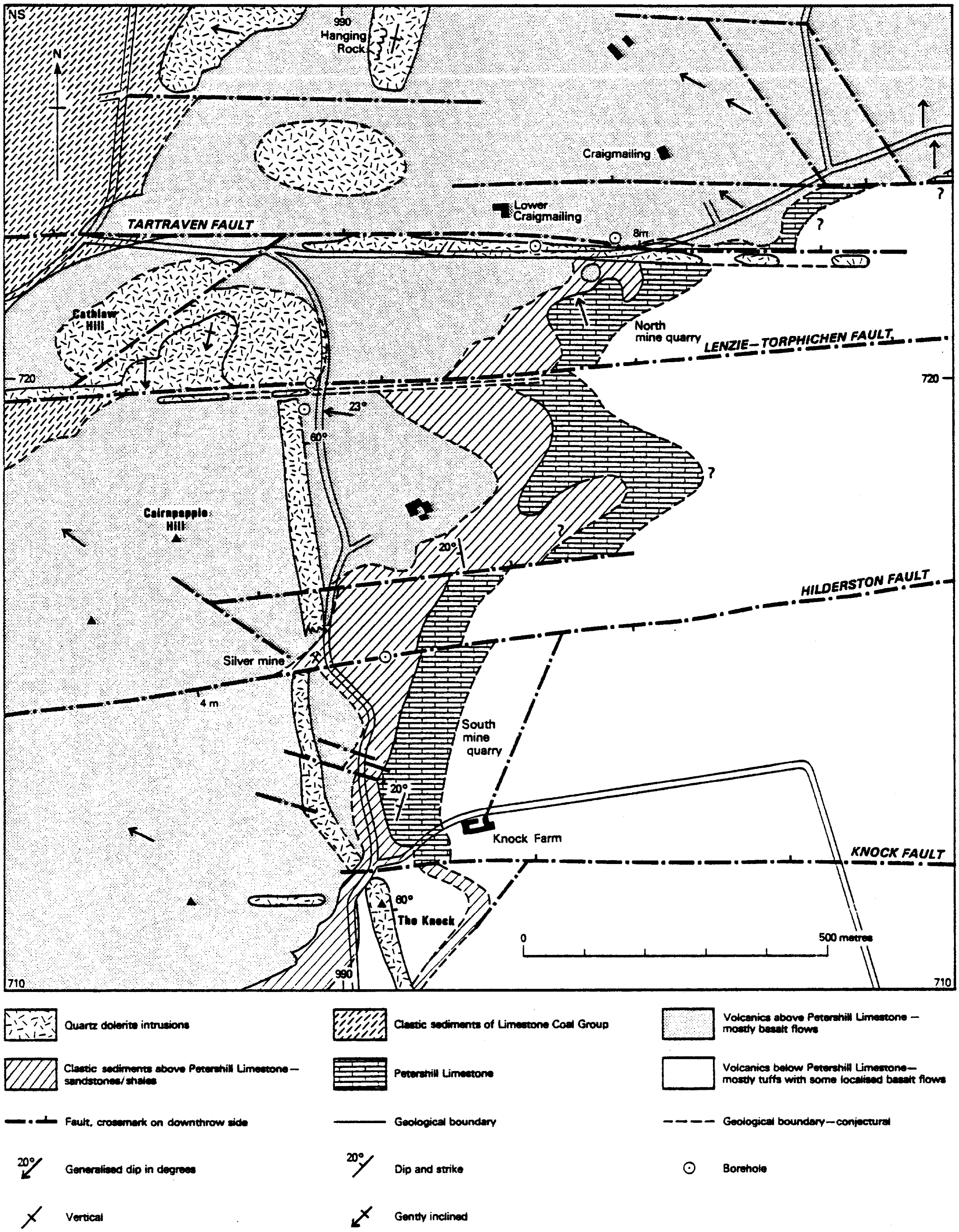


Fig. 3 Geology of the area of investigation around Hilderston Silver Mine and Cairnpapple Hill, based upon recent field mapping and air photo-interpretation at 1:10 000 scale.

casional chalcopyrite and zeolites occur in cavities and thin irregular calcite/baryte veins have been recorded. Calcite and chlorite also occur in amygdales, veins and joint coatings in both altered and unaltered dolerite. A distinctive feature of many dolerites in the Bathgate Hills is the presence of veins and joint coatings of sticky, black asphalt. This is particularly abundant in fault zones where more solid globules and 'pseudo-crystals' of hydrocarbon (frequently termed 'albertite') occur in cavities (BH 1B). Similar solid hydrocarbons are found in fault zones within limestone (BH 2).

'White whin' is particularly widespread in quartz-dolerites that are associated with carbonaceous shales, coals or oil shales (Day, 1932; Mykura, 1965; Peach, 1910). It is suggested that the alteration is produced by volatiles, released during the distillation of oil shales by heat from the intrusions (E. M. Bailey *in* Carruthers, 1927, pp. 230–236). The observed solid or viscous hydrocarbons constitute the mobilised residue of such distillation and more-refined brown solid paraffins and clear mineral oil have been recorded elsewhere in the area.

FAULTING

The most significant structures within the study area (Figure 3) are:

a The Tartraven Fault, which contains a dolerite dyke and terminates the main outcrop of Petershill Limestone at North Mine. To the north of this fault there is a marked swing of strike extending eastwards for 1100 m to the Tartraven limestone quarry. If the proposed correlation of the Tartraven Limestone with the Petershill Limestone is correct, the combined effect of the flexure and fault is a throw of 400 m to the north, most of which is caused by the ductile flexure (the brittle fault could be as little as 8 m). Boreholes 3A and 3B were sited close to this fault.

b A fault which passes between Cathlaw Hill and Cairnpapple Hill. This too is associated with major dolerite intrusions and seems to be a weakened continuation of a large, persistent fault (with dyke) which cuts across the whole of the Central Coalfield (the Lenzie–Torphichen Fault). In this area the downthrow is probably only a few metres to the north. Borehole 1B was sited on this fault.

c A small fault with a northerly downthrow which terminates the northern end of the Silvermine quarry.

d The Hilderston Fault which has a throw of at least 4 m to the south. This fault carried the original silver vein and was intersected by BH 2.

e The Knock Fault which terminates the southern end of South Mine quarry.

South of the area of immediate investigation the Petershill Formation is cut by many minor E–W faults and one major WNW fault system, the Galabraes Fault, which has a downthrow of about 150 m to the south.

MINERALISATION AT HILDERSTON MINE

GEOLOGICAL RELATIONSHIPS

Hilderston Mine was worked in the early 17th century, the 18th century and the late 19th century. Descriptions of the 17th and 19th century workings are given by Cadell (1925) and the known extent of all periods of working are shown on Figure 4 which is based upon plans held by the Scottish Records Office and IGS, Edinburgh. The mining history is detailed elsewhere (Stephenson, 1983). Cross sections of the original silver workings (Figure 5) are taken from a mine abandonment plan of unknown age and origin.

The general geology of the immediate mine area is shown on Figures 3 and 4. The Petershill Limestone, formerly exposed in the NNE line of quarries, is overlain by a massive sandstone at about the present water level, followed upwards by a series of shales, siltstones and sandstones with a few interbedded tuffs. This succession dips to the west-north-west at about 18 to 20° and is overlain by a thick sequence of basaltic lavas. A 40 m wide N–S dyke of quartz-dolerite is inclined to the east at about 60°.

Two major E–W faults are recognised, the southern one of which provides a control for the mineralisation. This is a normal fault with a throw to the south of at least 4 m which intersects the surface 15 to 20 m north of the present topographic 'low'. A thin E–W dolerite dyke, which may or may not be an apophysis from the wide, N–S dyke occupies the fault plane in the old workings. The vein occurred on the south side of this E–W dyke and appears to have terminated westwards at the N–S dyke. Eastwards, the fault continues as a mineralised breccia, but the E–W dyke dies out and there are no workable deposits (see also BH 2). It seems that the vein was restricted laterally within the fault plane to the extent of the E–W dyke, and vertically to the succession between the top of a major tuff unit and the base of the overlying basalt pile.

A longer vein, 60 m to the north of the mineralised fault was worked for lead in the 18th century, probably with only limited success. The depths of the shafts and levels on this vein (Figure 4) suggest that mineralisation occurred in both the limestone and in overlying clastic sediments. Workings extended westwards for 60 m beyond the major N–S dyke.

A careful exaination of the mining records and old descriptions (Stephenson, 1983) reveals evidence of two distinct types of mineralisation: (i) the Ba–Ag–Ni–Co mineral suite which was extracted during early shallow workings; and (ii) the Ba–Pb–Zn mineral suite of later, slightly deeper workings.

SILVER-NICKEL-COBALT SUITE

For details of this suite we are entirely dependent upon original descriptions (Atkinson, 1619; Aitken, 1893) and a few museum samples. The ore consisted essentially of niccolite ('red mettle') and contained filiform native silver. Both green nickel bloom (annabergite) and pink-red cobalt bloom (erythrite) occurred as oxidation products (Goodchild, 1897). Galena and sphalerite were not found in the old wastes (Aitken, 1893, p. 197) and it was reported that the ore contained little or no lead, so that lead had to be added to the ore to aid smelting (op. cit., p. 194). Museum samples containing both niccolite and galena may indicate minor galena in the Ni–Ag ore or may be from deeper levels of the vein. Electron microprobe studies have revealed the presence of bravoite (Fe, Ni)S_2 in association with pyrite, chalcopyrite and an unknown phase approximating to Ni_2As_2S in composition (A. J. Hall, *personal communication*, Ologun, 1978).

The full list of known minerals in the suite is: baryte, calcite, dolomite, pyrite, chalcopyrite, niccolite NiAs, bravoite (Fe, Ni)S_2, unknown Ni_2As_2S, annabergite $Ni_3(AsO_4)_2.8H_2O$, erythrite $Co_3(AsO_4)_2.8H_2O$, native silver, possibly with minor galena. Points to note are: (a) the assemblage includes a high proportion of secondary minerals; (b) the assemblage is sulphide-deficient, the

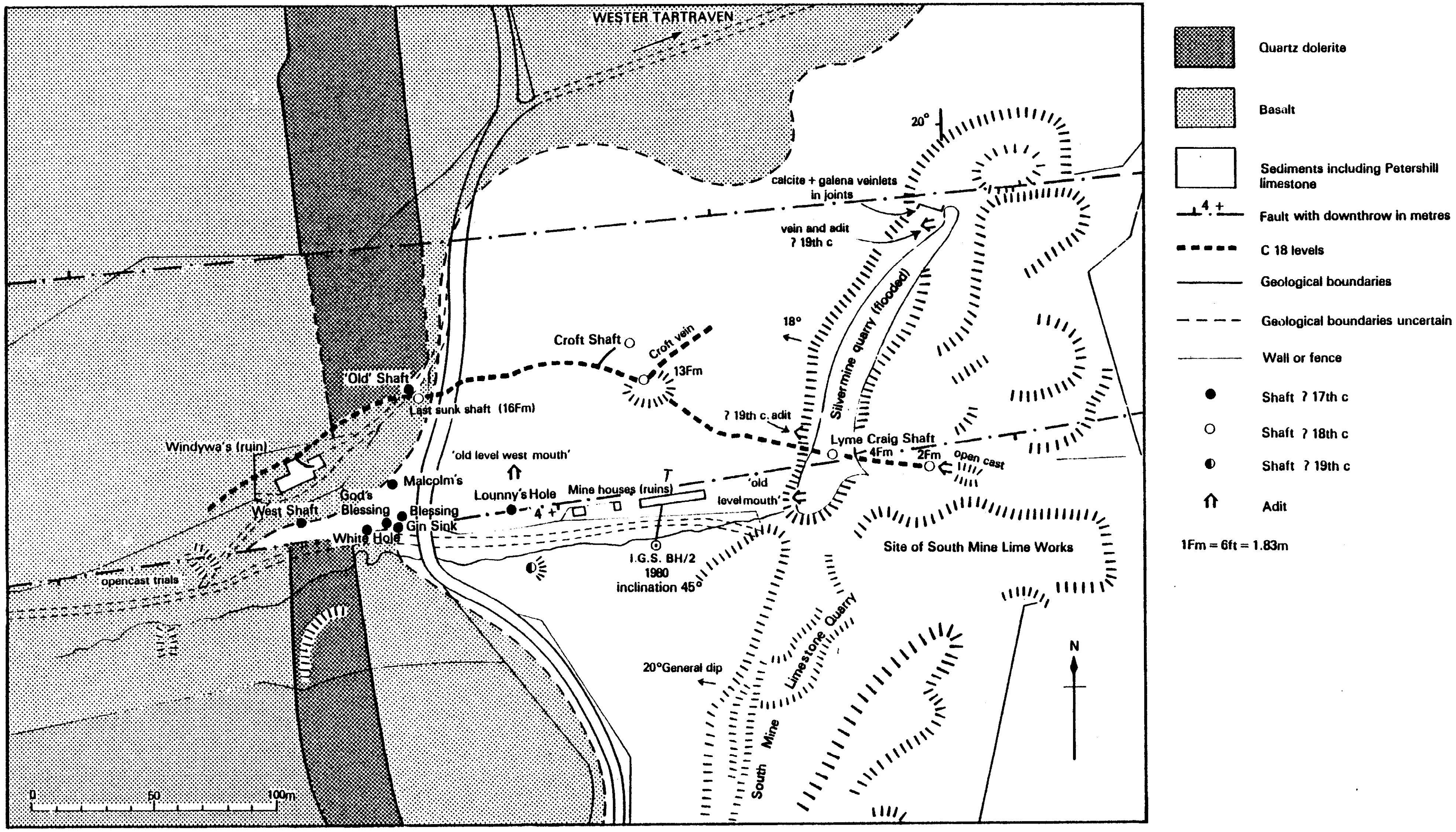


Fig. 4 Hilderston Silver Mine: Plan of known workings based upon original descriptions by Atkinson (1619); mine plan by Udny (1772, Scottish Records Office no. RHP 6854); Aitken's description of 1893; mine abandonment plan R175D; and surface observations.

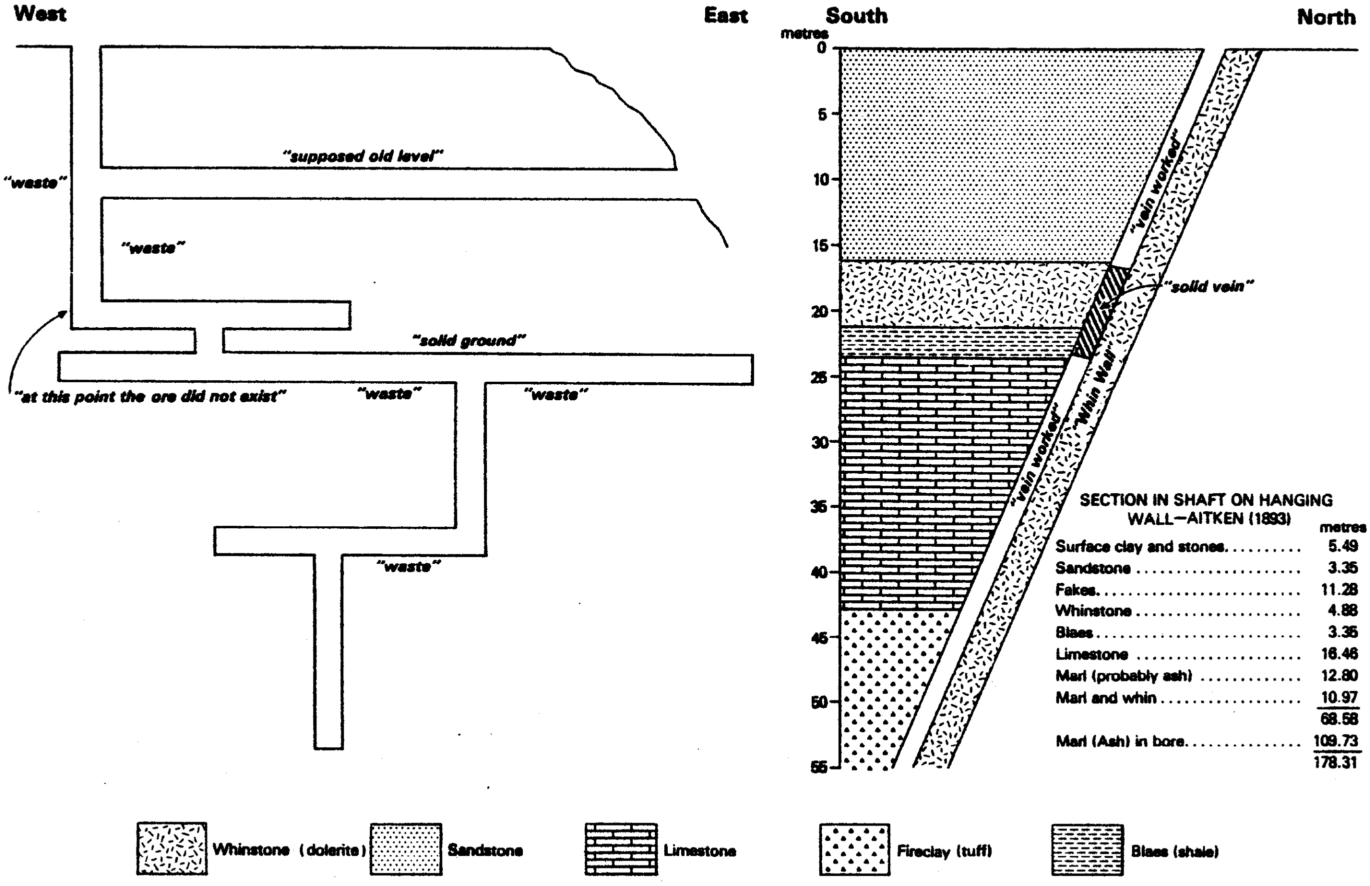


Fig. 5 Sections of old workings at Hilderston Mine, redrawn to scale from mine abandonment plan R175D. Original annotation is shown in quotes. The section seen in a shaft on the original hanging-wall side of the vein by Aitken (1893) is in close agreement with that depicted on the plan. See text for discussion.

base metals occurring mainly as arsenides or secondary arsenates; (c) in view of (b) and the low amounts of recorded lead, it seems unlikely that the native silver is derived from argentiferous galena as has been previously supposed. It would seem more likely that it is a primary phase associated with the niccolite, or that it is derived from an arsenide compound.

Records indicate that the silver ore was found entirely within 18 m of the surface, adjacent to the sandstones and shales of the hanging wall. The silver vein was up to 5 cm wide and assayed up to 1.34% Ag (Atkinson, 1619). The nickel ore was said to contain about 30% Ni and 2% Co (Heddle, 1901). This Ni–Ag orebody had a maximum extent of 18 × 80 m, equivalent to 300 tonnes of ore from which the maximum possible yield of silver would be 4 tonnes.

LEAD-ZINC SUITE

Below 18 m it seems that the baryte vein continued to a depth of 55 m with minor amounts of nickel ore ('red mettle'), accompanied by galena. Below this in the 'marls' (i.e. tuffs), the vein practically disappeared. The galena contained a small amount of silver (Goodchild, 1897), which has been confirmed by analyses of museum samples of galena + sphalerite (Moore, 1979). Analyses of the surrounding limestone from BH 2 indicate a few ppm of silver which may be present in finely-disseminated galena. The gangue in this part of the vein includes more calcite and dolomite than in the upper part and small globules of solid hydrocarbon (?albertite, $C_nH_{2n+2} + C_nH_{2n}$) have been recorded (Wilson, 1921 and this work).

The complete list of minerals from this suite is baryte, calcite, dolomite, pyrite, sphalerite, galena, quartz, albertite from which the following paragenetic sequence has been established: baryte→calcite — gap — pyrite→sphalerite→galena→quartz (Moore, 1979). In contrast to the suite in the upper part of the vein, this assemblage consists entirely of primary minerals, in particular Pb and Zn sulphides, with no appreciable Ni, Co, Ag or As.

SURFACE EVIDENCE

Surface manifestations of the mineralisation are rare. Calcite, baryte, galena and sphalerite may be found in the debris around the old shafts and a particularly impressive sample with much sphalerite and galena was found in a field 600 m to the north of the mine (A. J. Hall, *personal communication*). Thin calcite veins with galena can be seen in the sandstone roof of the northernmost adit in Silvermine quarry and dense, glassy slag in debris around the limekilns may testify to the lead–zinc content of the limestone. In South Mine quarry, a narrow 30 to 60 cm dolerite dyke trends N 5° W, cutting the clastic sediments above the Petershill Limestone. At its northern end, which is only 100 m from the Silver Mine, the dyke is an altered 'white trap', but 80 m to the south the rock is a fresh tholeitte (Gallagher, 1958, 1964). In an exposure 100 m east of North Mine quarry (NGR NS 9952 7220) the southern margin of an E–W quartz-dolerite dyke and

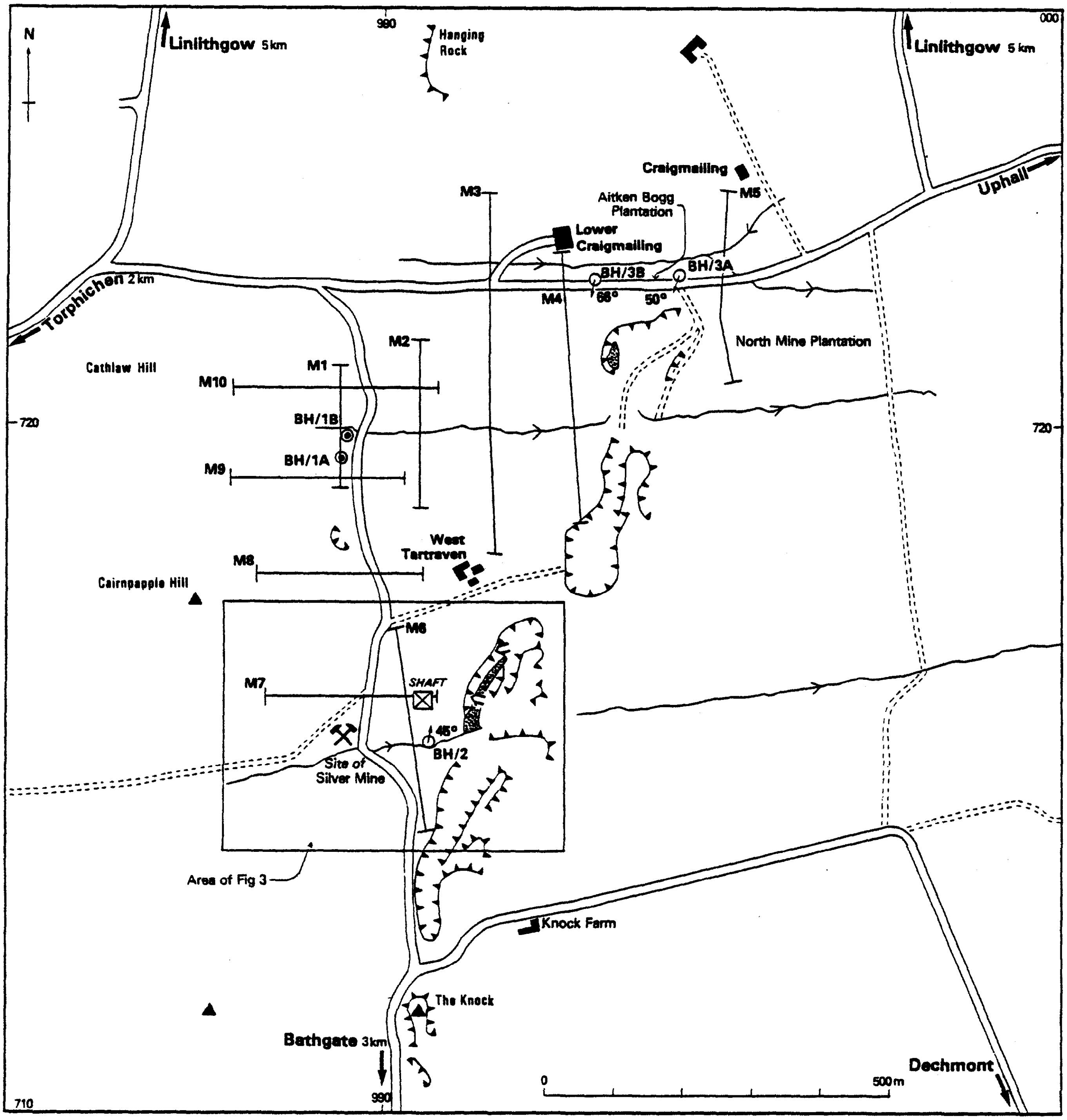


Fig. 6 Locations of I.G.S. boreholes and magnetometer traverses in the area around HilderstonSilver Mine and Cairnpapple Hill. Geology of the area is shown on Fig. 3.

baked limestone are both seen to be impregnated with pink baryte. Forsyth (1847, p. 265) reports that copper ore is said to have been worked at one time from a baryte vein at this locality.

PROSPECTING PLAN

From the information assembled above, two environments may be defined in which metalliferous mineralisation may be found in the area immediately surrounding the known deposits: (i) The Petershill Limestone may contain disseminated mineralisation, which could be particularly concentrated in the immediate vicinity of major E–W faults. (ii) Further vein deposits could be found in the altered margins of dolerite dykes, particularly where these coincide with fault planes. With these factors in mind, borehole sites were selected which aimed to sample the succession, and the Petershill Limestone in particular, close to E–W fault planes and/or dolerite dyke margins. Further, more accurate information was first obtained on the position of faults and dyke margins from selected proton-magnetometer traverses across likely sites.

Several of the most suitable sites selected had to be abandoned owing to difficulties of access or because the sites were close to buried pipelines. The immediate area is

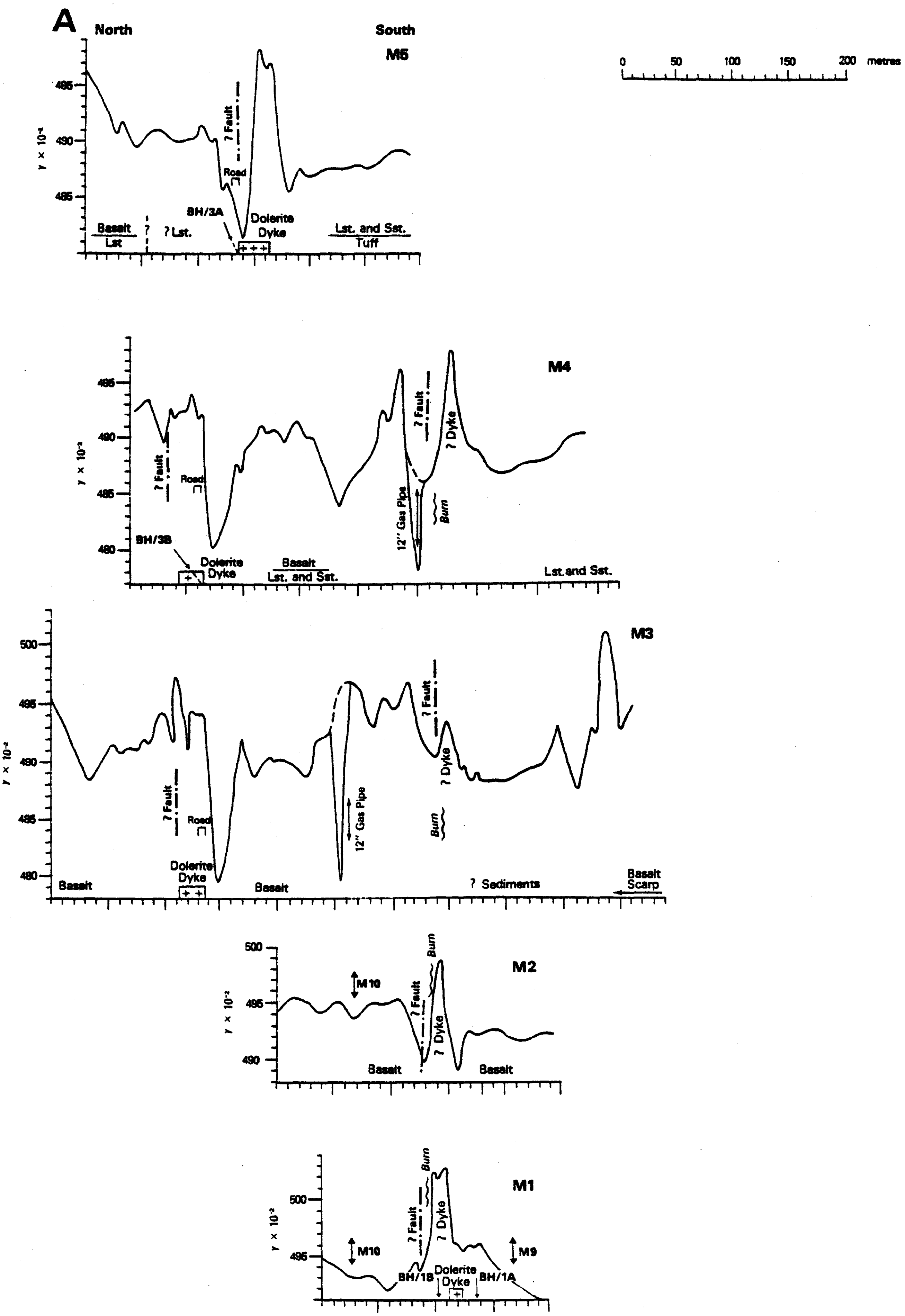
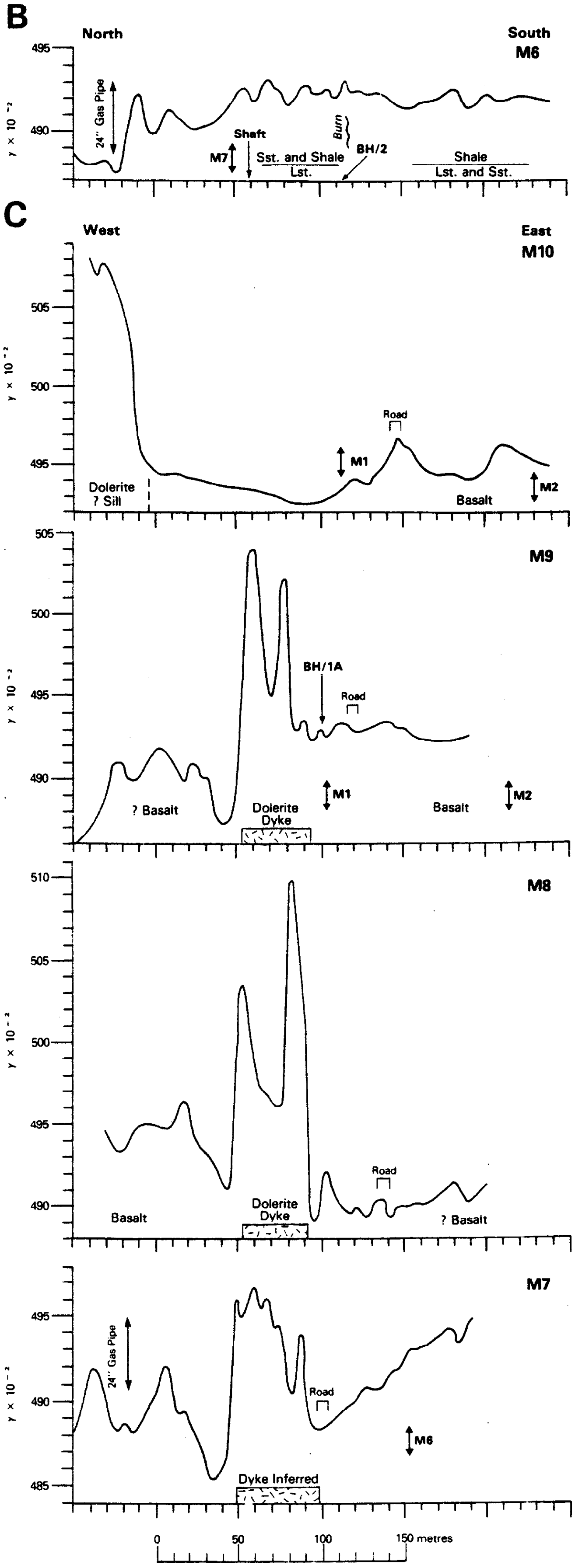


Fig. 7 Magnetic profiles across the area of investigation. Locations are shown on Fig. 6. See text for discussion and interpretation.



crossed by two natural gas pipelines (one 12" and one 24" diameter) and one ethylene pipeline. Other pipelines occur elsewhere in the Bathgate Hills, details of which can be obtained from Scottish Gas, Blandfield House, Edinburgh EH7 4LP (natural gas) and B.P. Chemicals Ltd, Grangemouth (ethylene). Five borehole sites were selected at three localities. These sites are shown on Figure 6 together with magnetometer traverse lines used in the siting.

MAGNETOMETER TRAVERSES

Ten magnetometer traverses were carried out using an Elsec Proton Magnetometer (type 771). The traverses are shown on Figure 6 which covers the same area as the geological map (Figure 3). Traverses varied in length from 250–530 m, some of the longer traverses being extended to cut more than one E–W feature. Readings were taken at 10 m intervals with a closer spacing of 5 m over areas of interest. Traces obtained are shown in Figures 7a, 7b and 7c.

Figure 7a shows five N–S traverses across two strong E–W features in the northern part of the area of interest. The northern feature is marked by surface outcrops of a dolerite dyke with a steep, fault-like scarp on the north side. The position of the dyke is confirmed by traverses M3, M4 and M5 in which the negative magnetic 'trough' on the southern margin is prominent. On the northern margin, the junction between dolerite and basalts to the north provides little magnetic contrast. Traverse M5 shows a contrast between a smooth profile over sediments south of the fault and a more irregular, higher γ, profile on basalts to the north.

The southern feature is a drainage hollow with outcrops of a thin dolerite dyke in the west, cutting the large N–S dyke. The feature is an eastward continuation of one of the most persistent dyke/fault features in the Midland Valley, the Lenzie–Torphichen dyke. The positive magnetic anomaly over the thin dyke is well seen in profiles M1 and M2 and may be present in M3 and M4. However, in these latter two profiles the amplitude of the dyke anomaly is no greater than other peaks caused by wild fluctuations in the magnetic field over basalt outcrops. Profiles M1 and M2 also show a marked displacement of the magnetic background due to a postulated fault, coincident with the dyke. The level of erosion, at profile M2 in particular, is close to the base of the basalts. A small downthrow to the north thus results in a significantly thicker layer of basalt to the north of the fault and consequently a higher overall γ. The sloping background in M1 must be related to the thicker dolerite intrusions and seems to continue to the northern end of M6.

Figure 7b shows the N–S profile M6 across the E–W fault feature at the Silver Mine. The profile is relatively smooth with only low amplitude variations, since the ground is underlain entirely by sediments. The thin dolerite dyke mentioned in the mine records has no effect on the profile and the mineralised fault produces no displacement, presumably because there are no magnetic horizons on either side to provide a contrast. At the northern end of the profile, a marked displacment may be caused by the E–W fault which passes through the northern end of Silver Mine quarry.

Figure 7c shows E–W traverses M7, M8 and M9 across the N–S dolerite dyke. The dyke forms a large

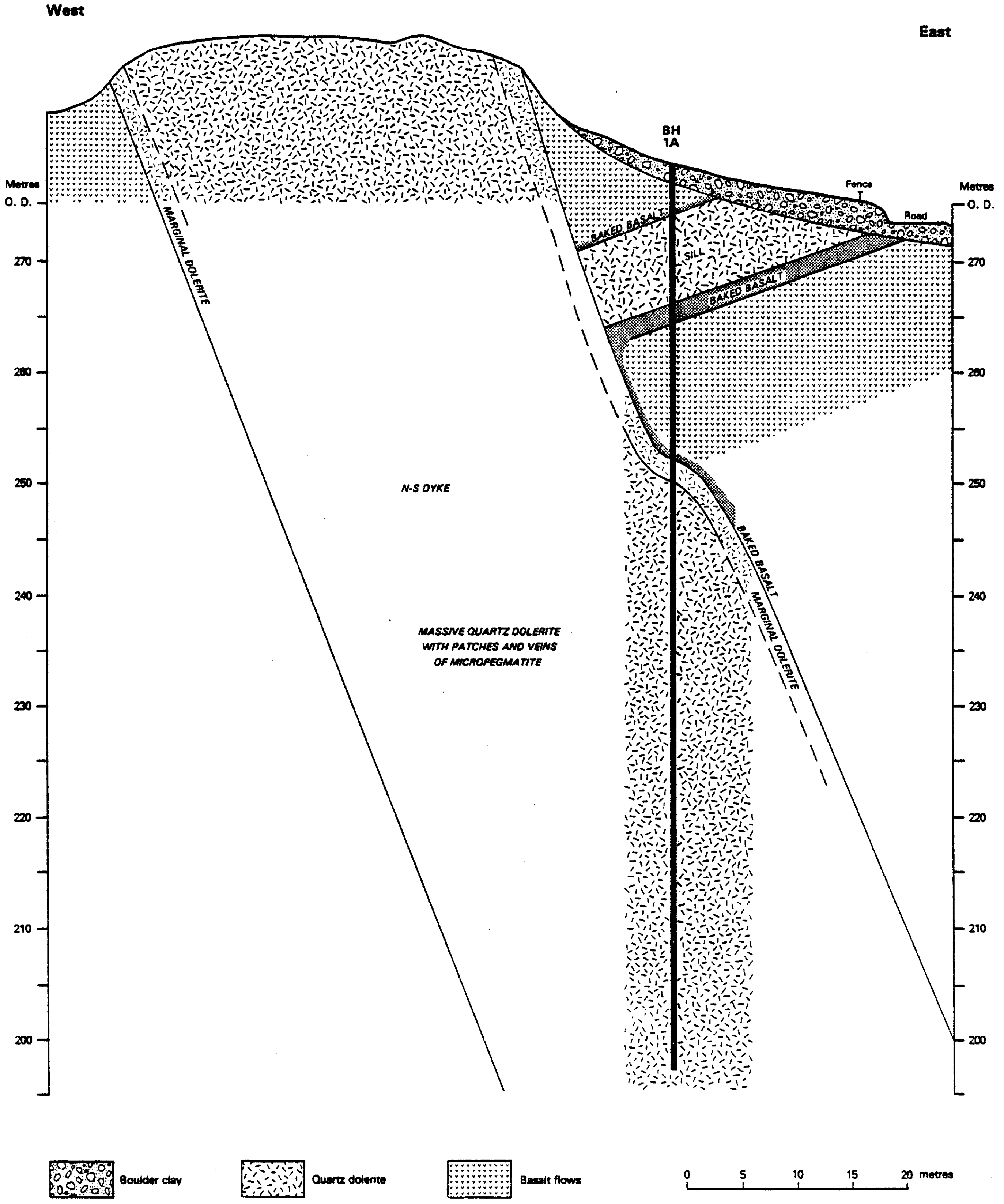
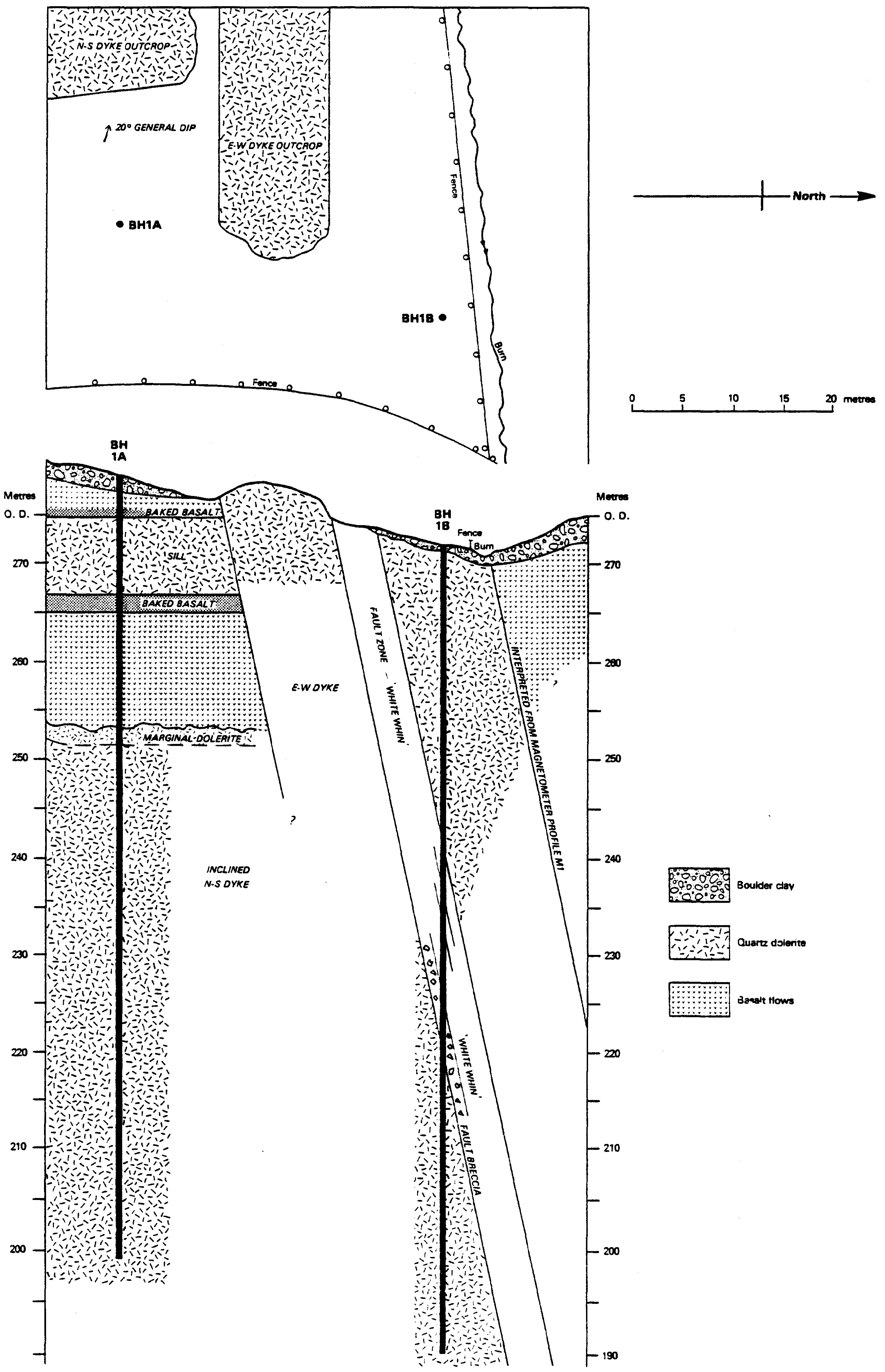


Fig. 8 Location plan and interpreted sections of Bore Holes 1A and 1B (Cairnpapple).


N-S DYKE OUTCROP
20° GENERAL DIP
E-W DYKE OUTCROP
● BH1A
BH1B ●
Fence
Fence
Burn
North
0
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10
15
20 metres
BH
1A
BH
1B
Fence
Burn
Metres
O. D.
270
260
250
240
230
220
210
200
190
BAKED BASALT
SILL
BAKED BASALT
MARGINAL-DOLERITE
E-W DYKE
?
INCLINED
N-S DYKE
FAULT ZONE – 'WHITE WHIN'
INTERPRETED FROM MAGNETOMETER PROFILE M1
'WHITE WHIN'
FAULT BRECCIA
Boulder clay
Quartz dolerite
Basalt flows

positive magnetic anomaly with small negative 'troughs' on each side. Strong positive peaks at each margin of the dyke are separated by a less magnetic zone in the dyke centre. There is no evidence to suggest that the dyke consists of multiple sheets of variable composition and a likely explanation is that the finer grained margins are fresher and contain a higher proportion of mafic minerals. The dyke centre is slightly more fractionated, possibly with less mafics and is also more likely to have contained trapped volatiles which would produce slight alteration and oxidation of the mafics, thereby reducing their magnetic properties. Profile M10 shows that the N-S dyke does not exist near surface to the north of the Torphichen fault. A remarkably smooth profile over basalts (possibly drift-covered) undergoes a steep and sudden increase westwards as it passes over the edge of a dolerite sill on Cathlaw Hill.

BOREHOLE RESULTS

The drilling was carried out by Drillsure Ltd during the period 19 January to 5 February 1980. Five holes were drilled to depths ranging from 55 to 91 m yielding approximately 365 m of 45-mm diameter core. Borehole sites are shown on Figure 6 and on the magnetometer profiles (Figure 7). Detailed site plans and borehole sections are shown on Figures 8, 9 and 10; borehole logs, assays and mineralogical data are given in Appendices to this report. Down-hole geophysical logging of γ-radiation and electrical conductivity (self-potential) was only possible in the vertical boreholes (1A and 1B) owing to collapse of the inclined bores.

Borehole 1A encountered mostly dolerite with no mineralisation; BHs 1B and 3A yielded information on weak mineralisation within the dolerite dykes; BHs 2 and 3B provided sections through the Petershill Limestone and underlying strata. Significant stratabound Zn-Pb mineralisation was encountered in BH 3B. In the following descriptions thicknesses and widths have been corrected for inclination of bore and dip of strata etc.

BOREHOLE 1A (CAIRNPAPPLE)

The hole was sited close to the intersection of a 40 m wide N-S dyke and a 12 m wide E-W dyke (Figure 8b) in an attempt to sample the limestone, at an estimated depth of 150-170 m. A cross-section based upon the borehole is shown in Figure 8a. After thin superficial deposits, the bore passed through 2.5 m of baked, aphyric basalts (dip 23°) followed by a 7 m sill of quartz-dolerite. A further 12.5 m of aphyric basalts, baked at the base are followed by more quartz-dolerite. The basalt/dolerite junction is sharp and dips at 25° suggesting the top of another sill. A 1.8 m wide chilled zone in the dolerite gradually passes into coarser grained dolerite with many patches and veinlets of pink micropegmatite. Some 55 m into the intrusion the dolerite is still coarse-grained with no sign of an approaching base and the hole was abandoned at 80.71 m. The 25° dip of the contact at first suggested a sill, comformable with the basalt succession. However, the magnetometer traces show no sign of such an intrusion and there are no outcrops of dolerite in the ground to the east, as would be expected. The preferred interpretation is therefore as shown on Figure 8a with a slight step in the margin of an inclined N-S dyke. Assuming this model the borehole would have had to continue for at least another 40 m before passing out of the dyke.

No significant mineralisation was encountered in this borehole and the assay data shows no anomalous concentrations of metals in the dolerite. One sample of basalt contains 200 ppm Ni but no appreciable arsenic, so the nickel is assumed to be present in sulphides or in the mafic rock-forming silicates. Geophysical logs show several peaks of anomalous radioactivity in the basalts, particularly in the baked zones, which is in marked contrast with the non-radioactive dolerite. No zones of anomalous conductivity (SP) were detected.

BOREHOLE 1B (CAIRNPAPPLE)

The hole was sited to the north side of the E-W dolerite dyke of BH 1A, midway between the dyke margin and the supposed surface expression of an E-W fault, to test for mineralisation in the vicinity of the dyke and fault (Figure 8b). The bore passed immediately into coarse-grained quartz-dolerite similar to the lower part of BH 1A. At 28.28 m a fault zone is encountered, consisting of 'white whin', heavily impregnated with vugs and veins of carbonate. 'White whin' alternates with bands of less-altered dolerite through the zone which has several brecciated bands towards the base dipping at 65-75°. The zone ends at 51.55 m and represents a true width of about 4.5 m. Below the fault zone coarse-grained dolerite continues to 82.26 m where the hole was abandoned. It is not clear from the borehole whether the dolerite encountered is part of the E-W dyke observed at the surface, repeated by the faulting; a separate E-W dyke; or part of the N-S dyke displaced by faulting. Whatever the interpretation it is clear that there is much dolerite at depth and the chances of encountering limestone in boreholes at this locality are remote.

The dolerite is cut throughout by thin calcite/chlorite veins, occasionally with open cavities containing quartz crystals. On the footwall side of the fault zone many calcite veins contain a sticky, black hydrocarbon which also occurs as a coating to vertical joints. Disseminated primary pyrite is widespread and sporadic, diffuse, horizontal pyrite-rich bands are observed (e.g. at 15 m). Within the fault zone calcite veins are larger and more numerous. Open cavities contain crystals of calcite, zeolite, nodular and disseminated pyrite and solid hydrocarbons. Green staining around some pyrite-rich cavities suggests the presence of chalcopyrite.

The assay data shows a slight increase in various metals in the 'white whin' of the fault zone compared with unaltered dolerite. Up to 100 ppm Cu is recorded in the central 1.5 m of the zone, with lead increasing to 900 ppm over 2 m on the footwall. Arsenic shows a marked increase in the 'white whin' (up to 127 ppm) and is probably present as arsenopyrite. Values of 3000 to 4000 ppm Ba are found at the margins of the fault zone, but not in the centre. No zones of anomalous radioactivity or conductivity were detected in the geophysical logs.

BOREHOLE 2 (SILVER MINE)

The hole was sited to the south of the E-W fault which controlled the main Ag-Ni-bearing vein at Hilderston Mine. The hole is approximately 50 m east of the limit of the original workings and was inclined northwards at 44° to intersect the fault zone where it cuts the Petershill Limestone (Figure 9). After about 5 m of superficial deposits the bore passed into a sequence of silty mudstones and tuffs with a 2.5 m thick massive sandstone

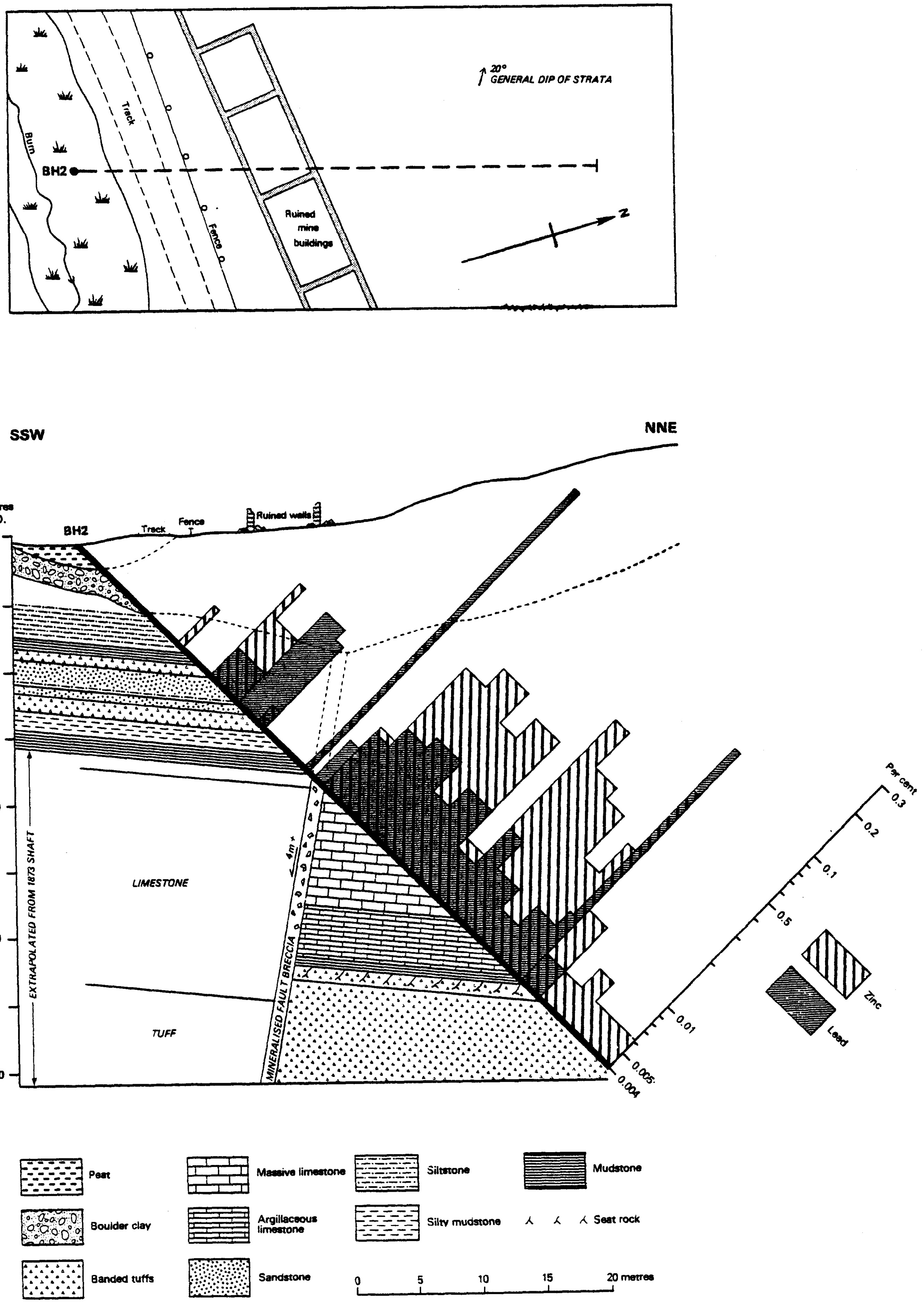


Fig. 9 Location Plan and interpretation of Bore Hole 2 (Silver Mine).Symbols as for Fig. 8. Histograms show concentrations of lead and zinc in a continuous section through the limestone and in selected samples from other lithologies.

at 14.35 m. A major fault zone intersected at 23.95 m has a true width of about 1 m, is steeply-inclined to the south and consists of brecciated fragments of wall rock (clastics and limestone) heavily veined with calcite. Beyond the fault zone the bore penetrated the Petershill Limestone, sampling a true thickness of about 12.5 m. (The full thickness in this area is 16.5 m according to Aitken, 1893 or 21 m according to the abandonment plan R175D.) The limestone consists of a massive, crystalline, medium grey upper unit (8.5 m seen) which passes down into a more-argillaceous, dark grey, banded, nodular, lower unit having a true thickness of about 4 m. Both units contain colonial and solitary rugose corals and bands of shell debris. At the base of the limestone, a 50 cm band of carbonaceous mudstone may be correlated with a similar band which underlies the limestone throughout the area (BH 3B, this work; Jameson, 1980). The mudstone rests upon 1 m of sandy tuffs at the top of a thick unit of green, bedded tuffs (6 m seen) similar to those encountered in BHs 3A and 3B. The borehole was terminated in the tuffs at an inclined depth of 55.02 m. Assuming Aitken's (1893) section for the hanging wall, the displacement of the fault may be estimated at about 4 m to the south, though this figure may have been reduced by fault drag.

Mineralisation on the hanging-wall side of the fault is confined to the massive sandstone unit, which contains appreciable amounts of pyrite as disseminations, in nodular bands parallel to the bedding, and as joint coatings. Thin veins contain mostly calcite and possibly a little baryte. Assays of this part of the succession show very slight enrichment in nickel (maximum 100 ppm) and zinc (maximum 160 ppm) in the tuffs and a little arsenic (maximum 29 ppm in mudstone). Moderate lead values occur in one sample of sandstone (160 ppm) and one of tuff (140 ppm).

The brecciated fault zone consists mainly of veins of calcite up to 2 cm wide with open cavities, up to 1 cm wide containing calcite crystals, solid hydrocarbon (albertite) and disseminated pyrite. A sharply-defined, 3 cm wide band at the southern margin of the fault zone is particularly rich in pyrite (30%) with baryte, gypsum and some replacement galena visible in polished section. Assays of this band show considerable enrichment in lead (2800 ppm), zinc (400 ppm), cobalt (70 ppm), nickel (100 ppm), arsenic (275 ppm) and barium (25 300 ppm) with 3 ppm silver. The remainder of the fault zone is not enriched in any of the base metals analysed, but does show 5–7 ppm silver.

On the footwall side of the fault, the Petershill Limestone contains thin veinlets and patches of calcite with some dolomite and a little baryte. The lower, more argillaceous part of the limestone has abundant, fine-grained, disseminated pyrite and sporadic bands of framboidal pyrite parallel to the bedding. Solitary corals and bands of shell debris usually show replacement by pyrite. Apart from the pyrite, sulphides are not common, even microscopically, and only traces of galena and sphalerite have been identified. The assay data for the limestones shows only slight enrichment in lead (maximum 140 ppm) and moderate enrichment in zinc (maximum 650 ppm), but does show a consistent silver content of 3–6 ppm. Barium is generally low (around 100–300 ppm) except where thin baryte veinlets are present (maximum 2900 ppm over 2.4 m). The histogram superimposed on Figure 9 shows the lead and zinc values and emphasises the high overall Zn/Pb ratio. It also illustrates the relatively uniform distribution of both metals through the limestone with, if anything, slightly lower values in the basal unit of argillaceous, nodular limestone. This is in strong contrast to the distribution found in BH 3B. The thin mudstone below the limestone contains specks of disseminated pyrite but in marked contrast to the identical horizon in BH 3B, enrichment in metals is restricted to 270 ppm Zn and 210 pm Ni. Higher values are found in the top 10 cm of sandy tuff immediately below the mudstone (250 ppm Cu, 1300 ppm Pb, 690 ppm Zn).

The bedded tuffs are not mineralised apart from sparse, disseminated pyrite and sporadic thin, irregular calcite veinlets. The assay data shows a slight enrichment in cobalt (maximum 80 ppm), nickel (maximum 210 ppm) and barium (maximum 3000 ppm), but silver values have fallen to background level.

The results from this borehole confirm the findings of Aitken (1893) that the E–W dolerite dyke and productive vein die out rapidly to the east of the mine workings and that metal values are markedly reduced below the limestone. The silver values of 3–7 ppm do, however, show that a considerable halo exists in the country rock around the rich silver vein.

BOREHOLE 3A (AITKEN BOG PLANTATION)

The hole was sited close to North Mine to the north of a 20 m wide E–W dolerite dyke having a strong, fault-like scarp feature on its northern margin (Figure 10a). Irregular patches of baryte mineralisation are found in surface outcrops of dolerite and limestone 100 m ESE of the site. The hole was inclined southwards at 50° to test for faulting and mineralisation on the north side of the dyke; to penetrate the dyke testing for within-dyke mineralisation; and to sample the succession on the south side of the dyke.

After 3 m of superficial deposits the bore entered steeply-dipping calcareous sandstone, most of which is highly brecciated in a fault plane on the margin of a thin (1.25 m) dolerite dyke. This dyke is presumably an apophysis of the main dyke, from which it is separated by 1.5 m of mineralised limestone. The main dyke formed in two stages. The earlier northern sheet is chilled against the 'screen' of limestone and has a 1 m wide zone of mineralised 'white whin' close to the margin. The true thickness of this sheet is 7 m. The later southern sheet has a true thickness of 22 m and is chilled against the northern sheet indicating a time lapse between the two. The southern margin, encountered at an inclined depth of 63 m, shows a remarkably smooth gradation from fine-grained dolerite into sandstone over a distance of about 40 cm, suggesting a slow development of the intrusion with pre-heating of the surrounding sediments. South of the dyke the bore passed through about 4 m of massive, slightly calcareous sandstone, 0.5 m of fine-grained, soft, soapy tuff, probably a seat-clay, 2.5 m of the underlying bedded tuffs and was terminated at an inclined depth of 71.38 m. Throw on the fault is difficult to estimate. The small amounts of calcareous sandstone and limestone encountered on the north side of the dyke suggest that brittle movement may be as little as 8 m to the north. However, the swing of strike associated with the fault could give a total downward movement of 400 m to the north.

The calcareous sandstone north of the fault and the brecciated fault plane are not mineralised and show no anomalous concentrations of analysed metals. The thin dolerite apophysis contains a few thin calcite veins and sparsely disseminated pyrite but no metal anomalies. The 'screen' of limestone between the dolerite branches is mineralised with several thin calcite veins, some baryte and patches of pyrite, possibly replacing shell debris, but no metal anomalies. Of particular interest are two thin (2–3 mm) veins consisting almost entirely of fluorite which cut the limestone; fluorite is of very rare occurrence in central Scotland. Along the contact with the main dolerite dyke a thin (5 mm) carbonate vein contains nodules of pyrite up to 5 mm diameter and assays 850 ppm Cu.

Within the main dolerite dyke, most of the mineralisation occurs in the earlier, northern sheet. Calcite veins are numerous, some with baryte and some with pyrite, particularly in the zone of white trap. Irregular yellow-green patches contain epidote but some green staining may be due to chalcopyrite (maximum 770 ppm Cu). Harmotome occurs in cavities. A few moderate zinc values occur (maximum 210 ppm) and barium is generally low (200–500 ppm) except in baryte veins (maximum 6.45% Ba over 10 cm). In the thicker, later, southern sheet calcite/chlorite veins are numerous, often following joint sets, and pyrite is rarely concentrated. Copper and zinc assays are moderately high throughout (maximum 170 ppm Cu, 400 ppm Zn) and barium highs (maximum 2.4% Ba over 25 cm) coincide with thin baryte veins.

To the south of the dyke the sandstone contains veins of calcite and dolomite with open cavities containing calcite and zeolite (?harmotome) crystals. Veins containing pyrite occur rarely but limonite staining is widespread. There are no metal anomalies. The underlying tuffs contain several thin stratabound bands of nodular pyrite, and assays show a slight enrichment in cobalt (70 ppm) and nickel (260 ppm). One sample contains 840 ppm Cu over 20 cm.

BOREHOLE 3B (AITKEN BOG PLANTATION)

The hole was sited 130 m west of BH 3A on the E–W dolerite dyke and was inclined southwards at 66° to drill out of the dyke and sample a full sequence of limestone close to North Mine (Figure 10b). (A vertical hole sited on the south side of the dyke would have been preferred, but was impossible owing to access difficulties.)

The bore passed through 2 m of boulder clay followed by an inclined thickness of 14 m of quartz-dolerite. The dolerite has a chilled and brecciated southern margin which is steeply-inclined to the north and may be a fault plane. On emerging from the dyke, the bore sampled 0.2 m of baked basalt, a thin tuff (0.5 m) and a 3 m sandstone. The sandstone has an intra-formational breccia of sandstone–mudstone in the centre and becomes calcareous towards the base, where it rests directly upon limestone. As in BH 2, the Petershill Limestone may be divided into two units. The upper unit has a true thickness of about 10.5 m and consists of fossiliferous dark, fine-grained, crystalline limestone with more-argillaceous, nodular bands increasing downwards and passing into the lower unit. This has a true thickness of about 9 m and is generally more-argillaceous with nodular bands, shell debris and disseminated mineralisation (see below). Sporadic cherty bands and bands of diagenetic silicification occur throughout both units. The limestone is underlain by a carbonaceous mudstone with coaly fragments and thin limestone bands (true thickness 0.9 m) as in BH 2. Beneath the mudstone the underlying tuffs are pale and soft with rootlets for 2 m, suggesting a seat-rock (fireclay), beneath which the bore penetrated a true thickness of 40 m of bedded tuffs and agglomerates. Within the pyroclastic sequence are a 3 m massive sandstone with tuffaceous fireclays at top and bottom and a 1 m band of shelly, nodular and argillaceous limestone.

The dolerite dyke contains a few calcite veins, possibly some baryte and sporadic pyrite with rare chalcopyrite. The brecciated chill is particularly impregnated with calcite and assays 280 ppm Cu over a 25 cm width. The basalt and thin tuff are not mineralised. The sandstone contains thin veins of calcite and baryte, particularly in the lower, calcareous part. Some of the calcite veins also contain a little galena. The mudstone band in the centre of the sandstone contains pyrite, a trace of chalcopyrite and, in the sedimentary breccia matrix, small euhedral crystals of galena and sphalerite. At the base of the unit, pyrite nodules (up to 5-mm diameter) occur in bands parallel to the bedding. Assays of the mudstone and lower part of the sandstone show relatively high lead (maximum 650 ppm over 25 cm) and zinc (maximum 470 ppm over 25 cm) and baryte veins are reflected by barium values up to 9.1%. High values of arsenic (75 ppm) may be located in pyrite.

The limestone is cut throughout by thin veins of calcite, many of which contain appreciable amounts of galena and more rarely sphalerite as small crystals. Baryte veinlets are rare. Pyrite occurs as disseminations, in replacement of shell debris and in thin bands of 5 mm nodules parallel to the bedding. The pyrite increases in amount downwards and becomes very abundant in parts of the lower unit of argillaceous limestone. In the underlying mudstone, some bands contain up to 30% pyrite. Sphalerite is rarely visible in the basal 5 m of limestone but can be recognised in the underlying mudstone in thin stringers and small nodules parallel to the bedding. It is also present in the tuffaceous seat rock in 1 cm bands of brownish nodules. Assays of the limestone show high values of lead and zinc, particularly in the lower unit with values of 850–1100 ppm Pb and 1250–18 000 ppm Zn. The underlying 0.9 m of mudstone has even higher values (6200 ppm Pb, 31 000 ppm Zn) and even the tuffaceous seat-rock has 770 ppm Pb and 3500 ppm Zn, presumably due to downward leaching. Below the seat-rock the high values end abruptly. The distribution of lead and zinc through the borehole is shown in the histogram superimposed on Figure 10b. It is seen that, whereas values of lead are high throughout the limestone, the overlying sandstone and the underlying mudstone and seat-rock, high zinc values are more-or-less restricted to the lower unit of limestone, the mudstone and seat-rock, defining a mineralised zone with a total true thickness of 11 m. Average concentrations within this 11 m are 0.14% Pb and 0.66% Zn. Galena is present in thin calcite veins and on joints and nodular sphalerite is seen in the mineralised zone. These minerals were also detected microscopically as fine grains in the mineralised limestone, especially in samples with very high assays. They are abundant as fine disseminations in the mineralised soft mudstone. Values of other metals within the mineralised zone are not anomalous, with the exception of arsenic (average 49, maximum 166 ppm) which is most likely present in the pyrite. This is a significant contrast with BH 2 where, although the lower unit of limestone is rich in pyrite, it does not contain appreciable arsenic or lead and is only slightly enriched in zinc.

Below the seat-rock, the tuffs and agglomerates have little visible sign of mineralisation. Thin veinlets of calcite or baryte occur rarely, and very sparse disseminated pyrite is concentrted in small nodules. The assay data shows a consistent slight enrichment in cobalt and nickel throughout the pyroclastic sequence averaging about 80 ppm Co and 170 ppm Ni. Arsenic is not enriched, so the

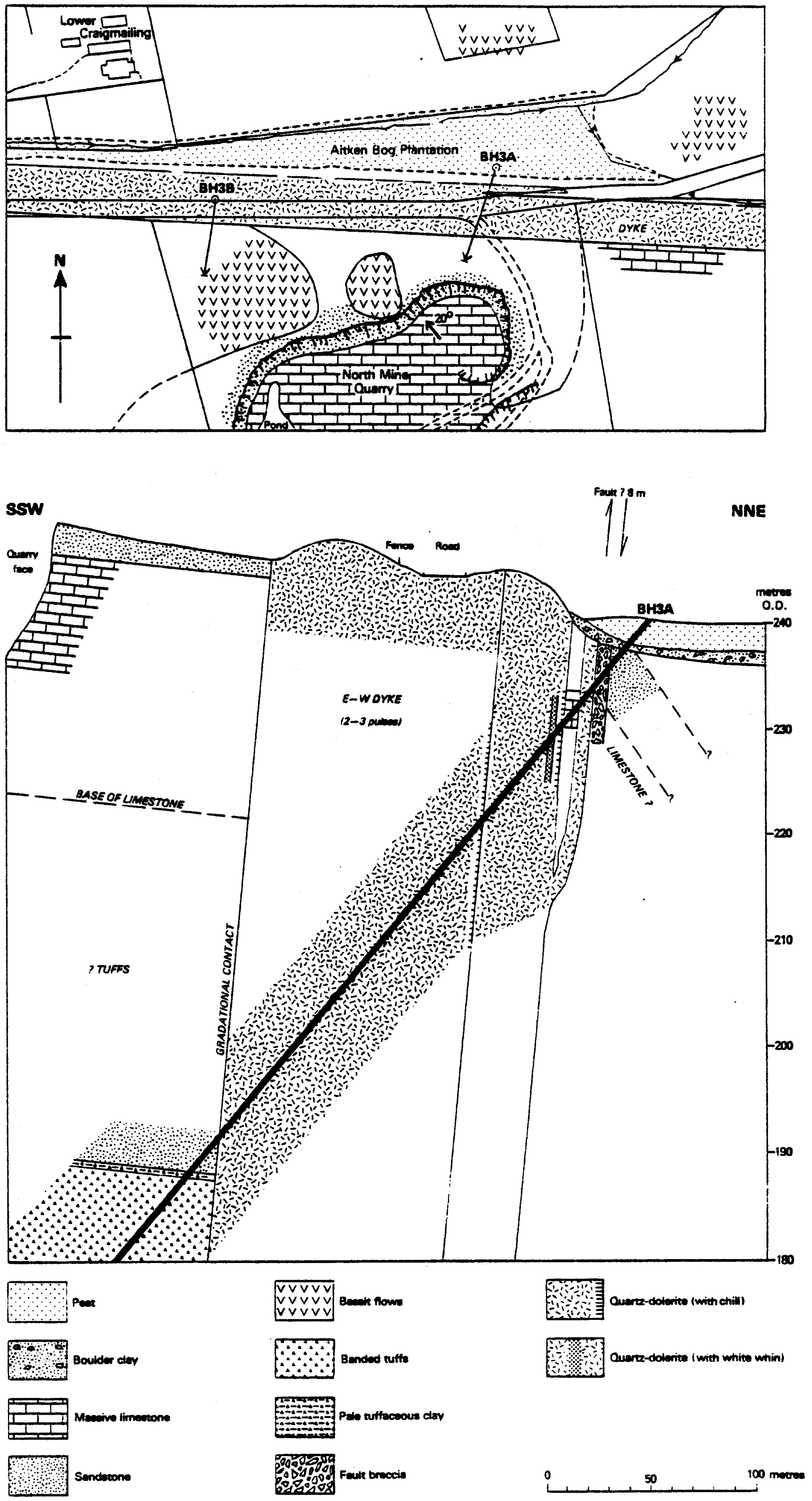
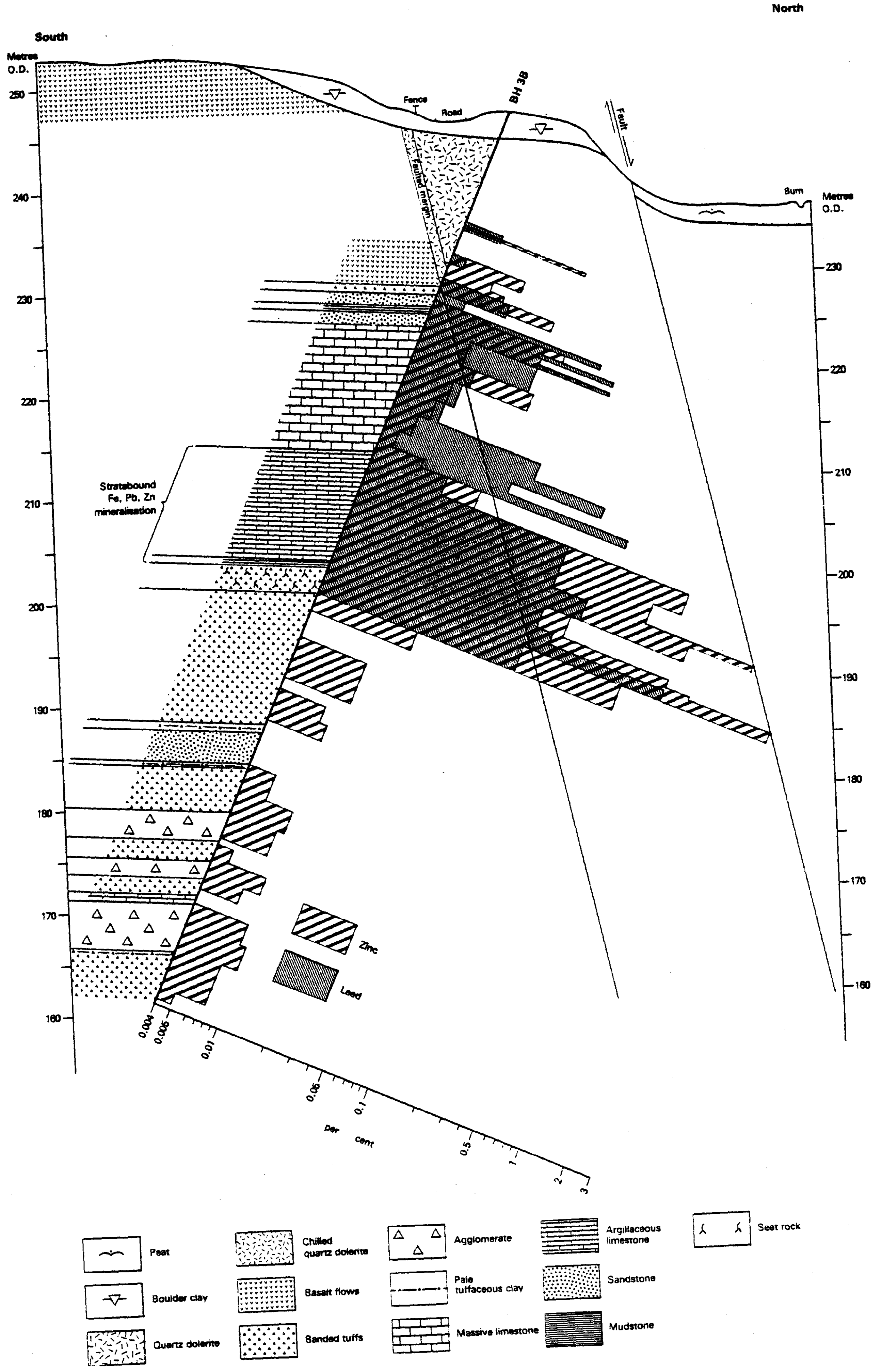


Fig. 10 Location plan and interpreted sections of Bore Holes 3A and 3B (Aitken Bog Plantation). Symbols as for Fig. 8. Histograms on Bore Hole 3B show concentrations of lead and zinc in a continuous section from the dyke margin downwards.


South
North
Metres O.D.
250
240
230
220
210
200
190
180
170
160
Fence
Road
BH 3B
Fault
Faulted margin
Burn
Metres O.D.
230
220
210
200
190
180
170
160
Stratabound Fe, Pb, Zn mineralisation
Zinc
Lead
0.004
0.006
0.01
0.05
0.1
per cent
0.5
1
2
3
Peat
Boulder clay
Quartz dolerite
Chilled quartz dolerite
Basalt flows
Banded tuffs
Agglomerate
Pale tuffaceous clay
Massive limestone
Argillaceous limestone
Sandstone
Mudstone
Seat rock

cobalt and nickel may be present as sulphides or in secondary minerals derived from mafic silicates of the basaltic volcanics. The thin limestone within the pyroclastics contains some pyrite-rich bands, but has no anomalous metal values. The sandstone band within the pyroclastics contains a sparse dissemination of pyrite. Macroscopic interstitial areas of metallic, pink-brown niccolite occur in the upper part of the sandstone which contains the highest values of cobalt, nickel and arsenic recorded in this investigation (105 ppm Co, 500 ppm Ni and 871 ppm As over 1.8 m thickness).

The 11 m thick zone of stratabound lead–zinc mineralisation encountered in this borehole is the most significant find of the present investigation and will be discussed in more detail in the following sections.

PETROGRAPHY AND MINERALOGY

Based on the descriptions given in Appendix III, five principal rock types are distinguished: limestone, sandstone, mudstone, dolerite and tuff, in which two principal styles of metalliferous mineralisation are recognised: synsedimentary (including diagenetic) and epigenetic.

LIMESTONE

The limestone is invariably dark grey or black due to the presence of organically derived carbon. The most prevalent texture is that of shell fragments, matrix-supported in a fine or medium-grained lime mud. The shell fragments are replaced by sparry calcite of diagenetic origin. Although entire fossils are virtually absent save for ostracod tests and other minute shells, delicate ornamentation is often preserved. The present grain size of the matrix probably reflects some diagenetic coarsening of original lime muds. Other than this diagenetic recrystallisation, the rock has been little altered since original deposition. Though fracturing and calcite veining were developed at some later stage, the host limestone is not altered about the veinlets, nor is there evidence of metal impregnation into the rock from the veinlets.

In some instances the limestone contains detrital quartz grains, though in several fossiliferous specimens this component is absent. Several of the specimens examined also contain thin seams of highly carbonaceous clay–calcite mud.

No examples of nodular chert were encountered in these specimens, but at least two limestone specimens showed clear evidence of silicification (e.g. replacement of shell fragments by chalcedonic silica). One of these was also highly pyritic, suggesting silicification by exhaling siliceous metal-bearing brine.

SANDSTONE

The few sandstone specimens are well sorted and lack rock fragments and other evidence of immature sediments. All contain a coarse calcite cement which, in one specimen, is in crystallographic continuity with cross-cutting calcite veinlets.

MUDSTONE

Dark grey to black graphitic mudstone, variously calcareous and non-calcareous, is the most important mineralised lithology observed. The specimens are very fine-grained, carbon rich, typically soft and crumble easily. In some examples coarse flakes of graphite are present. Some contain populations of sand-grade detrital quartz grains. Others have a lithological character approaching the limestone, and may be described as calc-mudstone or muddy limestone.

IGNEOUS ROCKS

Specimens of altered dolerite ('white whin') show a complex type of hydrothermal alteration in which two distinct, though probably effectively contemporaneous, alteration styles are superimposed. In one, pervasive clay/chlorite formation is accompanied by deposition of coarse quartz grains. In the other, veinlets and less regular patches of calcite ramify the rock.

Specimens of 'tuff' include a soft, porcellaneous, clay-quartz, tuffaceous seat-rock and heavily chloritised bedded agglomerate. A feature of the seat-earth is minute cavities filled with chlorite often accompanied by calcite, and discontinuous hairline veinlets of similar material [CXD 392, BH 3B, Appendix III]. It is possible that these represent vesiculation resulting from steam generated either by rapid heating of sea water or by boiling hydrothermal brine, or that they are of botanical origin (see preceeding text).

The agglomerate consists of rounded drops (lapilli) of quenched microporphyritic basalt which form a self-supporting fabric in the interstices of which occur chlorite and sparry calcite. The rock is generally chloritised and bleached. In its structure it suggests a spray of lava droplets accumulating in water from a nearby subaerial eruption.

SYNSEDIMENTARY MINERALISATION

Two styles of synsedimentary mineralisation were observed. One is the formation of fine pyrite grains in graphitic black mud, which is a common feature of such rocks. The other is the heavy impregnation of certain mudstone and muddy limestone beds with pyrite, sphalerite and minor galena. The sulphides occur as fine disseminations and in some cases as small dense lenses located on bedding planes. There is no textural evidence for epigenetic metal introduction in these rocks. The nature and intensity of the stratiform metal enrichment seen in BH 3B between 36.6 m and 49.5 m (see Appendix II) demand input from a metal-enriched hydrothermal brine. A biological aspect to the mineralising process is indicated by the frequency of well preserved pyrite framboids and, in one specimen [CXD 322, BH 2, Appendix III] well preserved cellular and laminar structures of possible algal origin.

Most of the sulphide grains (pyrite and traces of sphalerite) in the limestone formed during diagenetic recrystallisation, as evidenced by their euhedral crystal forms, their partial replacement of shell fragments and their coarse grain size. Coarse, cuboid pyrite crystals of diagenetic origin are also frequent in mineralised mudstone, and in the most metal-enriched specimens similarly coarse sphalerite grains are conspicuous in the otherwise finely disseminated sulphide.

EPIGENETIC MINERALISATION

Veins and thin veinlets are present in many of the specimens. Though dominated by calcite, they also contain pink baryte, pyrite, galena and rare sphalerite. This veining must account for most of the barium anomalies recorded in the drillcore, and for much of the lead. It is developed on brittle fractures and may be considerably younger than the host sediments. Only one generation of such veins was discerned.

Another style of possibly epigenetic mineralisation is seen in the occurrence of interstitial sulphide patches developed in the calcite cement of certain sandstone specimens. Though most examples were pyrite, one sandstone specimen was found to contain niccolite (NiAs) in excess of pyrite, and the geochemical sample from which it came [CXD 400, BH 3B, Appendix II] contains 105 ppm Co, 500 ppm Ni and 870 ppm As.

Minor sulphide enrichment occurs in the tuffaceous seat-earth, and in the underlying altered agglomerate in BH 3B. In the former, sphalerite, pyrite and galena occur in association with calcite in the vesicles and veinlets. In the agglomerate pyrite occurs in association with calcite in interstices. The age of these sulphides is unclear.

SUMMARY OF MINERALISATION

The present investigation provides information on previously-undetected stratabound mineralisation in the Hilderston Mine area. It also provides further insight into a reinterpretation of the old mining records, in order to establish the nature of the vein mineralisation.

STRATABOUND ZINC-LEAD SUITE

The borehole at Aitken Bog, North Mine (BH 3B) indicates considerable stratabound Zn-Pb mineralisation within the Petershill Limestone and to a lesser extent in associated sediments. The most heavily-mineralised zone has a true thickness of 11 m, comprising the basal 8 m of limestone, an underlying 1 m of carbonaceous shale and 2 m of tuffaceous seat-rock. The zone has average concentrations of 0.14% Pb and 0.66% Zn but values of 0.6% Pb and 3.1% Zn occur in the carbonaceous shale. Zn/Pb ratios are of the order of 5. Above the mineralised zone, in the upper part of the limestone and overlying sandstone, lead values are anomalous, but zinc is rarely significant and the Zn/Pb ratio is consequently lower (0.5 to 0.2). Within the mineralised zone, pyrite (probably with appreciable arsenic) occurs as disseminations, in nodular bands and as replacement of organic material; sphalerite is very finely disseminated and in nodular bands; and galena is very finely disseminated and as larger crystals in thin calcite veins. Calcite veinlets in surface exposures of limestone contain up to 1800 ppm Zn up to 350 m south of BH 3B (Ologun, 1978).

In the Silver Mine area 990 m south of BH 3B, a similar lithological sequence is observed, including 1 m of carbonaceous mudstone (BH 2). Here, levels of lead and zinc are only moderate (100 ppm Pb, 300 ppm Zn, Zn/Pb = 2 to 5) and there is no increase in the lower levels of limestone and mudstone. Pyrite is widespread but contains no appreciable arsenic. A small amount of silver (2-6 ppm) in the limestone is probably a halo around the silver vein and calcite veins contain up to 4.9% Pb and 440 ppm Zn (Ologun, 1978). Sandstones above the limestone have a low enrichment in lead comparable with that of the limestone.

Farther south, the lower part of the limestone is not exposed in the quarries but boreholes described by Jameson (1980) prove that the lower argillaceous limestone and carbonaceous mudstone persist beneath variable overlying facies for at least 2 km. Analyses of calcite veinlets from the limestone show sporadic lead anomalies (max. 842 ppm Pb), but no significant Zn south of the Silver Mine (Ologun, 1978).

Below the limestone and mudstone in both BHs 2 and 3B the pyroclastic rocks and interbedded sandstones show an overall slight enrichment in nickel and cobalt, but not arsenic.

VEIN LEAD-ZINC SUITE

In the lower part of Hilderston Mine the worked vein appears from old records to have consisted mostly of calcite and dolomite with galena, sphalerite, pyrite and minor amounts of niccolite and albertite. Baryte does not seem to have been so abundant as in the upper part of the vein. The vein occurred in an E-W fault breccia where it cut the Petershill Limestone. A thin dolerite dyke occurs in the western part of the fault but dies out eastwards. East of the worked vein (BH 2) the fault breccia carries little visible metalliferous mineralisation but a narrow zone (3 cm) with high values of Pb, Zn, Co, Ni, Ag, As and Ba confirms a connection with the vein.

A longer worked vein, 60 m north of the original mine has only calcite, pyrite and galena recorded. This vein appears to have passed up into sediments overlying the limestone and has also been traced westwards through a wide N-S quartz-dolerite dyke.

VEIN SILVER-NICKEL-COBALT SUITE

In the upper part of Hilderston Mine the vein contained economic concentrations of silver and nickel. Old records suggest that this part of the vein consisted chiefly of baryte with masses of niccolite and some calcite, pyrite, chalcopyrite and native silver. Secondary minerals were annabergite and erythrite. Galena and sphalerite were probably not present in appreciable amounts. The assemblage thus consists of arsenides, arsenates and sulphates rather than sulphides. The vein occurs in an E-W fault plane containing a thin quartz dolerite dyke in clastic sediments and tuffs above the Petershill Limestone. The vein terminated in the west at a N-W dolerite dyke and is not recorded beyond the eastern limit of the E-W dyke. A silver halo is detected in the Petershill Limestone close to the mine (BH 2) and Ologun (1978) records anomalous values of cobalt, lead and zinc in calcite veinlets.

VEIN BARIUM-COPPER SUITE

Away from the immediate Hilderston Mine area vein mineralisation of a slightly different, less intense nature is found within and on the margins of E-W quartz-dolerite dykes. On Cairnpapple Hill (BH 1B) a wide zone of 'white whin' in a fault zone contains visible baryte, pyrite, some chalcopyrite and hydrocarbons in addition to more widespread chlorite and calcite veins. Assay data reveals an overall enrichment in arsenic; copper values up to 100 ppm in the centre of the zone; barium values of 3000-4000 ppm on the margins of the zone; and 500-900 ppm Pb on the footwall margin. Zinc, being a relatively mobile element, is slightly depleted in the zone and may have been leached out and redeposited elsewhere.

At North Mine, where Forsyth (1847) reports that copper was once worked, the margins of a dolerite dyke and the enclosing sediments are impregnated with irregular baryte veins. Disseminated pyrite is widespread, chalcopyrite is rarely observed and open cavities in country-rock limestone contain zeolites and fluorite. Most of the mineralisation occurs in the earlier, northern dyke sheet which has generally high copper assays (maximum 850 ppm), the highest encountered in this investigation. The later, southern sheet is less mineralised with few moderate copper and zinc assays (maximum 180 ppm Cu, 400 ppm Zn). The contrast between the two sheets suggests that the vein mineralisation was more-or-less contemporaneous with dyke intrusion.

GENESIS

The depositional environment of the Petershill Formation as described by Jameson (1980) would seem to be ideal for the accumulation of metalliferous minerals. The formation was deposited in a shallow shelf sea fringing a volcanic landmass and represents a relatively short quiescent period within a very active volcanic and volcaniclastic development. Between the Silver Mine and North Mine Quarry, Jameson (1980) postulates a shallow, sheltered, coastal lagoon (Figure 2). Anaerobic conditions with restricted circulation are indicated by the dark, argillaceous carbonate lithologies with shell debris and algal structures replaced by iron sulphides. It is also reasonable to suppose that the rate of heat flow was high in the area at the time of deposition, manifested by intense and prolonged volcanic activity and possibly associated with a large intrusion at depth, now seen as regional magnetic and gravity anomalies close to the Bathgate Hills.

If the strata accumulating in the area were sufficiently permeable, it is likely that convective cells, generated and perpetuated by the high heat flow, could circulate potential mineralising solutions throughout the succession. A rapidly developing, essentially volcanic pile in a tensional, mid-basin stress regime could be expected to be very permeable, due to a combination of lithology and penecontemporaneous jointing and faulting. The source of the mineralising solutions is always a matter of great debate. In a marine environment the possibility always exists that seawater may be circulated as suggested by Russell and others (1981). In contrast Badham (1981) has suggested that many shale-hosted massive sulphide deposits are the product of exhalation of formation waters. In view of the stratigraphic horizon of the Hilderston deposits above the Oil-Shale Group and the common presence of hydrocarbons it is possible that connate waters from the oil-shales may have been responsible for the mineralisation. Carruthers (1927, p. 230) records the presence of such brines within Scottish oil-shale workings, as 'brackish water containing carbonates and chlorides of lime and magnesia, along with alumina, but no sulphate', and similar sulphate-deficient brines from springs and mine waters originating in Carboniferous-age rocks are well-documented elsewhere in Britain (Anderson, 1945; Edmunds, 1975).

Assuming that brines existed and that a mechanism was available to circulate them, it is now necessary to consider the origin of the metals. It is unlikely that they may have been derived directly from the volcanics. Few analyses are available from the immediate area but there is no evidence to suggest that they are unusually enriched in base metals and it is probably significant that no mineralisation is known to exist within the volcanics themselves. It is possible that metals may have been leached out of the pre-Carboniferous basement but the simplest explanation seems to be that they may have been expelled, with the brines from the oil-shales. Unfortunately, trace element data is not available for the Lothian oil-shales but elsewhere the association of ores with hydrocarbon-bearing sedimentary sequences and the presence of Fe–Zn–Pb sulphides (+Ba and Cu) in oil reservoirs, is well-established (Carpenter and others, 1974; Hitchon, 1977). Boyle (1968) records that oil-shales are also enriched in silver relative to other sediments.

The origin of the sulphur cannot be determined with any certainty in the absence of sulphur-isotope data, but there is an abundance of potential sources, all of which may have contributed. The close proximity of active vulcanicity would ensure a supply of primary sulphur, and SO_4 dissolved in sea water would be readily precipitated by biological reduction in the euxinic environment of the coastal lagoons. Although the underlying oil-shales have a high sulphur content, metallic sulphides are very insoluble and mineralising fluids in general are sulphur deficient. This is confirmed in this specific case by the composition of brines observed in the oil-shales and quoted above (Carruthers, 1927). It therefore seems likely that the metals were transported as soluble chlorides and combined with sulphur from a separate source at higher levels.

From the above discussion it is possible to propose a tentative model as follows. High heat flow during the Lower Carboniferous, possibly associated with a deep seated igneous body, gave rise to intense volcanic activity centred upon the present Bathgate Hills. Convection currents were generated within the stratigraphic pile involving expelled formation water and possibly downward-circulating sea water. Fluids originating in, or circulating through sediments of the Oil-Shale Group became charged with ionic chloride complexes and were expelled onto the floor of a coastal lagoon. There they formed pools of dense brine in a calm, reducing environment and reacted with sulphur in the sea water and sediments around the volcanic landmass to form stratabound sulphides within the argillaceous carbonates which were precipitated in the lagoon.

The reduction in mineralisation southwards from North Mine (BH 3B) can be explained in two ways. On sedimentological evidence the lagoonal environment passes southwards into a more turbulent, oxidising environment which would preclude mineral deposition on both dynamic and chemical grounds. This does not, however, explain why the argillaceous carbonates and carbonaceous shale, which underly the whole of the reef development to the south, show no signs of stratabound mineralisation. An alterntive suggestion is that the mineralising fluids were localised in a restricted lagoon (cf. Figure 2b) or by a syndepositional fault (i.e. the E–W fault at North Mine) in a situation analagous to that seen in many Irish base-metal deposits (Morrissey and others, 1971; Deeny, 1981). Slumped and eroded bedding interfaces and thin sedimentary breccia horizons indicating periodic disturbance of the sediments add support to this hypothesis.

It is possible that at least some of the stratabound mineralisation may be post-sedimentary. For example, the sulphides in the 2 m of tuffaceous seat-rock at the base of the mineralised sequence could have originated by downward leaching under sub-aerial conditions from an earlier stratabound accumulation as it was removed by erosion. Alternatively it could represent deposition from rising solutions trapped or retarded beneath the relatively impermeable carbonaceous mudstone. Post-depositional and post-diagenetic circulation of mineralising solutions is also indicated by the thin sulphide-bearing calcite veinlets throughout the limestones.

Epigenetic veins are concentrated in E–W fault lines, most of which contain quartz-dolerite dykes. The evidence of BH 3A indicates that the vein mineralisation was contemporaneous with dyke intrusion and may therefore be of late-Carboniferous age. High heat flow was probably localised in the vicinity of quartz-dolerite intrusions, resulting in renewed circulation of metalliferous brines. The high hydrocarbon content of the veins suggests that distillation of the oil-shales by the intrusions played a major part and all of the metals present in the veins could have been derived from this source. Leaching of country rocks by the same solutions at higher levels could have reactivated and redistributed the earlier stratabound Pb–Zn mineralisation to produce veinlets throughout the Petershill Limestone and contribute to the larger veins. Some cobalt and nickel may also have been leached from the tuffs and concentrated in the veins during this phase. Within and on the margins of the dolerite dykes, copper and fluorine indicate mineralising fluids of slightly higher temperature, possibly more directly associated with the dykes.

This later, epigenetic mineralisation is contemporaneous with a major Carboniferous–Permian phase which was responsible for many of the mineral deposits of the British Isles and northern Europe (Dunham and others, 1978). Similar polyphase vein deposits involving Fe–Cu–Zn–Pb and later Ba–Ni–Co–Ag–As, separated by Permian dolerite intrusion, occur at Kongsberg in the Oslo Graben, Norway (Bugge, 1978; Neumann, 1944). In age, composition and location these are the closest comparable deposits to those of Alva and Hilderston.

FURTHER EXPLORATION

The presence of a vein containing high-value metals at Hilderston mine is unlikely to be an isolated occurrence. Identical environments to that at Hilderston occur throughout the Bathgate Hills where E–W faults and quartz-dolerite dykes cut the Petershill Formation and other limestones within the volcanic pile. However, the worked vein was very limited in lateral and vertical extent, so the chances of intersecting similar small deposits with boreholes is slight. The Ni–Co–Ag vein occurred on a faulted dyke margin in clastic sediments above the Petershill Limestone. Any exploration for vein deposits should, therefore, be concentrated in areas in which limestones are cut by dykes and faults, either in surface crops or projected to depth. An orientation soil survey around the known vein (Ologun, 1978) suggests that deep-drift sampling in suitable target areas may be successful. Mn, Ba and As show the greatest coincidence with the vein within a wider halo of Pb, Co and Ni.

Despite the possibility of further Ag–Co–Ni bearing veins, the greater potential for mineable economic deposits in the area lies in the stratabound Zn–Pb mineralisation discovered in the present investigation. The significant thickness of stratabound Zn–Pb deposits identified in the Petershill Formation does not appear to continue south of North Mine for more than about 400 m. It could, however, extend (i) westwards, down-dip beneath a rapidly-increasing thickness of overburden or (ii) eastwards and northwards along strike, allowing for a possible eastward swing of strike through the Tartraven quarries. Such extensions could still be in the coastal lagoonal facies (Jameson, 1980) and, therefore, be favourable to sulphide precipitation. Other limestones within the volcanic pile may also provide a suitable environment, especially where small, laterally-restricted lenses may result in particularly high concentrations. One such lens is the Wairdlaw Limestone, which consists of 4 m of very pyritous, argillaceous and nodular limestone similar to the lower part of the Petershill Limestone. Analyses of calcite veinlets in the Petershill, Hillhouse and Wairdlaw Limestones are not encouraging (Ologun, 1978). However, these samples are all from the exposed upper parts of the limestones whereas BH 3B shows that stratabound mineralisation is concentrated towards the base. Nicol (1844, p. 92) records that the Castlecary Limestone at Bowdenhill, which lies directly beneath a thick dolerite sill, contains 'a vein formed of minute unconnected cubical crystals of iron pyrites'. This could indicate the presence of metalliferous mineralisation in limestones of the area at levels well above that of the Petershill.

A programme of shallow boreholes was planned to prove northward extensions of the Petershill Limestone and to test for stratabound mineralisation within the lower part of this formation throughout its known strike length. These holes have now been drilled. A short report, giving detailed logs and geochemical data, is being prepared by Dr M. J. Gallagher and will be available on application to the IGS, Murchison House, West Mains Road, Edinburgh EH9 3LA.

ACKNOWLEDGEMENTS

The project was instigated by E. G. Poole, former District Geologist, North Lowlands Unit. Field assistance and sample preparation were provided by A. Grout, M. G. Hills, F. Lochtie and S. Turley. Analyses were performed by B. S. Chaumoo, D. Peachey, T. K. Smith and B. P. Vickers, and additional mineralogical work was done by B. R. H. Skilton. Access to additional material was kindly arranged by E. N. K. Clarkson (University of Edinburgh) and A. Livingstone (Royal Scottish Museum, Edinburgh). Discussions with our colleagues R. J. Gillanders, I. H. S. Hall and C. D. Will have been beneficial. A. J. Hall and M. J. Russell (University of Strathclyde) were helpful in discussing results on their own work in the area.

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APPENDIX I

BOREHOLE LOGS

Detailed logs of the five boreholes are given in Tables I to V. Inclinations of planar features are given as true dips in the two vertical boreholes (1A and 1B) and as inclinations relative to the core axes in the inclined holes (2, 3A and 3B). Sample numbers (all prefixed by CXD) refer to analyses listed in Appendix II, some of which are also given petrographic and mineralogical descriptions in Appendix III. Sample numbers in brackets are for samples which include parts of more than one lithological unit.

APPENDIX I TABLE I BOREHOLE 1A (CAIRNPAPPLE)

G.R. NS 98938 71954 vertical borehole

All inclinations are given as true dips

Depth (m)	Intersection (m)	Lithology	Mineralisation	Sample No. (CXD)
1.46	1.46	Boulder Clay		
3.12	1.66	Basalt; recovered in fragments		
3.26	0.14	Basalt; dark blue-grey, fine-grained, aphyric.	Small amount of widely-disseminated pyrite.	
4.03	0.77	Basalt; pale greenish-grey, fine-grained, aphyric, altered, some elongate vesicles (3-5 mm). Horizontal parting and alternating darker/paler bands. Some thin bands of flow-brecciation (e.g. 3.46 m and 3.88 m). Very pale with banding dipping at 23° and disseminated carbonate below 3.90 m	Disseminated carbonate in pale, altered zone at base.	
4.20	0.17	Basalt; cream-coloured, fine-grained, aphyric, baked and possibly silicified. Core broken 4.10-4.28 m		
12.13	7.93	Dolerite (sill); greenish-grey, fine-grained, equigranular, scattered ocelli (1-2 mm) of carbonate and a few larger calcite and calcite/chlorite amygdales (up to 15 mm). Becoming slightly coarser downwards below 4.40 m. Irregular pale pink patches (up to 5 mm) of micropegmatite appear below 5.90 m. Coarser-grained (0.5 mm) below 6.02 m. Vertical joints and broken core 6.02-7.20 m. Becoming more patchy in texture below 7.30 m with irregular, interstitial, pale pink micropegmatite patches (up to 10 mm). Several veins (1-5 cm wide) of micropegmatite dipping at a high angle (around 70°) at 8.86 m, 8.96 m, 9.36 m, 9.66 m, 10.20 m, 10.85 m and 11.00 m.	Irregular calcite/chlorite veinlets in top 20 cm. Thin calcite/chlorite coating on joints (vertical and 65°). Some pyrite on irregular, horizontal fractures e.g. 5.08 m and 5.58 m and on joint surface at 6.95 m. Calcite/chlorite vein (5 mm) from 7.05-7.20 m. Basal 5 cm has much disseminated pyrite.	449
13.68	1.55	Basalt; pale grey, fine-grained, aphyric. Appears to be baked with irregular pale green/cream veinlets and bands of pale brecciated material dipping 25°.		
25.62	11.94	Basalt; purplish-grey, fine-grained, aphyric with scattered ocelli (1-2 mm) of calcite. Core is mostly broken. Ocelli not present from 15.19-17.10 m then become larger (up to 3 mm) and more numerous as well-defined amygdales. Zone of very broken rock from 21.59-22.29 m may include a thin dolerite at 22.00 m. Core loss 22.88-23.07 m. Below 23.07 m basalt is generally fresher, blue-grey, fine-grained, aphyric and quite massive. Crumbly and friable from 24.70-24.85 m and very broken below.	Brecciated with pale green/cream/white carbonate vein network 13.80-14.50 m. Zone of diffuse vein network with calcite/chlorite dips 38° from 17.20-17.54 m. Brecciated with calcite/chlorite vein network 18.35-18.76 m. Irregular pale green veinlets often dip 40° below 18.76 m. Some large, lenticular calcite/chlorite patches e.g. 20.67 m and 20.75 m	450
25.74	0.12	Basalt; baked, very pale green, fine-grained, aphyric. Very sharp base dips 25°.		
25.83	0.09	Dolerite (intrusion); chilled, dark to medium grey, very fine-grained.		
27.84	2.01	Dolerite; medium grey, fine to medium-grained, equigranular, few small, scattered calcite ocelli (1 mm), still within the chilled zone but gradually becoming coarser. Passes down into:	Irregular calcite veinlets present.	451
29.00	1.16	Dolerite; pale grey, medium-grained, equigranular, massive and free from any traces of mineralisation. Passes down into:		
30.50	1.50	Dolerite; pale grey, medium-grained (1 mm), regular-textured, equigranular but with many pinkish-white, irregular patches (up to 10 mm) of micropegmatite. 1.5 cm wide vein of doleritic pegmatite (crystals 2 mm long) dips 30° at 30.03 m	Open vesicles (3 mm) with calcite in places.	
58.20	27.70	Dolerite; coarser-grained (>1 mm) with patches of micropegmatite, becoming larger and more numerous downwards, resulting in a paler overall rock colour. Generally massive, unbroken core, pale grey with pinkish micropegmatite occupying 50% of the rock in patches up to 10 mm in size. Thin, irregular pink/grey veins of micropegmatite average 5 mm in width. Also irregular patches of cream/white doleritic pegmatite with elongate pyroxene crystals up to 2 mm long. Large patch of dolerite pegmatite from 58.00-58.19 m has large, black blades of pyroxene (up to 15 mm) in a fine-grained, slightly drusy, creamish white matrix.	Very small amounts of fine-grained, widely-disseminated pyrite.	452 453
80.71	22.51	Dolerite; dark purplish-grey, coarse-grained (1.5 mm), fresher and more equigranular than above with little obvious, interstitial micropegmatite. Massive and unbroken core with very few, unmineralised joints dipping 46°, 50° and 82°. Slightly coarser-grained below 64.00 m. Doleritic pegmatite patch with pyroxene blades (15 mm long) in fine-grained, cream mesostasis 68.00-68.27 m. Near-horizontal, 5-15 mm wide veins of banded micropegmatite at 75.33 m, 76.85 m, 78.68 m and 80.60 m. Continuing as very coarse-grained (1-1.5 mm) dolerite with a regular equigranular texture. No sign of an approaching base to the intrusion.	Small amounts of fine-grained, disseminated pyrite throughout. Few, thin (2 mm wide) quartz/calcite veinlets dip 77° from 75.56-77.00 m.	454 453 455
80.71		End of Borehole		

APPENDIX I TABLE II BOREHOLE 1B (CAIRNPAPPLE)

G.R. NS 98946 71986 vertical borehole

All inclinations are given as true dips

Depth (m)	Intersection (m)	Lithology	Mineralisation	Sample No. (CXD)
0.64	0.64	Boulder Clay; with dolerite clasts		
1.10	0.46	Dolerite; recovered as limonite-stained fragments.		
1.10 20.50	19.40	Dolerite; bluish-grey, medium-grained (1 mm feldspars), equigranular texture, fresh, massive; white or glassy plagioclase laths in a fine-grained, grey groundmass; black, mafic patches are often ophitic; irregular, interstitial pinkish patches (up to 2 cm) and diffuse veins (5 mm) of micropegmatite. Open, limonite-stained joints and fractures to 2.82 m. Broken core 2.82-3.40 m. Coarser-grained (1 mm mafics) below 3.40 m with larger, more frequent, pink micropegmatite patches up to 5 mm and sometimes 10 mm wide. Few joints dip at 32°, 48° and 66°. Below 6.50 m irregular patches and sub-vertical veins of micropegmatite are more frequent to 12.00 m. Below 12.00 m dolerite is darker with less micropegmatite. Core broken along many 80-90° dipping joints from 12.90-14.50 m. More pink patches below 18.50 m, increasing downwards with irregular 2 cm, sub-vertical veins to a sharp cut-off with calcite/chlorite veins at 20.50 m.	Very small, very widely-scattered specks of pyrite visible throughout. Very thin layer of chlorite on some joints. Irregular, sub-vertical calcite/chlorite veins (up to 2 cm wide) with some small, prismatic crystals (1 mm) of smokey quartz in cavities from 10.00-11.20 m and 11.73-11.96 m. Calcite-lined joints dip 80-90° from 12.90-14.50 m. Diffuse, horizontal, red-brown, oxidised, pyrite-rich bands from 14.80-15.36 m. Thereafter, chlorite-lined joints throughout with occasional very small amount of calcite. Sharp cut-off of micropegmatite veins at a calcite/chlorite vein at 20.50 m	425 426 427 428
28.28	7.78	Dolerite; coarse-grained; pegmatitic in parts with large, acicular crystals (up to 5 mm) and stellar aggregates of dark green pyroxene; also large, irregular, sub-vertical, pink patches of micropegmatite to 21.22 m. Dolerite below is more greenish, less pink, with an almost mottled appearance due to white patches of feldspar up to 5 mm wide; coarse-grained (1-2 mm). Pegmatitic with 5 mm long acicular pyroxene from 23.90-24.24 m. Continuing below as very coarse, mottled dolerite with 3-5 mm white patches. Becoming pale green below 26.25 m with a little disseminated carbonate. Very sharp, faulted base dips 60° from 28.28-28.39 m	Irregular, sub-vertical calcite/chlorite veins and patches at 23.55 m and 24.25-24.70 m. Many irregular calcite/chlorite veins below 25.15 m with more regular veins (5-10 mm wide) dipping at 27°, 45° and 70°. Veins contain small vugs with possible quartz below 26.90 m	429 430
33.98	5.70	"White whin" (fault zone); very pale grey to white, coarse-grained (1-2 mm feldspars), altered dolerite consisting of white plagioclase, pale grey mafics and pink micropegmatite patches; texture and degree of alteration are very constant; some carbonate, possibly replacing mafics and much white kaolin. Angular "fragment" of pale green dolerite with a sharp margin and rim of calcite from 30.78-30.94 m. Low density and very friable with much white clay (?kaolinite) and yellow iron-staining from 33.39-33.98 m.	Cut by thin, irregular calcite veinlets. Veins are larger with many open vugs (up to 5 cm wide) from 28.96-30.53 m. Vugs contain rhombic and dog-tooth crystals of calcite and occasional small specks of pyrite. Some sub-vertical, closed veins of calcite. Dark staining may be hydrocarbons. Small, clear, prismatic crystals in stellate clusters in vugs (e.g. 29.59 m) are probably zeolites. Small calcite veins and vugs from 31.00-31.80 m. Larger veins and vugs from 31.80-33.39 m. Large, pyrite-rich vug with a greenish tint from 32.92-33.05 m. Irregular vein with calcite and pyrite in small vugs has sharp contact with footwall dipping 83°.	431 432 433
37.40	3.42	"White Whin"; visible dolerite texture as above. Passing down into:	Few thin, irregular calcite veins. Disseminated pyrite abundant in top 30 cm. Some small vugs lined with black hydrocarbon.	434
38.60	1.20	Dolerite; pale green, coarse-grained (1-2 mm), equigranular, fresh, black, shiny pyroxene. Passing down into:	Calcite/chlorite veins (5 mm) with a little pyrite dip 56° and 66°.	435
45.85	7.25	"White whin"; doleritic texture as above, pink patches prominent. Ends at a sharp junction with a 1 cm wide calcite vein dipping 40°.	Little disseminated pyrite throughout. Few, irregular calcite veins, many of which are sub-vertical. Some have small pyrite nodules (e.g. 40.71 m). White ?kaolinite vein dips 60° at 41.32 m. Irregular, sub-vertical vein (2 cm) with calcite, cream coloured clay, hydrocarbon and small pyrite patches from 41.70-41.98 m. Thin, irregular, sub-vertical calcite/hydrocarbon veins continue to 42.90 m. Irregular open vug with much pyrite from 44.50-44.55 m. 2 cm vein, mostly of cream-coloured ?clay mineral + hydrocarbon and few vugs, dips 40° at 45.40 m. Sub-vertical, 1-2 cm vein of pure calcite from 45.56-45.85 m.	436 437 438
51.55	5.70	Dolerite; blue-grey, altered, passing down into cream-coloured dolerite and "white whin" around 46.80 m. Brecciated from 47.25-48.45 m ending in a joint dipping 60°. Continuing as "white whin" with pinkish patches to a sharp, brecciated base dipping 65-75° from 51.35-51.55 m. End of fault zone	Irregular calcite patches and veinlets with some pyrite. Pyrite on joints dipping 40° at 47.25 m. Pyrite in interstices of breccia zone and in thin veinlets from 47.25-48.45 m. Joint at base of breccia is coated with hydrocarbons and pyrite. Below this are thin calcite veins with pyrite and hydrocarbons. Irregular, white veinlets of clay mineral occur below 48.95 m together with cream and white clay mineral/calcite veins with pyrite. Very pyrite-rich vug (5 mm wide) at 50.68 m. Brecciated base is heavily-veined by calcite with pyrite.	439 440 441

APPENDIX I TABLE II (continued)

Depth (m)	Inter-section (m)	Lithology	Mineralisation	Sample No. (CXD)
59.00	7.45	Dolerite; pale grey, medium-grained (1 mm), equigranular, massive; some free quartz visible; small interstitial pink patches. Larger (5 mm) patches of pinkish micropegmatite below 58.00 m with a 2 cm wide horizontal vein at 58.55 m.	Few very thin calcite veinlets; sparse disseminated pyrite. Long, thin vertical veins of thick, sticky, black hydrocarbon with a little calcite from 53.74-54.62 m. Less hydrocarbon-rich, vertical calcite vein from 54.94-55.80 m. Calcite veins (5 mm wide) dip 52°, 72° and 82° from 56.00-56.35 m. Sub-vertical calcite/chlorite vein (5 mm) from 58.55-58.99 m.	442 443
82.26	23.26	Dolerite; grey, mottled, coarse-grained (1-2 mm), slightly pinkish micropegmatite patches up to 5 x 10 mm in size. Slightly brecciated with large, interstitial patches of pinkish micropegmatite from 67.75-67.85 m. Irregular texture due to dark patches of chloritic alteration from 68.95-69.40 m. Dolerite is pale greenish below 69.40 m and below 70.00 m it has a coarse, pale, mottled appearance due to conspicuous white to pale pink patches of micropegmatite. Particularly pale, patchy and coarsely-mottled from 73.70-74.70 m. Finer-grained, green and mottled below 74.85 m to around 76.18 m. Pegmatitic patches with long crystals of pyroxene in a pink groundmass from 76.67-77.10 m. Dolerite is darker grey-green, mottled and coarse-grained (1-2 mm) with white, interstitial patches below 77.10 m, continuing with a very uniform texture to base of borehole.	Little disseminated pyrite throughout. Calcite veins (5-10 mm), vertical and 56° from 59.71-60.10 m. Zoned pod (10 x 4 cm) from 60.94-61.04 m consisting of, from the outside; calcite/chlorite - calcite - thick, sticky, black hydrocarbon - crystals of smokey quartz - central void. 2 cm vein of calcite with hydrocarbons dips 70° from 61.30-61.42 m. Vertical 5 mm calcite vein from 63.18-63.38 m. 5-10 mm calcite/chlorite vein dips 78° from 63.89-64.16 m. Calcite veins (5 mm) from 65.40-65.81 m. Thin calcite veinlets (< 5 mm) with pink acid pegmatite patches from 66.50-67.85 m. Irregular, thin (5 mm) calcite vein dips 80° from 68.15-68.50 m. Irregular, sub-vertical and 75° calcite/chlorite veins from 69.56-71.00 m. Below 71.00 m are many thin calcite veinlets with occasional thicker veins (5 mm) dipping 75° from 72.27-72.90 m. Calcite/chlorite veins (5 mm) dip 50° at 73.73 m and 68° at 74.45 m. 3-5 mm wide calcite/chlorite veins with pyrite dip 75° in opposing directions from 75.10-75.54 m and 75.60-76.01 m. Thin, sub-vertical calcite/chlorite veinlets persist to 77.80 m. Occasional chlorite/calcite veins (5 mm) dip 45° at 78.22 m, 78.85 m, 79.20-79.32 m, 79.90 m, 80.10 m, 80.46 m, 81.00 m.	444 445 446 447 448
82.26		End of Borehole		

APPENDIX I TABLE III BOREHOLE 2 (SILVER MINE)

G.R. NS 99063 71540 Azimuth: 015° Inclination: 44°

All inclinations are measured parallel to the core length

Inclined Depth (m)	Inter-section (m)	Lithology	Mineralisation	Sample No. (CXD)
2.91	2.91	Peat		
7.29	4.28	Boulder Clay		
12.00	4.71	Silty Mudstone/Siltstone; dark grey, massive, poorly-bedded, non-calcareous, small flakes of muscovite visible. Some plant debris. Banding (32°) at 7.95 m. Thin band of mudstone pellets 10.00 m-10.50 m. Becoming finer-grained below 10.50 m. Passing down into:		300
13.11	1.11	Mudstone; dark grey, lipey surfaces in basal 50 cm		
14.35	1.24	Tuff; pale buff-grey, medium-grained (1 mm), poorly-sorted, poorly-bedded, some larger, cream-coloured clasts up to 8 cm in size. Friable and flakey in most parts and intensely sheared in basal 30 cm. Probably a faulted base.		301
16.77	2.42	Sandstone; off-white, medium-grained (0.3 mm), sub-rounded, well-sorted grains, some carbonate cement, irregular dark mudstone clasts (up to 10 mm) quite common, massive with sinuous laminations in top 15 cm inclined at 37°. Faulted base inclined at 20°.	Several pale pink veins (up to 5 mm wide) inclined at 60° are mainly calcite, possibly with baryte. Mudstone clasts are slightly to heavily pyritised below 15.30 m. Much disseminated pyrite from 15.30-16.06 m.	302
17.20	0.43	Sandstone/Siltstone interlaminated; fine, irregular, sinuous interlaminations of off-white sandstone and black siltstone with carbonaceous-micaceous lamellae, inclined at 25°. Passes down into:		
18.75	1.55	Sandstone; off-white, fine-grained (0.1 mm), sub-rounded, well-sorted grains, micaceous, massive but intensely bioturbated in top 20 cm. Coaly clasts (up to 2 mm diameter) in places. Core is very broken from 18.00 m to base.	3 mm wide calcite vein inclined 55° at 17.30 m. Small pyrite specks and a single black, metallic speck (possibly tarnished chalcopyrite). Cream-coloured 1 mm wide carbonate vein with pyrite and black specks inclined 30° at 17.60 m. Calcite and pyrite on joints at 17.90 m.	303
19.69	0.94	Tuff; buff-grey, medium-grained (1 mm), poorly-sorted, poorly-bedded, non-calcareous, mainly friably. Sandy and well-sorted towards base with small (0.1 mm) "oolitic" clasts. Base may be faulted.		304
21.50	1.81	Silty Mudstone; buff-grey, visible mica, poorly-bedded, soft, soapy feel, small irregular lipey surfaces. Brecciated and sheared.		
23.95	2.45	Mudstone; medium to dark grey, fine-grained, poorly-bedded, irregular blocky jointing, lipey surfaces. Brecciated and sheared below 22.10 m		305
25.55	1.60	Major fault zone; mostly consisting of carbonate-rich vein material with only small patches of brecciated wall-rock - mudstone/siltstone at top with a band of brecciated, pale buff-coloured clay band ironstone. Below 24.60 m most of the breccia clasts are of pale buff-grey limestone. Sharp margin at base	Starts with a sharply-defined 3 cm wide band, perpendicular to the core, very rich (30%) in disseminated pyrite. Ironstone is heavily impregnated with white calcite veins up to 2 cm wide containing coarsely crystalline (1 cm) rhombic calcite. Open vugs (up to 1 cm wide) contain rhombic calcite crystals and black hydrocarbons, often with much pyrite and a little chalcopyrite e.g. 24.33 m, 24.60 m, 24.73 m. A particularly continuous mass of calcite from 24.88 m-25.32 m has many large, open vugs. One such vug at 25.13 m is 2.5 cm wide and contains blobs and apparent faceted crystals of hard, black, shiney hydrocarbon (up to 8 mm diameter) together with fine-grained specks of pyrite.	306 307 308
39.40	13.85	Limestone (Petershill Limestone); pale buff-grey, becoming medium grey, crystalline, massive. Small fault inclined 45° from 26.00 m-26.25 m contains brecciated limestone. Joints inclined at 32° show limited pressure solution. Two possible bedding planes inclined at 22° are separated by sheared limestone from 27.37 m-27.67 m. Lithostrotion colony 28.04-28.32 m and 29.80-30.00 m. Caninia at 28.70 m. Small fault with brecciation and shearing inclined 37° from 28.72-28.84 m. Joint inclined 23° at 28.50 m. General shearing inclined 34°. Rubbly with broken shell fragments from 30.20-30.50 m Particularly thick (5 mm) calcite lenses from 30.75-30.85 m may be shell cross-sections. Banded from 31.00-31.90 m with light and dark bands inclined at 30° (bedding). Many shell fragments and darker horizons contain large, solitary corals. Bedding shears are common along thin, shaley partings inclined 34-38°, particularly from 32.50-32.65 m. Large rugose coral 32.67-32.87 m and many small Lithostrotion corals. Sheared dark band with coral debris inclined 30° from 33.03-33.60 m. Stylolites sub-parallel to core from 34.25-34.40 m. Joints inclined 23° at 34.50 m. Bedding shear inclined 34° at 35.00 m and inclined 31° from 35.70-36.05 m and 36.45-36.55 m. Sheared and broken with shell and coral fragments from 37.40-38.90 m.	Some thin calcite veinlets and small patches of brown, crystalline dolomite. Small fault at 26.00 m contains thin calcite veins. Occasional thin (< 1 mm) calcite veinlets below 26.25 m. 2-10 mm wide calcite vein from 29.00-29.13 m. Breccia impregnated with calcite, inclined 52° from 29.27-29.37 m. Calcite/?dolomite veinlets inclined 15° from 29.60-29.80 m and inclined 53° at 29.95 m. Calcite patches 30.20-30.50 m. Thin (2-5 mm) calcite veins inclined 48° at 33.75 m, inclined 31° at 36.00 m and 37.30 m.	(308) 309 310 311 312 313 314 315 316
45.37	5.97	Limestone; dark grey, streaks of lighter (?nodular) material, slightly sheared with dark partings inclined 30°. Many coral and shell fragments. Below 43.60 m the unit is particularly dark, banded (inclined 28°) and packed with shell debris. Basal 15 cm is very shelly and slightly sandy above a sharp base to the unit	Very small specks of sparsely-distributed pyrite are present throughout this unit with slightly more-concentrated 5 mm patches in dark horizons at 39.60 m and 40.03 m. Larger (10 mm) nodules of pyrite occur in dark bands inclined 30° at 40.90 m, 41.60 m, 42.40 m, 43.20 m, 43.47 m, 43.70 m, 43.90 m and 44.00 m. Smaller (2-5 mm) pyrite nodules are common in fine-grained, shelly bands e.g. 44.55 m, 44.77 m and 44.97 m. A sandy/shelley band in the basal 15 cm is particularly pyrite-rich.	317 318 319 320

APPENDIX I TABLE III (continued)

Inclined Depth (m)	Inter-section (m)	Lithology	Mineralisation	Sample No. (CXD)
46.15	0.78	Mudstone; banded medium grey and pale grey, fine-grained, non-calcareous. Banding inclined 28°. Sharp base.	Minute specks of pyrite present throughout.	321
47.45	1.30	Sandy tuff; pale grey, fine-grained (<1 mm) with some elongate, larger clasts up to 5 mm in size. Generally friable with much shearing and brecciation.	Much pyrite (about 30%) in top 1 cm, thereafter as small, disseminated specks.	322
48.82	1.37	Tuff; cream and pale grey, medium-grained (1 mm). Generally soft and friable with streaking and shearing. Becoming very pale greenish below 48.50 m	Small amounts of widely-disseminated pyrite throughout. Pyrite also present on joints.	323
55.02	6.20	Tuff; pale green and cream, streaked and mottled with 2 mm mossy patches, uniform textured, non-calcareous, generally massive and unbedded. Harder than overlying tuffs, maybe due to silicification. Scattered brick-red mineral. Some bands consist of 1 mm dark green clasts in a pale green/cream groundmass. Brecciated with an irregular band of pale grey, very fine-grained mudstone from 52.80-53.00 m. Slightly coarser tuff with a more equigranular texture below 53.20 m. Banding of colour and texture, inclined 29° below 53.50 m. Broken core with brown staining 53.90-54.20 m. Tuff is mottled below with dark green clasts in a pale green groundmass. Red-purple staining 55.01-55.02 m.	Many irregular, white calcite veinlets (1-5 mm wide) from 50.10-52.70 m. Some have thin pyrite-bearing layers on vein margins.	324 421 422
55.02		END OF BOREHOLE		

APPENDIX I TABLE IV BOREHOLE 3A (AITKEN BOG PLANTATION)

G.R. NS 99448 72225 Azimuth: 200° Inclination: 50°

All inclinations are measured parallel to the core length

Inclined Depth (m)	Inter section (m)	Lithology	Mineralisation	Sample No. (CXD)
3.00	3.00	Peat		
3.89	0.89	Boulder Clay; boulders of amygdaloidal basalt in pale green matrix.		
5.20	1.31	Calcareous Sandstone; off-white, fine-grained (0.2 mm); well-sorted, sub-rounded, glassy quartz grains in white calcareous cement; massive, hard. Few joints inclined 30°.		325
7.20	2.00	Calcareous Sandstone (brecciated); rock-type as above; rounded, ellipsoidal fragments (1 cm) separated by thin (1 mm) streaks of dark, crushed material; much broken core. Brecciation is slightly more intense with more dark, crushed planes and cuspate pressure-solution lines from 6.15-6.39 m. Wider, more irregular bands of brecciation with more angular 1 cm fragments to 6.76 m then less brecciated white sandstone with thin, dark, sinuous pressure-solution lines, possibly parallel to bedding planes inclined at 37°.		326
8.30	1.10	Broken core; fragments of calcareous sandstone and fine-grained dolerite		
9.89	1.59	Dolerite; dark grey, very fine-grained, equigranular texture; many small ocelli (1 mm) of calcite and elongate xenoliths of calcareous sandstone, arranged in bands inclined at 25°. slight limonite staining on joints inclined 30°, 36° and 48°. Dolerite becomes altered and greenish at 9.32 m with 1 mm ocelli and thin veinlets of calcite weakly-aligned at 50°. Broken core 9.84-9.89 m.	Calcite vein (4 mm) inclined 19° from 9.10-9.23 m contains specks (0.5 mm) of irridescent, blue/green metallic mineral (?tarnished chalcopyrite).	327 328
11.82	1.93	Limestone; dark grey, fine-grained, crystalline, sandy in places, massive with vague banding inclined at 35°. Dark, cuspate shell fragments in places. Few joints inclined at 26° and 47°. Sharp base inclined at 35° from 11.82-11.86 m.	Few thin (< 1 mm) calcite veinlets inclined at 10° and 20°. Two thin veins (2-3 mm) inclined 20° from 10.50-10.65 m are mostly fluorite (1 mm cubes, pale purple to yellowish) growing into a narrow, open cavity with limonitic surface staining. Small (1-3 mm) irregular patches of pyrite in places e.g. 10.90-11.05 m and 11.33 m, possibly concentrated in bands containing shell fragments. A rounded area (30 x 10 mm), possibly a mineralised coral, at 11.40 m has a rim of dark pink mineral. A similar mineral occurs on a joint surface at 11.65 m.	418 419 420
11.87	0.05	Baked Limestone; cream/white, relatively textureless, calcareous. Forms a sharply-defined band in contact with chilled dolerite from 11.87-11.91 m.	Thin (5 mm) mineral vein along contact with dolerite consists of banded dark and light grey glassy material with thin (1 mm) bands of pale carbonate and nodules of pyrite up to 5 mm wide. Includes a band of small (1 mm) voids lined with limonite.	329
12.30	0.43	Dolerite chill; very pale green, very fine-grained, altered. Soft, broken core from 11.92-12.10 m.	Thin (< 1 mm) limonite-stained veinlets. Calcite vein (2 cm) inclined 35° with offshoots from 12.15-12.25 m.	330
12.85	0.55	Dolerite; green, medium-grained, equigranular texture; ragged white plagioclase laths (0.5 mm) in green matrix; scattered 1 cm ocelli of calcite; massive with occasional joints inclined 20° and 60°. Sharp change to "white whin" below.	Calcite vein (1 cm) inclined 16° from 12.60-12.75 m. Banded pink and white calcite/baryte vein inclined 41° from 13.75-13.85 m.	(330)
14.20	1.35	"White Whin"; pale cream-white altered dolerite; texture still visible with white feldspar laths and black mafics. Ends at mineralised zone.	Scattered, very small specks of pyrite. "White whin" ends at a network of 1 cm banded calcite/baryte veins from 14.20-14.42 m. Lowest vein, inclined at 35° contains a little pyrite.	331 332
14.80	0.60	Dolerite; pale green, medium-grained, equigranular texture.	Diffuse 1 cm vein of calcite inclined 45° at base.	(332)
20.37	5.57	Dolerite; dark green, medium-grained (0.5 mm), fresh, equigranular texture; joints inclined at 30°, 52°, 61°. Becoming paler green and slightly coarser-grained downwards. Sharp junction at 20.37 m.	Calcite veins: 5 mm wide, inclined 8°, 58°, 70° from 15.20-15.40 m; 25 mm wide, banded, inclined 41° at 15.80 m; 10 mm wide, banded, inclined 33° at 16.20 m; 35 mm wide, banded with some 2 mm pyrite nodules, inclined 30° from 17.50-17.72 m; 10 mm wide, inclined 20° from 18.70-18.90 m; 10-15 mm wide, banded with red-brown siderite, inclined 32° from 19.40-19.50 m. Below 19.00 m are many irregular calcite veinlets and some irregular calcite patches (up to 3 cm) to 19.77 m. Pale yellow-green patches (? epidote) at 19.77 m and 20.37 m	335
24.35	3.98	Dolerite; greenish, very fine-grained, mottled with an almost devitrified appearance. Slickensides on low angled, chlorite-lined joints. In sharp contact with:	Many, irregular, cream and white carbonate veins up to 3 mm wide. Many have bands of pale pink baryte. Calcite veins: 20 mm wide, inclination 0° from 21.50-21.90 m; 20 mm wide inclined 47° at 22.53 m; 20 mm wide, inclined 38° at 22.90 m; 10 mm wide, inclined 35° at 23.50 m; 10 mm wide, banded, inclined 46° at 24.05 m; 10-20 mm wide, sinuous, banded with some baryte from 24.35-24.99 m.	336 337

APPENDIX I TABLE IV (continued)

Inclined Depth (m)	Inter-section (m)	Lithology	Mineralisation	Sample No. (CXD)
24.75	0.40	Dolerite chill; green, very fine-grained, passing into:		338
		Dolerite; green, medium-grained, equigranular texture, some 1 mm ocelli of calcite and thin (1 mm) calcite veinlets. Passing into very dark green dolerite, possibly with much secondary chlorite. Joints inclined at 32° and 38° often with banded calcite/chlorite veins. Below 30.00 m dolerite is coarser-grained (1 mm), more equigranular in texture with no calcite ocelli. Thereafter continuing as massive, dark green, coarse-grained (1-2 mm), equigranular dolerite. Massive and generally fresh with joints inclined at 26°, 34°, 40° and 48°. Finer-grained with scattered 2-8 mm calcite ocelli below 59.00 m; ocelli more numerous below 62.00 m; paler with fewer ocelli below 62.40 m. Marked increase in amount of interstitial calcite at 62.77 m and thereafter grades imperceptively, through very pale dolerite, into off-white sandstone. Visible quartz grains appear at 63.10 m and calcite ceases to be present at 63.35 m.	Thin calcite veinlets and banded (1-10 mm) calcite/chlorite veins and veinlets parallel to joints at 0°, 32° and 38°. Thicker (10-30 mm) calcite/chlorite veins at 28.50 m, 31.10 m and 33.10 m. Calcite/chlorite veins at 32.20 m and 33.10 m contain few pyrite nodules (up to 5 mm) concentrated in dark bands. Continuing with many calcite/chlorite veins, generally inclined around 30°. Crystals are often fibrous, with fibres perpendicular to walls of vein suggesting that the veins are tensional cooling joints filled by late mineralising fluids. Other tensional features include small tension gashes and many closed joints which offset mineral veins. Calcite/chlorite veins at 33.80 m, 34.25 m, 34.40 m, 35.05 m, 35.75 m, 35.95 m, 37.15 m, 38.95 m, 40.15 m, 40.75 m, 41.50-41.91 m, 42.20 m, 42.55 m, 42.75 m, 43.25 m, 43.85 m, 44.60 m, 44.75 m, 45.90 m, 46.85 m, 47.35 m and 47.70 m. Chlorite is less abundant below 45 m. Below 47.70 core is broken above a series of thick calcite veins (up to 5 cm wide), inclined 20° from 48.00-48.50 m. Limonite-stained voids in centre of veins have well-formed crystals (3 mm) of nail-head calcite. Small vein from 48.70-48.85 m contains cavities with small (1 mm), elongate, prismatic, twinned, clear crystals of zeolite. Calcite/chlorite (5-10 mm) at 49.30 m, 49.90 m, 50.90 m, 54.55 m, 54.90-55.50 m, 57.83 m and 62.40-62.60 m.	339 340 341 342 343 344 345 346 347 348 349 350 351 352 353 354 355 356
63.35	38.60			
		Sandstone; off-white to pale grey, possibly "bleached", medium-grained (0.3 mm), sub-rounded, moderately well-sorted grains, silica cement, very little carbonate, vague bedding planes inclined 50°. Dark bands, inclined at 59° below 65.25 m, becoming more pronounced, inclined at 54° from 65.55-66.55 m. Rock becomes more massive with a slight increase in the amount of carbonate cement below 66.25 m. Bands of coarser sandstone (0.5 mm grain size) with little calcite cement occur below 67.05 m. Sharp base to unit.	Carbonate vein (10 cm), brecciated, white and cream coloured carbonates, latter shows less reaction with acid and may be dolomite, inclined 46° from 63.52-63.67 m. Irregular vugs contain small (<1 mm), clear, prismatic crystals of zeolites. Some limonite staining on margins. Two intersecting veins of carbonate, mainly cream ?dolomite, some rhombic crystals with curved faces, with some white calcite, inclined at 23° and 34° from 63.80-64.10 m. Vug at intersection of veins contains very clear, glassy crystals (2-4 mm) of nail-head calcite and specks of pyrite. Thin, irregular dolomite/calcite veins with pyrite from 64.53-64.66 m and 64.90-65.05 m. Dark bands inclined 59° below 65.25 m contain pyrite specks and some thin (1 mm) veins of cream-coloured carbonate. Thin (1 mm) veins parallel to the banding around 65.60 m contain carbonate and limonite. Vein (8 mm) of cream-coloured carbonate with pyrite inclined 20° at 65.94 m. Little veining or mineralisation below 66.25 m apart from occasional very small disseminated specks of pyrite and a stratabound 2 mm vein of calcite + 30% pyrite inclined 55° at 66.95 m.	357 358 359 360
67.82	4.47			
		Tuff; very pale grey, very fine-grained (0.1 mm), no carbonate, soft with a soapy texture, recovered in pieces, cream-coloured below 68.10 m. Bedding inclined 54°. Joints inclined 34° and 50. Sharp base.	Vein (5 mm) of pale pink baryte and some calcite, inclination 0°, from 68.08-68.27 m	361
68.44	0.62			
		Tuff; pale green, medium-grained (0.1-0.5 mm); bands of cream-colour with small, mossy green patches; occasional bands are slightly coarser-grained with a carbonate cement. Generally coarser-grained below 69.00 m with vague, rounded clasts of similar tuff, usually 2-5 mm in size but occasionally 20 mm. Continuing as mottled cream/green tuff with a "mossy" texture. Well-banded below 70.15 m with bands 5-35 mm wide, inclined at 56°, of pale green, reddish-purple and cream colour. Lower parts are generally pale coloured greenish and "mossy", medium-grained but with occasional bands containing clasts up to 5 mm in size.	Vein (0.5 mm) of pale pink baryte/calcite inclined 46° at 68.65 m. Several thin veinlets (1 mm) of calcite/baryte to 70.45 m with a single small speck of pyrite observed at 70.00 m. Thin pyrite-rich bands parallel to the bedding occur at 70.20 m and a diffuse thicker band (5 mm) at 70.35 m contains 1-2 mm pyrite nodules. A pale band at 70.75 m contains specks of pyrite in larger clasts and a diffuse band with disseminated pyrite occurs at 70.80 m. Carbonate vein (2 cm) inclined 32° contains pale pink, rhombic dolomite, some calcite and pyrite grains up to 2 mm in size.	362 417
71.38	2.94			
71.38		End of Borehole		

APPENDIX I TABLE V BOREHOLE 3B (AITKEN BOG PLANTATION)

G.R. NS 99312 72219 Azimuth: 190° Inclination: 66°

All inclinations are measured parallel to the core length.

Inclined Depth (m)	Inter-section (m)	Lithology	Mineralisation	Sample No. (CXD)
2.40	2.40	Boulder Clay; with dolerite boulders at base.		
3.86	1.46	Dolerite; weathered, brown, sandy and friable.		
16.54	12.68	Dolerite; grey-green, coarse-grained (1 mm), moderately fresh; broken core at top and curved exfoliation fractures from 4.20-4.80 m. Joints inclined at 30° and 60°. Becoming finer-grained below 10.00 m. Joints at 8°, 30° and 60°. Scattered ocelli (1 mm) of calcite below 14.50 m. Much finer-grained, chilled, pale green and slightly mottled below 14.90 m. Much interstitial carbonate below 15.40 m. Very pale green, mottled and very fine-grained below 16.02 m; becoming soft and cream-coloured with partings inclined at 73°. Brecciated, chilled dolerite in basal 16 cm with a sharp, faulted contact inclined at 36°.	Calcite veins (1 cm), with open cavities and very few, very small specks of chalcopyrite, inclined 48° from 4.80-5.00 m and around 6.00 m. Some thin (up to 1 cm) calcite veins, generally inclined at 60° from 10.00-10.84 m. Some interstitial calcite. Numerous calcite veins (5-10 mm) with very occasional, very small specks of pyrite, inclined 18°, 35°, 40° and 65° between 11.24-16.56 m. Network of thick calcite veins up to 2.5 cm wide from 15.00-15.40 m. Brecciated margin is impregnated with calcite from 16.38-16.54 m.	363 364 365
16.98	0.44	Basalt (baked); dark grey, very fine-grained, uniform texture; small, thin (1 mm) calcite-filled gashes.	Calcite in small tension gashes	366
18.10	1.12	Tuff (basaltic); medium-grey to purplish, medium-grained; 0.5-5 mm poorly-sorted, angular clasts with occasional larger clasts up to 10 mm. Crude bedding inclined at 80°. Sharp base inclined at 69°.		367
19.70	1.60	Sandstone; off-white, medium-grained (0.3 mm), well-sorted, sub-rounded, silica cement, massive. Micaceous silty bands (1 cm) with lodecasts, inclined at 75° in top 50 cm. Joints at 0° and 24°. Passing down into:	Vein (1 cm) of calcite and pink baryte inclined at 20° from 18.10-18.25 m. Thin, irregular calcite veinlets and a little pink baryte.	368 369 (370)
20.37	0.67	Mudstone; intraformational breccia of sandstone and mudstone clasts (up to 2 cm) in a dark grey mudstone matrix. Becoming mostly mudstone with lipey surfaces below 20.00 m		(370) 371
21.74	1.37	Calcareous Sandstone; pale grey, medium-grained, carbonate cement. Brecciated from 20.37-20.65 m with large (up to 5 cm), angular clasts in a mineralised matrix. Dark grey, banded limestone with shell fragments, inclined 63° from 20.65-20.80 m. Passes down into massive calcareous sandstone with harder, more siliceous bands and softer bands of pale grey, impure limestone.	Network of veins (up to 2 cm) of white calcite and pink baryte with a little galena from 20.37-20.65 m. Hard, dark, less calcareous band inclined 46° from 21.44-21.74 m contains much pyrite; disseminated; as 5 mm nodules elongated parallel to the bedding; and as disseminated grains replacing up to 30% of sandstone clasts. Pyrite-bearing band is cut by thin (1 mm) calcite veinlets.	372 373 374
34.90	12.16	Limestone (Petershill Limestone); dark grey, fine-grained, crystalline; often nodular with well-rounded nodules (1-2 cm) of paler limestone in a dark grey matrix. Slight pressure-solution around edges of nodules and sub-parallel to bedding. Bands of shell debris are common; large solitary coral at 22.28 m. Dark, calcareous mudstone band with lipey surfaces and large (1 cm) rounded calcareous nodules from 24.29-24.45 m. Limestone continues to be nodular with many shell fragments, often in a lipey, dark, calcareous mudstone matrix. Solitary corals at 26.67 m, 26.88 m, 26.94 m, 27.08 m, 29.08 m, 31.44-31.79 m. Dark band with tension gashes from 30.22-30.49 m. Lithostrotion colony 33.45-33.60 m. Pyritised solitary corals 34.77-34.90 m and 35.08 m.	Many thin, irregular veins (2-5 mm) of calcite with occasional pink baryte to 24.29 m. Thick veins (1-5 cm) of calcite, low inclination from 23.93-24.29 m. Little pyrite on lipey surfaces in calcareous mudstones. 2 cm wide band of 3 mm pyrite nodules at 25.16 m. Network of 3 mm wide calcite/baryte veins from 25.16-25.40 m. Some very fine-grained disseminated pyrite and occasional calcite veinlets (1 mm). Calcite veins; (3 mm) inclined 29° from 26.38-26.52 m; (5 mm) inclined 31° at 26.67 m. Calcite veinlets 26.67-26.87 m; calcite in tension gashes 28.11-28.25 m. Calcite vein (2-5 mm) inclined 20° from 30.00-30.22 m. Calcite vein (2-4 cm), irregular but generally parallel to core, with scattered 2 mm specks of galena throughout from 32.10-32.58 m; ends at a 4 cm vein of calcite with galena, perpendicular to core at 32.58 m. Calcite veinlets continue to 32.78 m without galena. Tension gashes and veinlets of calcite (up to 4 mm) from 33.85-34.77 m contain occasional specks (1-2 mm) of galena and pyrite. Veinlets terminate at a dark band containing pyrite nodules and a solitary coral with heavy pyrite replacement from 34.77-34.90 m.	375 376 377 378 379 380 381 382
39.90	5.00	Limestone (heavily mineralised); dark grey, shelly, massive	Abundant disseminated nodules of pyrite, 1-10 mm in size and some cubic crystals up to 3 mm (e.g. 35.45 m). Pyrite is particularly concentrated on margins of shell fragments and in large solitary corals (e.g. 35.08 m). Some thin (1 mm) calcite veinlets.	383 384 (385)
45.70	5.80	Limestone (mineralised); dark grey, shelly, nodular, quite strong banding	Much disseminated pyrite in nodules up to 5 mm in size and around shell and coral fragments. Thin layer of calcite on joints. Calcite vein (3 mm) and veinlets with pyrite and galena, inclined 15° from 40.86-41.09 m. Pyrite less abundant below 44.70 m. Occasional sphalerite and galena.	(385) 386 387 388 389
45.90	0.20	Limestone/Mudstone; interbanded, bedding inclined at 65°.	Very rich in pyrite with nodules up to 5 mm.	(390)
46.97	1.07	Mudstone; medium grey, very fine-grained, thin limestone bands and good parting inclined at 71°. Carbonaceous with small coaly fragments. Passing down into:	Calcareous band with 30% pyrite from 46.28-46.37 m. Mudstone below contains pyrite, disseminated and in nodules. Very thin smear of galena on a joint surface at 46.55 m. Pyrite rich band, 1 cm wide at 46.90 m. Nodules (up to 5 mm) and thin stringers, parallel to bedding, of sphalerite throughout. Little associated galena.	(390) 391
46.97	1.07			

Inclined Depth (m)	Inter-section (m)	Lithology	Mineralisation	Sample No. (CXD)
49.50	2.53	Tuff; off-white, mottled, very fine-grained, non-calcareous, poor bedding. Becoming slightly coarser-grained, mottled, with pale green specks in a cream/white matrix below 47.40 m. Well developed joints inclined at 40° and 75°. Off-white, non-calcareous, possibly silicified patches of irregular texture occur between areas of regular texture (e.g. 48.05-49.50 m). Mottled grey and white banding present below 48.90 m. Thin rootlets present throughout.	1 cm band of dense, brownish nodules at 47.20 m may be sulphides (?sphalerite). Irregular streaks of pyrite at 47.40 m. Very finely disseminated pyrite towards base.	392
58.05	8.55	Tuff; pale green and cream coloured, mottled, medium-grained, banded with colour bands 0.5-10 cm thick and very flat bedding inclined at 71°. Some bands show well-developed graded bedding and lode casts suggesting deposition in an aqueous environment. Less well-bedded, purplish to dark green in colour below 50.90 m, then coarser-grained, pale green and cream with irregular mottling below 51.55 m. [2.57 m core loss between 51.77 and 54.34] Coarser-grained (2-3 mm) and poorly-sorted below 54.90 m with poor bedding inclined at 71°. Generally pale green, darker green and cream with occasional pink streaks. Some interstitial calcite cement below 57.70 m. Passing sharply into:	Some very fine-grained, disseminated pyrite. Calcite vein (5 mm), irregular at 56.36 m and thin veinlet at 57.40 m. Several dark, metallic bands, up to 1 cm wide from 56.35-58.05 m.	393 394 (395)
62.67	4.62	Tuff; dark green to 58.28 m, then very pale greenish-grey with greenish mottling in places; very fine-grained, relatively featureless. Regular, fine, green mottling below 59.30 m; purplish and brecciated from 59.85-60.34 m; then pale greenish-grey, fine-grained tuff with fine mottling and a very regular, almost sandy texture, persisting to 60.96 m; then similar in texture, but medium green in colour. Banding is present below 61.20 m, becoming generally coarser-grained with some coarse-grained (3 mm) bands. Pale-coloured in basal 20 cm.	Thin film of pyrite present on joints at 58.60 m.	(395) 396 397 398
63.30	0.63	Tuff; off white/pale grey, very fine-grained; slight streaky banding parallel to the bedding, otherwise featureless. Rather soft with lipey bedding surfaces. Grades down into:		399
66.73	3.43	Sandstone; off white, fine to medium-grained (0.1 mm), well-sorted, sub-angular; micaceous in parts resulting in a good parting inclined at 71°. Coarser-grained (0.2-0.3 mm) below 64.00 m but still with micaceous partings; some carbonate cement, slightly greenish in places. Very massive below 65.40 m. Sharp base.	Thin (102 mm) calcite/baryte vein sub-parallel to the bedding (71°) at 64.06 m. Interstitial, pinkish, metallic mineral present at 64.58 m. = ?niccolite.	400 401
67.30	0.57	Tuff; pale grey, very fine-grained, featureless, mudstone-like appearance; flakey, parallel bedding. Mottled towards base. Passing down into:		402
72.40	5.10	Tuff; pale green/cream/grey, mottled, medium to coarse-grained (1-6 mm) banded. Poor bedding inclined 65°. Large, angular 6 cm clast at 68.40 m. Pale-coloured bands of ellipsoidal lapilli from 69.30-69.65 m and 70.82-70.95 m. Coarser-grained (5-8 mm) below 71.30 m with sub-angular, poorly-sorted clasts. Passing down into:	Lapilli bands contain irregular 3 mm patches of calcite/baryte and small amounts of disseminated, fine-grained pyrite in places.	403 404
74.77	2.37	Agglomerate; purplish-grey, ill-sorted clasts up to 15 mm in size with occasional larger clasts; sub-angular with rounded corners, mostly of fine-grained tuff. Bedding poor or absent. Slight carbonate cement in places with a particularly carbonate-rich band (possibly limestone clasts) from 74.26-74.62 m. Finer-grained with carbonate cement from 74.48 to base. Sharp, possibly faulted base inclined at 40°.	Few vague, thin carbonate veinlets. Clasts in carbonate-rich band from 74.26-74.62 m contain small pyrite nodules.	405
76.90	2.13	Tuff; medium to dark grey, fine-grained, calcareous below 74.93 m to 75.50 m. Pale green and mottled with some larger clasts and banding inclined 56° from 75.00-75.96 m; pale bluish grey and very fine-grained from 75.96-76.90 m.	Thin lenses (1 cm long) of calcite with pyrite in upper part. Calcareous horizon at 75.00 m contains 1 cm pyrite nodules. Veinlets (1-2 mm) of calcite with pyrite and possibly baryte from 75.13-75.33 m and 75.54-75.67 m. Calcareous clasts (up to 8 cm) with pyrite at 75.45 m. Thin, irregular calcite vein with much pyrite at 76.90 m.	406 407
78.60	1.70	Agglomerate; pale greenish and grey, irregular texture; large, rounded clasts (7 cm) of fine-grained, mottled tuff with irregular cracks and some finely-vesicular lava. Stratigraphic base.	Some disseminated pyrite. Impersistent veins (1-3 mm) of calcite with some pink baryte from 78.48-78.64 m.	408
80.32	1.72	Tuff; pale green, fine-grained (0.1 mm), sandy texture, poor bedding, slight autobrecciation. Slight banding with a little carbonate cement below 79.05 m, becoming more pronounced and irregular below 79.50 m. Passing down into:	Autobrecciated with irregular patches and veinlets of calcite from 78.87-79.05 m. Pyrite nodules (1 cm) at 79.87 m. Calcite vein, 2 mm, irregular, low inclination from 80.02-80.23 m.	409
81.16	0.84	Limestone; muddy and shelly. Dark mudstone in top 15 cm, then very shelly and nodular with shell fragments, corals and pale nodules in a medium grey, calcareous mudstone matrix. Fairly sharp base.	Pyritiferous streaks in top 15 cm. Very pyrite-rich band, 1 cm wide from 80.44-80.47 m. Some disseminated pyrite within and around nodules and shell clasts to 80.59 m.	410
86.15	4.99	Agglomerate; pale green, poor bedding; ill-sorted, rounded clasts up to 2-4 cm, mostly of fine-grained tuff or finely-amygdaloidal lava. Lower parts have mostly clasts of amygdaloidal basalt with calcite/chlorite in the amygdales and some interstitial calcite. Slightly better sorting with tightly-packed, well-rounded clasts (3-8 mm) from 84.94-85.46 m. Quite a sharp base.	Few irregular calcite veinlets and little interstitial calcite.	411 412
86.60	0.45	Tuff; dark grey at top, becoming pale grey, very fine-grained, non-calcareous, mudstone-like appearance. Becoming coarser-grained downwards and passing down into:		413
91.46	4.86	Banded Tuff; grey or greenish, fine to medium-grained (0.1-0.3 mm, occasionally 1 mm), good banding about 1-2 cm wide, inclined 64-66°, poor-sorting, sub-angular clasts, non-calcareous. Bands of 2-5 mm lapilli are quite common. Less regular banding with poorly-sorted clasts of various shapes and sizes below 90.27 m. More regular and banded below 90.92 m.	Rare, disseminated, fine-grained pyrite e.g. 88.11 m	414 415 416
91.46		End of Borehole		

APPENDIX II

GEOCHEMICAL ANALYSES OF BOREHOLE CORES

Analyses of drillcore from the five boreholes are listed in Tables I to V. General lithological descriptions only are given but the sample numbers are cross-referenced in the tables of borehole logs in Appendix I.

Most of the sedimentary units and the mineralised zones within dolerite were analysed in total with an average sample length of 1.5 to 2 m. Further isolated samples were chosen to given representative analyses of the remainder of the core and to determine background concentrations (i.e. in dolerite). The selected core lengths were split in half longitudinally. Half of each sample was crushed in a jaw crusher to less than 5 mm particle size, coned, quartered and approximately 200 g were ground to less than 50 μm grain size in an agate Tema mill. The samples were analysed for Cu, Pb, Zn, Co, Ni and Ag by atomic absorption spectrophotometry (AAS) and for As and Ba by X-ray fluorescence spectrometry (XRF). Samples showing traces of Ag were subjected to a more efficient acid attack and reanalysed by AAS with no improvement in yield.

APPENDIX II TABLE I BOREHOLE 1A (CAIRNPAPPLE)

Sample No. CXD	Depth (m)		Intersection (m)	Lithology	Trace Element Concentrations (ppm)							
	From	To			Cu	Pb	Zn	Co	Ni	Ag	As	Ba
449	9.88	10.80	0.92	Dolerite + calcite/chlorite vein	50	20	70	40	50	1	3	310
450	19.19	21.00	1.81	Basalt	50	30	90	50	200	2	5	663
451	27.32	27.80	0.48	Dolerite, chilled	60	20	90	30	30	1	0	794
452	39.58	40.07	0.49	Dolerite, coarse with micropegmatite	15	20	90	20	15	0	0	291
453	[58.00 [68.00	58.19] 68.27]	0.46	Pegmatite patch in dolerite	20	30	70	25	20	1	0	349
454	61.37	61.85	0.48	Dolerite, coarse-grained	55	20	60	30	30	1	0	485
455	74.57	75.14	0.57	Dolerite, coarse-grained	50	20	70	35	40	1	0	793

APPENDIX II TABLE II BOREHOLE 1B (CAIRNPAPPLE)

425	5.35	5.54	0.19	Dolerite	50	20	100	40	30	1	0	514
426	10.00	11.20	1.20	Dolerite + calcite/chlorite/quartz veins	35	20	80	30	25	1	0	441
427	14.80	15.36	0.56	Dolerite + pyrite bands	90	20	110	70	60	1	0	549
428	19.78	20.50	0.72	Dolerite + micropegmatite veins	50	20	100	50	45	0	0	600
429	25.26	26.71	2.45	Dolerite + calcite veins	65	20	200	60	60	1	0	524
430	26.71	28.28	1.57	Dolerite + calcite veins	60	20	170	55	55	1	2	579
431	28.39	30.53	2.14	"White whin" + calcite and vugs	5	30	20	30	40	1	22	3673
432	30.53	32.15	1.62	"White whin" + calcite and vugs	20	20	40	50	40	1	3	883
433	32.15	33.98	1.83	"White whin" + calcite and vugs	10	20	10	35	40	1	44	952
434	33.98	37.40	3.42	"White whin" + calcite and vugs	10	20	20	60	60	0	54	294
435	37.40	38.60	1.20	"White whin", pale green	100	20	120	40	50	1	1	419
436	38.60	41.44	2.84	"White whin"	100	20	30	30	40	0	30	453
437	41.44	42.90	1.46	"White whin" + calcite and hydrocarbons	20	30	40	50	50	1	37	537
438	42.90	45.85	2.95	"White whin"	35	190	40	50	60	1	16	398
439	45.85	47.25	1.40	"White whin", pale blue-grey	80	500	70	60	60	1	21	654
440	47.25	48.50	1.25	"White whin" + much pyrite	10	900	60	55	45	1	127	2975
441	48.50	51.55	3.05	"White whin"	10	40	20	35	20	1	41	780
443	53.74	54.62	0.88	Dolerite + calcite/hydrocarbon vein	15	30	110	30	20	1	1	4147
444	60.90	61.44	0.54	Dolerite + calcite/hydrocarbon vein	40	40	200	55	40	1	2	1146
446	69.56	71.00	1.44	Dolerite + calcite/chlorite vein	30	30	90	50	50	1	0	831
447	75.10	76.01	0.91	Dolerite + calcite veins	100	40	280	60	60	3	0	326
448	78.45	78.76	0.31	Dolerite	80	50	140	65	50	1	1	1666

APPENDIX II TABLE III BOREHOLE 2 (SILVER MINE)

Sample No. CXD	Inclined Depth (m) From	Inclined Depth (m) To	Intersection (m)	Lithology	Trace Element Concentrations (ppm) Cu	Pb	Zn	Co	Ni	Ag	As	Ba
300	10.70	10.83	0.13	Silty mudstone	30	30	70	25	55	0	5	349
301	14.14	14.28	0.14	Tuff	50	30	160	40	100	2	7	176
302	14.35	16.77	2.42	Sandstone + pyrite nodules	5	60	100	5	10	1	3	238
303	17.20	18.75	1.55	Sandstone + pyrite on joints	5	160	10	5	20	1	12	559
304	19.33	19.53	0.20	Tuff	5	140	50	25	75	1	2	827
305	21.47	21.70	0.23	Mudstone	5	10	10	20	30	1	29	387
306	23.95	24.05	0.10	Mineralised Limestone - top of fault zone	30	2800	400	70	100	3	275	25300
307	24.05	24.82	0.77	Mineralised Limestone	20	40	20	15	20	5	2	723
308	24.82	25.70	0.88	Mineralised Limestone + hydrocarbons	25	70	10	20	30	7	4	618
309	25.70	27.27	1.57	Limestone + calcite veinlets	20	100	110	20	30	5	1	79
310	27.37	29.27	1.90	Limestone + calcite veinlets	20	120	300	15	40	4	9	97
311	29.27	29.37	0.10	Brecciated Limestone + calcite	25	40	70	15	30	4	2	188
312	29.37	31.94	2.57	Limestone	40	140	400	15	40	6	7	2897
313	31.94	33.60	1.66	Limestone	20	90	260	20	45	5	6	289
314	33.60	36.20	2.60	Limestone (massive)	20	120	350	15	40	5	10	119
315	36.25	37.90	1.65	Limestone (massive)	20	70	80	20	50	5	6	82
316	37.90	39.43	1.53	Limestone (massive)	20	120	650	20	50	3	8	678
317	39.43	41.55	2.12	Limestone, dark, banded, + pyrite	20	80	380	10	40	3	3	1473
318	41.55	43.44	1.89	Limestone, dark, banded, + pyrite	25	60	320	25	50	3	3	305
319	43.44	45.10	1.66	Limestone, dark, banded, + pyrite	25	80	170	30	70	4	11	436
320	45.10	45.32	0.22	Limestone base, pyrite rich	55	80	270	25	60	2	5	559
321	45.74	45.85	0.11	Mudstone	20	100	270	60	210	2	1	522
322	46.15	46.25	0.10	Tuff, grey, much pyrite	250	1300	690	130	240	1	35	3030
323	47.70	47.85	0.15	Tuff, + disseminated pyrite	90	60	120	70	200	1	0	2977
324	49.70	49.90	0.20	Tuff, greenish	50	30	60	80	180	1	0	1528
421	50.31	50.77	0.46	Tuff, greenish + calcite veins	30	20	80	50	190	1	3	886
422	53.50	53.64	0.14	Tuff, green, banded	180	20	60	80	210	1	0	1960

APPENDIX II TABLE IV BOREHOLE 3A (AITKEN BOG PLANTATION)

Sample No. CXD	Inclined Depth (m) From	Inclined Depth (m) To	Intersection (m)	Lithology	Trace Element Concentrations (ppm)							
					Cu	Pb	Zn	Co	Ni	Ag	As	Ba
325	4.29	5.59	1.30	Calcareous Sandstone	5	20	20	10	20	0	0	154
326	5.59	7.20	1.61	Calcareous Sandstone	10	30	20	10	20	0	2	216
327	8.37 9.23	9.10 9.84	1.34	Dolerite	5	70	60	20	50	1	5	551
328	9.10	9.23	0.13	Dolerite + calcite vein + sulphide	20	20	20	20	30	1	5	149
418	9.89	10.55	0.66	Limestone	30	100	10	20	50	0	1	127
419	10.55	10.85	0.30	Limestone + fluorite	40	90	20	20	50	1	2	582
420	10.85	11.82	0.97	Limestone + occasional pyrite	20	50	10	20	40	1	13	60
329	11.82	11.91	0.09	Mineralised Limestone in contact with Dolerite	850	20	20	30	30	3	5	337
330	12.26	12.41	0.15	Dolerite + carbonate veins	100	10	40	70	70	1	1	8450
331	13.75	13.85	0.10	Dolerite + calcite/baryte vein	400	10	50	30	30	1	0	64500
332	14.18	14.29	0.11	"White whin"	300	20	130	80	40	1	3	1726
333	17.50	17.72	0.22	Dolerite + calcite vein	100	20	120	40	70	2	0	475
334	18.40	18.54	0.14	Dolerite	160	20	210	60	100	1	0	181
335	19.65	19.77	0.12	Dolerite + green, mineralised patch	770	20	130	60	90	1	0	551
336	21.00	21.40	0.40	Dolerite, mottled, brecciated + carbonate	25	20	90	40	140	2	0	1804
337	22.01	22.19	0.18	Dolerite, mottled	70	20	140	80	230	2	0	170
338	24.50	24.73	0.23	Dolerite, chilled + calcite veins	105	60	130	30	60	1	0	3093
339	27.18	27.29	0.11	Dolerite	150	30	180	55	80	0	5	566
340	28.40	28.50	0.10	Dolerite + calcite/chlorite veins	30	610	60	20	60	2	0	127
341	31.90	32.15	0.25	Dolerite + calcite/chlorite + pyrite	60	30	80	50	80	2	0	24100
342	32.96	33.10	0.14	Dolerite + calcite/chlorite + pyrite	85	200	120	35	70	3	1	2293
343	34.08	34.20	0.12	Dolerite	140	40	400	60	90	1	0	320
344	35.65	36.00	0.35	Dolerite + calcite/chlorite vein	140	70	190	60	105	2	0	212
345	38.90	39.00	0.10	Dolerite + calcite/chlorite vein	95	60	100	40	80	3	0	102
346	41.66	41.91	0.25	Dolerite + calcite/chlorite vein	120	50	230	55	100	1	0	909
347	45.45	45.56	0.11	Dolerite	170	40	330	70	100	3	3	300
348	47.98	48.38	0.40	Dolerite + calcite vein + vugs	40	40	120	35	60	2	0	676
349	48.57	48.65	0.08	Dolerite + calcite vein + zeolites	130	40	300	55	90	1	0	3477
350	52.33	52.50	0.17	Dolerite + calcite veins	90	40	190	50	70	1	0	311
351	54.20	54.36	0.16	Dolerite, coarse-grained	170	40	210	50	100	1	1	208
352	55.04	55.34	0.30	Dolerite + calcite veins	115	50	70	40	90	1	0	172
353	62.14	62.29	0.15	Dolerite, marginal + calcite ocelli	170	40	80	45	75	1	2	149
354	63.00	63.16	0.16		180	40	40	70	100	1	5	120
355	63.16	63.28	0.12	gradational contact between dolerite and sandstone	35	40	20	45	60	1	1	67
356	63.28	63.41	0.13		15	50	20	35	60	1	48	44
357	63.52 63.90 64.53	63.67 64.10 64.70	0.52	Carbonate/limonite/pyrite/zeolite veins in sandstone	20	40	20	15	25	1	0	235
358	63.41 63.67 64.10	63.52 63.90 64.53	0.77	Sandstone	10	30	10	15	25	1	9	55
359	64.70	66.29	1.59	Sandstone + disseminated pyrite	25	30	10	15	30	0	4	776
360	66.29	67.82	1.53	Sandstone + disseminated and thin bands of pyrite	25	40	10	20	30	0	22	162
361	68.21	68.35	0.14	Tuff, cream, fine-grained	15	30	10	5	50	0	30	1256
362	70.14	70.34	0.20	Tuff, banded + pyritiferous bands	840	40	120	70	140	2	0	261
417	70.75	70.86	0.11	Tuff, banded + pyritiferous bands	70	20	80	65	260	0	0	345

APPENDIX II TABLE V BOREHOLE 3B (AITKEN BOG PLANTATION)

Sample No. CXD	Inclined Depth (m) From	Inclined Depth (m) To	Intersection (m)	Lithology	Trace Element Concentrations (ppm) Cu	Pb	Zn	Co	Ni	Ag	As	Ba
363	11.47	11.63	0.16	Dolerite	160	70	250	60	95	1	0	215
364	14.63	15.50	0.87	Dolerite + calcite veins	110	50	120	50	75	1	0	2532
365	15.88	16.50	0.62	Dolerite, chilled + calcite veins	280	40	80	40	75	1	0	736
366	16.60	16.88	0.28	Basalt	20	40	100	30	80	1	2	908
367	16.98	18.10	1.12	Tuff	30	110	220	55	140	2	21	356
368	18.10	18.25	0.15	Sandstone + calcite/baryte veins	30	110	100	15	40	1	2	9706
369	18.35	19.57	1.22	Sandstone + calcite/baryte veins	20	60	30	10	35	1	1	15100
370	19.57	19.84	0.26	Sandstone/Mudstone breccia	20	500	90	35	90	1	75	2822
371	19.84	20.37	0.53	Mudstone	40	220	300	30	90	1	43	507
372	20.37	20.65	0.28	Calcareous Sandstone, brecciated + veins	30	640	210	20	30	2	6	91400
373	20.65	21.44	0.79	Calcareous Sandstone	30	210	130	20	60	1	10	798
374	21.44	21.74	0.30	Mudstone + pyrite	20	650	470	20	40	2	18	540
375	21.74	24.29	2.55	Limestone + carbonate veins	20	220	80	20	40	1	20	636
376	24.29	25.99	1.70	Limestone, nodular + some veins	20	100	240	20	40	1	10	1175
377	25.99	28.11	2.12	Limestone, massive	15	90	80	20	40	1	15	81
378	28.11	30.22	2.11	Limestone, nodular + calcite veins	15	80	70	20	45	1	12	414
379	30.22	32.10	1.88	Limestone, massive	15	380	60	20	40	2	11	122
380	32.10	32.78	0.68	Limestone, massive + calcite/galena	30	1110	50	20	45	2	33	78
381	32.78	33.85	1.07	Limestone, massive	45	280	50	20	70	2	23	101
382	33.85	34.90	1.05	Limestone, massive + calcite/galena/pyrite	20	1830	80	40	90	2	105	599
383	34.90	36.63	1.73	Limestone, massive + pyrite	25	120	200	25	55	2	28	95
384	36.63	38.57	1.94	Limestone, massive + pyrite	30	850	5350	35	70	2	63	107
385	38.57	40.82	2.25	Limestone, nodular + pyrite	30	860	3500	30	70	2	57	107
386	40.82	41.14	0.32	Limestone, nodular + pyrite and galena	20	1500	18000	60	120	2	166	193
387	41.14	42.64	1.50	Limestone, nodular + pyrite	20	1450	7000	30	55	3	57	514
388	42.64	44.70	2.06	Limestone, nodular + pyrite	20	850	1250	35	70	4	55	170
389	44.70	45.70	1.00	Limestone, nodular	25	1100	6500	45	80	2	56	313
390	45.70 46.28	45.90 46.37	0.29	Limestone/Mudstone + much pyrite	40	1080	9200	90	180	2	52	964
391	45.90 46.37	46.28 46.97	0.98	Mudstone	50	6200	31000	55	180	3	30	2478
392	46.97	49.50	2.53	Tuff, mottled	60	770	3500	60	160	1	12	1432
393	49.50	51.55	2.05	Tuff, bedded	55	40	180	70	170	1	14	883
394	54.34	56.25	1.91	Tuff, mottled	60	20	110	70	210	1	15	302
395	56.25	58.28	2.03	Tuff, green, bedded	40	20	110	80	180	1	2	236
396	58.28	59.30	1.02	Tuff, cream, fine-grained	40	10	20	50	100	1	4	816
397	59.30	60.96	1.66	Tuff, sandy	30	10	80	120	160	1	2	717
398	60.96	62.67	1.71	Tuff, green, bedded	25	20	90	75	170	1	7	638
399	62.67	63.30	0.63	Tuff, white, fine-grained	0	10	10	35	55	1	16	1367
400	63.30	65.40	2.10	Sandstone, bedded	10	20	10	105	500	1	871	465
401	65.40	66.73	1.33	Sandstone, massive	5	20	10	5	15	1	14	73
402	66.77	67.30	0.53	Tuff, grey, very fine-grained	5	20	10	35	180	1	156	1240
403	67.30	69.92	2.62	Tuff, mottled, banded, medium/coarse	100	20	60	80	195	1	7	414
404	69.92	72.40	2.48	Tuff, banded	90	20	90	70	180	0	0	270
405	72.40	74.77	2.37	Agglomerate	170	20	80	65	160	0	2	179
406	74.77	75.50	0.73	Calcareous Tuff + pyrite	60	20	30	30	70	0	4	156
407	75.50	76.90	1.40	Tuff, blue-grey, very fine-grained	20	20	50	45	145	0	0	407
408	76.90	78.60	1.70	Agglomerate	30	20	90	60	250	0	0	374
409	78.60	80.21	1.61	Tuff, green, sandy textured	30	40	70	40	160	1	5	421
410	80.21	81.16	0.95	Limestone	20	20	40	45	80	0	17	186
411	81.16	83.65	2.49	Agglomerate	40	20	90	60	215	1	0	331
412	83.65	86.15	2.50	Agglomerate	65	20	100	60	230	0	0	372
413	86.15	86.60	0.45	Tuff, fine-grained	30	20	80	110	190	0	8	338
414	86.66	88.45	1.79	Tuff, banded + lapilli	70	20	80	60	170	0	7	234
415	88.45	90.27	1.82	Tuff, banded + lapilli	70	20	80	70	170	1	7	269
416	90.27	91.46	1.19	Tuff	30	20	50	70	220	0	0	637

APPENDIX III

PETROGRAPHY AND MINERALOGY OF DRILLCORE SPECIMENS

Note: PTS numbers refer to polished thin-sections held by IGS Applied Mineralogy Unit (PS refers to a polished block).

(a) BH 1B

CXD 436: 39.52–39.61 m. PTS 7166.

Soft, pale altered rock ('white whin') showing relict dolerite texture. Two superimposed alterations (one silicification and argillation, the other calcite veinlets and sparry replacements) are probably of the same age. Brown semi-opaque leuxoxene rims calcite veinlets and has replaced pyroxene and ilmenite. Epigenetic *pyrite* is common. One calcite veinlet contains a grain of semi-opaque 'albertite'.

CXD 440: 48.14–48.20 m. PTS 7167.

Outwardly similar to the PTS 7166 specimen but in thin section the texture is of irregular quartz grains in a fine argillised matrix. Calcite veinlets are accompanied by leucoxene and Fe-hydroxide phases. Pyrite is abundant in these veinlets.

(b) BH 2

CXD 306: 23.95–23.99 m. PTS 6483.

Fault breccia comprising three components: grey mudstone, pyritic material and sparry calcite cement. At some points the *pyritic material (framboids and coarser grains in a dolomite matrix)* encloses brown mudstone fragments. The coarse calcite is accompanied by *pink baryte, accessory galena* and a *trace of probable gypsum,* and represents an epigenetic stage of brittle fracturing.

CXD 308: 25.05–25.11 m.

Sparry calcite vein material containing mudstone fragments and part of a mudstone selvage. Pyrite is finely disseminated in the mudstone and occurs with *galena* in small vugs and discontinuous hairline seams.

CXD 312: 29.95–30.01 m.

Black fossiliferous limestone, including a substantial coral fragment, is crossed by a vein of coarse brown calcite. No sulphide was observed.

CXD 316: 39.26–38.35 m. PTS 7168.

Grey fossiliferous limestone containing a few black mudstone fragments. *Fine, often framboidal, pyrite* occurs in sparry fossil replacements, and may be enclosed by *isolated sphalerite crystals.* No evidence for epigenetic metal introduction was observed.

CXD 317: 39.65–39.71 m. PTS 6484.

Black lime mud rich in sparry shell fragments. Fine carbonaceous bands indicate bedding and show irregular forms indicative of sedimentary instability. Thin 'crumpled' plates made up of fine calcite could be corrugated shell fragments or be derived from layers of pure calcite mud. Fine grains and coarse cubes of *pyrite* occur in the darker bands, in fractures in shell fragments and in sparry shell replacements, being accompanied in the last setting by *isolated sphalerite crystals.*

CXD 320: 45.35–45.40 m. PTS 6485.

Sandy limestone with sparry calcite shell fragments and crossed by fine-grained carbonaceous seams. Fine *pyrite* occurs in shell replacements and, more prevalently, in the carbonaceous material as clusters of framboid-like grains accompanied by minor *galena* and *sphalerite.*

CXD 322: 46.15–46.25 m. PTS 7169.

Graphitic calc-mudstone containing a *massive pyrite band.* This band varies from truly massive pyrite to clusters of *perfect framboids,* and also contains coarse flakes of *graphite* which may themselves contain framboids.

At other points graphite forms a thin-walled cellular structure or may be finely laminated, suggesting preserved *algal structure.* Ovoid areas of laminar structure in the massive pyrite may also be biological in origin.

(c) BH 3A

CXD 328: 9.10–9.17 m. PTS 6486.

Sandy limestone with sparry fossil fragments, cut by a 5 mm thick sparry calcite vein. Metallic minerals are absent save for a trace of pyrite.

CXD 419: 10.60–10.68 m.

Massive grey limestone barren save for local disseminations of fine *pyrite.* A limonitic fracture-vein surface has coarse calcite crystals adhering to it.

CXD 420: 11.75–11.86 m.

A *sharp contact* between grey *crystalline limestone* and pale *altered dolerite.* Accessory *fine pyrite* occurs in both. One end of the specimen, in dolerite, shows a fracture-vein surface of limonitic calcite. Adjacent to this is a 5 mm calcareous zone with *coarse pyrite,* then a 4 mm zone of black, highly magnetic material consisting dominantly of *diopsidic pyroxene* and quartz (XRD powder-photograph Ph 6627); the magnetic property is presumably due to magnetite or pyrrhotite micro-inclusions.

CXD 331: 13.80–13.85 m. PTS's 6487 and 6496.

Vein in dolerite: coarse white calcite and pink *baryte,* with a minor amount of chalcedonic silica. The specimen encloses slivers of green altered dolerite carrying *pyrite* and *hematite* granules.

CXD 335: 19.70–19.74 m. PTS 6488

Coarse dolerite showing intense chlorite-sericite-clay alteration and patches of fine pink chalcedony. The rock is crossed by calcite veinlets. Hematitised ferromagnesian and oxide minerals are common, and accessory *pyrite* and *chalcopyrite* are present.

CXD 348: 48.36–48.46 m.

Chloritised dolerite with intensive *calcite veining.* Vuggy cavities are line with euhedral prisms of probable *harmotome* (see below).

CXD 349: 48.65–48.75 m. PTS 6489.

Calcareous chloritised dolerite with accessory *pyrite* is crossed by limonitic calcite veinlets. Hematite and accessory sphene have replaced primary mafic silicates and oxides. Vuggy cavities are line with *harmotone* (square prisms with cruciform hemidome terminations due to interpenetrant twinning: confirmed by XRD powder photograph Ph 6628).

CXD 357: 63.55–63.65 m.

Heavily limonitised limestone carrying developments of coarse sparry calcite.

CXD 362: 70.14–70.37 m.

Chloritised flow-banded *lapilli tuff* crossed by calcite veinlets. *Pyrite* occurs in calcite vesicle-fills. Other vesicle-fills have a pale clay-chlorite filling.

(d) BH 3B

CXD 368: 18.15–18.20 m.

Massive even-textured *calcareous sandstone* crossed by veinlets up to 1 cm thick of calcite and subordinate *pink baryte* plus occasional specks of *galena.*

CXD 372: 20.55–20.60 m. PTS 6490.

Breccia: angular fragments of dark grey *limestone* form some 40% by volume and are set in a coarse matrix of white calcite, *pink baryte* and clear quartz, which also carries *pyrite, galena,* and *sphalerite.* Fine *pyrite* granules occur disseminated through the limestone.

CXD 374: 21.44–21.48 m.

Black calcareous mudstone crossed by veinlets of calcite. *Pyrite* is a major constituent finely disseminated and in small (1–3 mm thick) lenses in the mudstone. *Pyrite* also occurs in the veinlets. The pyrite enrichment of the mudstone appears to pre-date formation of the veinlets.

CXD 376: 25.18–25.23 m.

Black calc-mudstone containing branching seams of highly graphitic material. A few coarse calcite crystals of diagenetic character, and sparry shell fragments, are present. Two epigenetic veinlets, one of calcite, quartz and *pyrite*; the other of calcite, baryte and 'albertite', appear in opposite corners of the core specimen (thus not establishing age relationships). The mudstone carries fine disseminated *pyrite.*

CXD 380: 32.15–32.21 m, 32.55–32.63 m.

Two pieces of *black, fossiliferous limestone* crossed by a calcite veinlet carrying *galena, sphalerite* and *pyrite.* The limestone itself appears to be barren.

CXD 382: 34.17–34.22 m. PTS 6491.

Black graphitic mudstone with a network of calcite hairline veinlets. The specimen contains a sinuous boundary between silified rock and calcareous rock. Disseminated euhedral *pyrite* grains are abundant, and a single *sphalerite* crystals was located in a veinlet. The silicification is regarded as early diagenetic, which with the abundant pyrite may indicate proximity to a contemporaneous siliceous hot spring.

CXD 384: 36.63–36.73 m. PTS 7171.

Black limestone and *black calc-mudstone* in sharp contact at which irregularities suggest local erosion or disturbance of the limestone prior to deposition of the mud. Diagenetic *pyrite* cubes occur in sparry shell fragments, or randomly sited in the limestone. A cross-cutting calcite hair veinlet is barren and apparently not related to the sulphide.

CXD 384: 37.25–37.31 m.

Dark crystalline limestone with diagenetic *pyrite* cubes. Carbonaceous seams carry fine *pyrite* and small lenses of sparry calcite.

CXD 385: 39.69–39.75 m. PTS 7172.

Dark limestone with sparry shell fragments and occasional thin seams of fine-grained carbonaceous material. *Pyrite* forms fine grains in fossil fragments, and larger diagenetic cubes. Calcite hair veinlets are barren save for rare *sphalerite* grains.

CXD 385: 40.28–40.33 m. PTS 6492.

Black muddy cherty limestone with sparry shell fragments. An irregular boundary between calcareous and siliceous bands suggests syn-depositional instability (local down-sagging of the siliceous lithology). *Pyrite* and minor *sphalerite* occur in areas of sparry limestone.

CXD 386/387: 41.10–41.18 m.

Black limestone crossed by numerous white calcite veinlets and containing small patches of sparry calcite. *Pyrite* occurs in the sparry patches and, with *galena,* in the veins. The sulphide here looks epigenetic.

CXD 387: 42.58–42.64 m. PTS 7173.

Dark fossiliferous limestone specimen, one end of which consists of a *galena* bloom developed in a calcite hair veinlet. The rock generally contains disseminated fine *pyrite.* Muddy bands contain fine *sphalerite, pyrite, galena* and *'albertite'.*

CXD 388: 43.20–43.23 m.

Grey fossiliferous limestone in which common pyrite grains occur disseminated and preferentially sited in sparry shell fragments.

CXD 390: 45.75–45.81 m.

Muddy limestone with graphitic seams: very rich in fine disseminated *pyrite* and isolated coarser *pyrite* crystals. *Pyrite* is especially abundant in branching graphitic seams. *Galena* occurs in calcite hairline veinlets. *Sphalerite* is almost certainly present.

CXD 390: 46.32–46.37 m.

Moderately *calcareous black mudstone* varying from sulphide-poor to sulphide-rich and calcareous. The sulphide is mostly *pyrite*, but fine sphalerite and galena could well be present.

CXD 391: 46.90–46.92, 46.92–46.95. PS 7175 (second piece)

Consecutive pieces of *friable carbonaceous mudstone,* almost non-calcareous but heavily sulphide impregnated. The first has a *pyrite* band showing a breccia structure with barren mudstone fragments in a pyritic matrix. Adjacent mudstone bands are barren and not brecciated. The second specimen shows heavily *sphalerite* with *galena* impregnated bands alternating with less mineralised mud.

CXD 392: 47.09–47.15 m. PTS 7176.

Grey mudstone (possibly tuffaceous) containing hair veinlets and lobate micropatches of very fine silica and clay/chlorite. Many also contain sparry calcite crystals, and also host *sphalerite* and, less commonly, *galena.* The lobate patches are vesicle-like.

CXD 392: 47.25–47.29 m.

Porcellanous clay-rich tuffaceous rock rich in minute chlorite spots. The rock also displays small chloritic patches, lenses and veinlets which contain *sphalerite* and *galena.* This, and the preceding specimen, are interpreted on geological criteria as a seat-earth (see Appendix I).

CXD 395: 56.25–56.33 m. PTS 6493.

Tuff in which small rounded *lapilli* of quenched basaltic lava, now clay/chlorite altered, form an open textured fabric whose interstices are filled with sparry calcite. These calcite areas have chlorite rims and contain *pyrite* grains.

CXD 395: 56.49–56.57 m. PTS 6494.

Bedded tuff in which interstices between plastically deformed *lapilli* contain chlorite and calcite, and in some cases *pyrite.* The specimen is crossed by a seam of intense chloritisation centered on a calcite veinlet.

CXD 400: 64.07–64.12 m. PTS 7177.

Calcareous sandstone crossed by chloritic hairline seams. The rock is also crossed by a hair fracture carrying small patches of a red resinous hydrocarbon. A little *pyrite* occurs interstitially.

CXD 400: 64.58–64.67 m.

Calcareous sandstone crossed by a barren calcite veinlet. Small patches of a coppery metallic phase oriented parallel to the bedding consist mostly of *niccolite* with lesser *pyrite* (XRD powder photograph Ph 6630).

CXD 405: 74.30–74.34 m. PTS 6495.

Calcareous agglomerate in which pale fragments occur in a fine dark matrix. *Pyrite* and minor *chalcopyrite* are common in certain zones in the matrix. Some *pyrite* occurs as discrete patches of massive sulphide. In thin-section micro-porphyritic texture is visible in some fragments, while others show a micro-cellular structure indicating either exploded pumice or a biological origin.

CXD 410: 80.44–80.47 m.

Grey fossiliferous limestone in which *pyrite* is abundantly impregnated through the rock and preferentially sited in shell fragments.