Natural Environment Research Council
Institute of Geological Sciences

Mineral Reconnaissance Programme Report

A report prepared for the Department of Industry

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No. 53

Investigation of polymetallic mineralisation in Lower Devonian volcanics near Alva, central Scotland

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Investigation of polymetallic mineralisation in Lower Devonian volcanics near Alva, central Scotland

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SUMMARY

The subsurface characteristics of three known occurrences of fracture-controlled mineralisation in the Lower Devonian Ochil Volcanic Formation near Alva, central Scotland, were tested by shallow boreholes. Target structures were intersected by each borehole, but they contain only minor amounts of baryte and geochemical enrichments of copper, arsenic and uranium. Differential fracturing within the variegated volcanic sequence and enhanced brecciation at fault intersections are principal controls. Earlier silver-cobalt mineralisation appears to have been followed by copper-barium mineralisation. The andesitic rocks of the volcanic pile represent a suitable source for the metals.

INTRODUCTION

LOCATION

The three sites on which this investigation is based lie along the southern margin of the Ochil Hills, some 45 km to the north-west of Edinburgh (Figure 1). They are situated either at the base of the steep south-facing scarp of the Ochils (Blairlogie, Balquharn) or at a short distance above the sharp break of slope as in Alva Silver Glen (Burnside). At all three sites, however, access for heavy equipment is so severely restricted that optimum drilling positions were unobtainable.

MINING HISTORY

Metalliferous mineralisation was exploited in the Alva area intermittently from the seventeenth to the nineteenth centuries at numerous small mines, many of which were little more than trial adits into steep valley and hill sides. This is particularly true of many small baryte veins in the area where trial workings probably represent unsuccessful prospects for copper or silver. By far the most successful workings were in the Silver Glen, a little to the north-east of Alva, where mineralisation was first discovered in 1711. These workings provided most of the silver produced from the area in the early part of the eighteenth century. Records suggest that this amounted to at least 45 tonnes of ore assaying 85% Ag. Furthermore, a substantial amount of cobalt ore was produced from the Alva Silver Glen workings and earlier spoil heaps for use in the pottery industry, following its first recognition in 1759.

A detailed modern account of the mineralisation in the Alva area is already available (Francis and others, 1970), based partly on earlier published records (Wilson and Flett, 1921) so that only brief reference to the main localities is needed here. However, it is of interest to note that anomalous radioactivity was identified for the first time at several localities in the relatively recent examination of the area (Francis and Dawson, *in* Francis and others, 1970). A brief reference to the Alva area is made in the 'Mineral Deposits of Europe' volume dealing with north-west Europe (Dunham and others, 1978).

Two main groups of workings can be recognised, depending on whether (a) silver was produced or (b) other metals such as copper, iron or lead were exploited, as follows:

Mine locality	*National Grid Reference (NS)*
a. *Silver producers*	
1 Airthrey	815 972
2 Alva	892 976
3 Carnaughton	878 975
4 Tillicoultry	912 978
b. *Producers of other metals*	
5 Airthrey Hill	795 978
6 Allan Water	787 983
7 Alva	892 976
8 Jerah	832 995
9 Tillicoultry (Daiglen)	911 983

It can be seen that copper, as well as silver and cobalt, were produced from the Silver Glen workings at Alva.

In general it would appear that mining in the Alva area was restricted by awkward terrain and lack of capital as well as by the small size of the deposits.

SCOPE OF THE PRESENT INVESTIGATION

A small programme of shallow drilling was carried out in 1978 to investigate the sub-surface characteristics of three of the more significant occurrences of mineralisation in the Ochil Volcanic Formation near Alva. Prior geophysical surveys

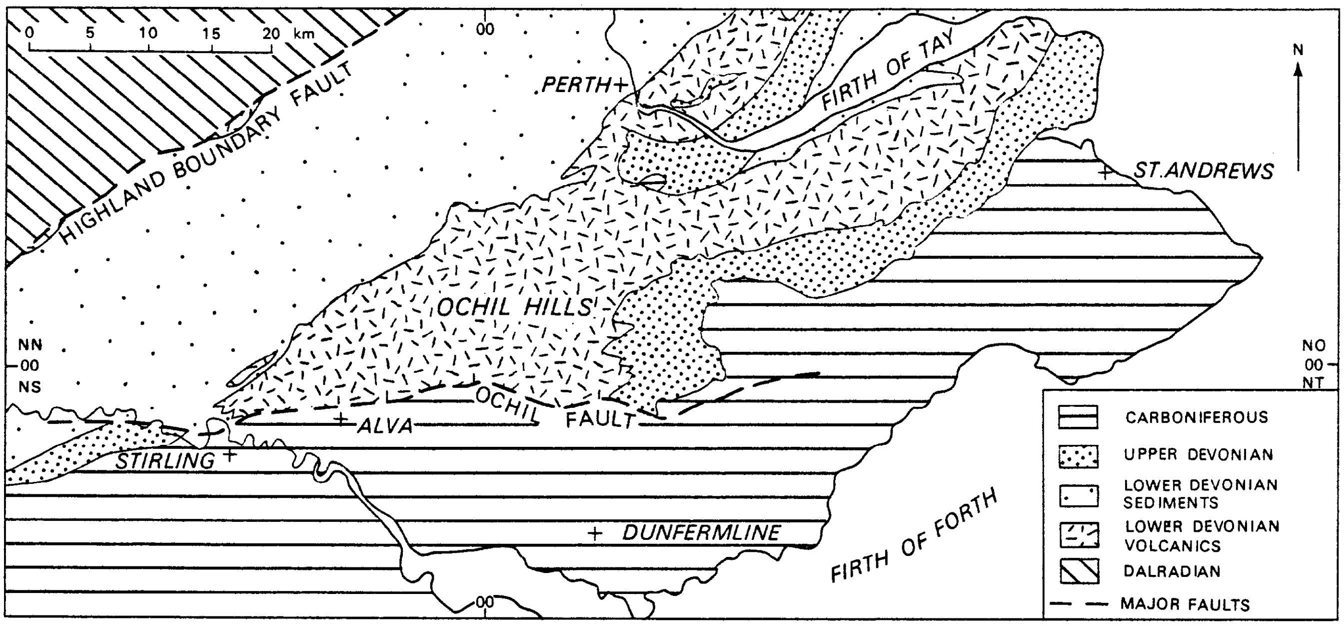

Fig. 1 Generalised geology of central Scotland

were attempted but because of the high level of cultural noise meaningful results were unobtainable (see Appendix IV). As geochemical soil sampling was also inhibited by artifacts and the nature of the topography, the selection of drilling sites was based entirely on the available geological and mining information. The criteria for selection of the three borehole sites are presented in the detailed accounts of the Burnside, Balquharn and Blairlogie districts given later in the report. The plans of each borehole site given in Figures 4a, 5 and 6 are based on theodolite surveys.

Locational and other information concerning the three boreholes are summarised in Table 1. Core recovery exceeded 95% overall but significant losses occurred over small sections in the drilling of all three boreholes. These losses are most probably attributable to intersections with fracture zones, some of which may carry mineralisation. Unfortunately, sludge sampling proved impossible because of the loss of drilling returns over the same sections.

Following the detailed logging of the borehole cores (Appendix I), the mineralised intersections and the typical rock types were subsampled for geochemical analysis (Appendix II) and for petrographical and mineralogical studies (Appendix III and Appendix IV–V respectively). A suite of channel samples was also taken for analysis from the old mine workings in Alva Silver Glen (Table IV, Appendix II).

Geochemical sampling of tributary alluvium from the entire area of the Ochil Hills has been carried out in recent years and the analytical results are being prepared in map form for future publication.

GEOLOGY

SUCCESSION

The general succession of geological formations in this area is summarised below:

Superficial deposits

Recent and Pleistocene
- Scree
- Freshwater Alluvium (as alluvial cones)
- Marine and estuarine alluvium (post-Glacial)
- Boulder clay

Solid formations

	Thickness, m
Carboniferous	
Upper Carboniferous (including Coal Measures)	1350
Lower Carboniferous	unknown
Devonian	
Upper Devonian (Old Red Sandstone)	325
Lower Devonian (Old Red Sandstone)	
Various formations of conglomerate sandstone and mudstone	4200
Ochil Volcanic Formation	3300

The oldest rocks cropping out in this area comprise the Lower Devonian Ochil Volcanic Formation. The regional dip is to the north-west at about 15° and near Tillicoultry they are c. 2400 m thick. No base is seen but c. 900 m of older rocks occur further east bringing the total thickness to a minimum of 3300 m (Francis and others, 1970). The volcanics are succeeded by over 4000 m of Lower Devonian sediments, of which the lowest 1000 m are largely derived from the volcanic rocks. These sediments occupy a broad tract of land to the north of the Ochil Hills but are absent in the east where the Upper Devonian lies unconformably on the volcanic rocks.

The Upper Devonian and Lower Carboniferous rocks do not crop out in this area but are almost certainly present at depth on the south side of the Ochil Fault. Various groups of the Upper Carboniferous abut against the Ochil Fault and there is evidence that at least the highest divisions thin towards the fault (Francis, 1956).

Boulder clay covers the lower part of the Ochil Fault scarp and extends southwards where it is in turn covered by post-Glacial Carse Clays. All the south-draining streams have developed alluvial cones at the base of the scarp and spread out over the Carse Clays. Screes and hillwash have also developed in places along the fault scarp.

OCHIL VOLCANIC FORMATION

The Ochil Volcanic Formation consists of a thick sequence of lavas with interdigitating coarse tuffs and agglomerates cut by frequent minor intrusions. The lavas are mainly andesites and basalts, many of which have a chemical composition near the andesite-basalt boundary (Francis and others, 1970). Several varieties of andesite, notably pyroxene-andesite with feldspar phenocrysts, pyroxene-andesite and hornblend-andesite occur together with subordinate trachyandesite and rhyodacite. Many of the lavas have fissures filled with sandstone and siltstone indicating contemparary deposition of exotic sediments. Thus, though the lavas provided considerable detritus, subsidence was also taking place in some areas. Most of the lavas show alteration with replacement by carbonate and chlorite and albitisation is particularly prevalent. Recent work (French and others, 1977) suggests that potassic metasomatism took place at a late stage in the volcanic history of the western Ochil Hills.

The coarse tuffs, lapilli tuffs and agglomerates show considerable lateral variation in thickness but are coarsest and thickest along the southern margin of the Ochil Hills suggesting that this area was proximal to the source. They include rocks which appear to be partially of sedimentary origin and may also include autobrecciated lavas which have a very similar appearance. The composition of the fragmental material in the

Table 1 Summary characteristics of boreholes

Borehole No.	1	2	3
Borehole name	Burnside	Balquharn	Blairlogie
NGR (NS)	8915 9757	8674 9742	8293 9690
Collar elevation (m)	93.4	50 (approx.)	17.5
Inclination/azimuth (magnetic)			
a At surface	45/053	45/060	45/076
b Tropari surveys at various depths	49/054 (80.0 m) 43/049 (140.0 m) 41/047 (186.0 m)	43/061 (150.0 m)	45/073 (100.0 m)
Depth (m)	215.15	160.74	115.23
Map references			
1:50 000		39E (Alloa)	
1:10 560	NS 89 NE	NS 89 NE	NS 89 NW

pyroclastics is largely comparable with that of the lavas but also includes some fragments of a felsitic nature which cannot be matched locally.

LOWER DEVONIAN INTRUSIONS

The volcanics are cut by many intrusions, the most important of which are the diorite stocks near Tillicoultry. The stocks are cut off by the Ochil Fault but geophysical evidence (McQuillin, *in* Francis and others, 1970) suggests that they extend, at depth, under the younger sediments to the south side of the fault. There is a metamorphic aureole round the stocks with the development of feldspar porphyroblasts and aplitic veins which, at the present level of erosion, extends outwards for c. 400 m. There are also frequent dykes cutting the volcanic rocks, mostly albitised porphyrites, porphyries and plagiophyres. Textural and petrological evidence suggest a genetic relationship between the diorites and the dykes (Francis and others, 1970). The latter display a crude radial relationship to the diorite stocks and also a marked concentration parallel to the main fault trends. This suggests that the structural grain was already established before the intrusions were emplaced and possibly explains the fact that these trends can seldom be traced in the overlying sediments.

PERMO-CARBONIFEROUS INTRUSIONS

Discontinuous intrusions of quartz-dolerite cut the volcanic rocks along the line of the Ochil Fault. These are assumed to be of Permo-Carboniferous age by comparison with neighbouring areas.

FAULTING

A number of faults affect the Ochil Volcanic Formation and are most frequent along the southern margin (Figure 2). This concentration may be partly due to good exposure, but comparison with other well exposed areas of rocks of similar age to the north and east suggests that it is factual rather than apparent. Two main trends of fracturing occur, one roughly north-west and the other roughly north-east. These are considered to be of Lower Devonian age because of their close association with the Lower Devonian dykes. A third, less common trend occurs, roughly east-west, which is thought to be of Permo-Carboniferous age by anology with neighbouring structures in the Midland Valley.

All these trends have been mineralised to some extent.

OCHIL FAULT

The Ochil Fault is the dominant structure in this area and trends roughly east-west. It is a major fault with maximum downthrow near Alva which decreases both to east and west. In this area, there are about 650 m of volcanic rocks below Lower Devonian sediments in the scarp to the north of the fault. To the south of the fault there is estimated to be 1000 to 1500 m of Upper Carboniferous sediments, and probably also Lower Carboniferous, Upper Devonian and possibly Lower Devonian sediments overlying the volcanic rocks exposed to the north of the fault. Thus the minimum displacement is 2000 m and possibly considerably greater. Limited field evidence indicates the southerly hade of a normal fault but this is at variance with geophysical evidence which suggests a northerly hade (Davison, 1924). Alternatively, the geophysical evidence may indicate a second subsurface structure hading north, parallel to and north of the Ochil Fault. Recent comparatively shallow seismic activity also appears to have been centred north of the fault (Davison, 1924; Burton and Neilson, 1979) and along the fault (Dollar, 1951).

The evidence of structure, vulcanicity, sedimentation and the geophysical data all suggest that a zone along the Ochil Fault has had a long

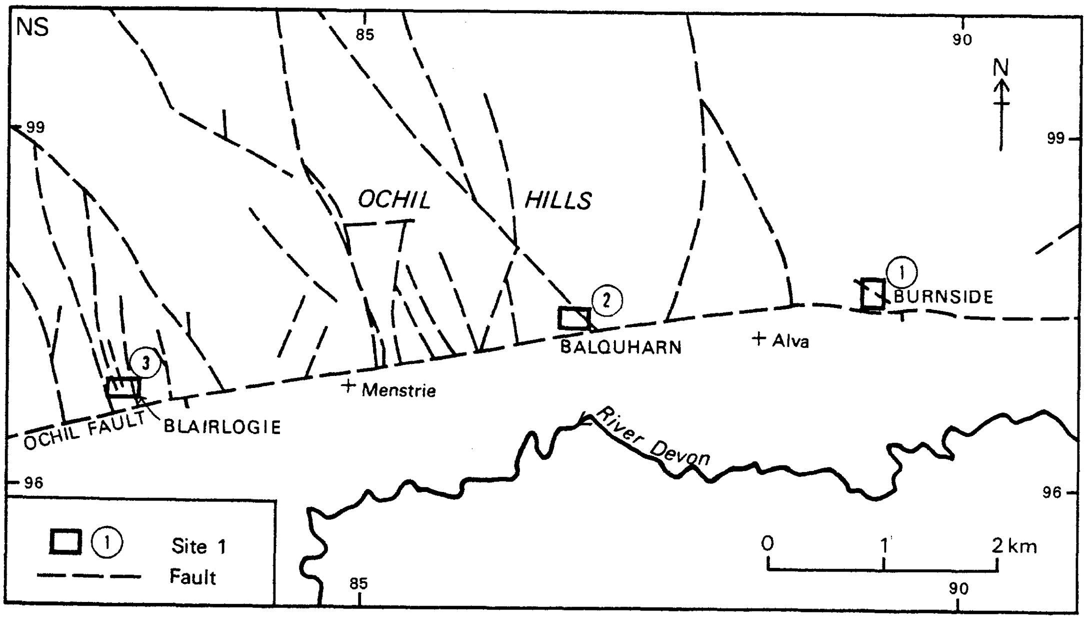

Fig.2 Map showing fault pattern along southern margin of Ochil Hills and borehole sites

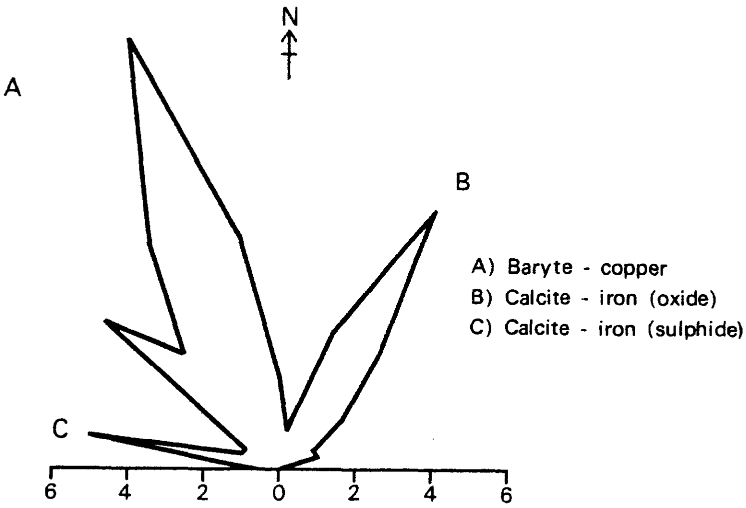

Fig 3. Orientation of mineralised structures

and complex history.

MINERALISATION

All the known mineralisation in the Ochil Hills is along fault planes and fracture zones which in some cases are also the sites of minor intrusions. The three main trends of faulting (Figure 3) have all been mineralised to some extent but are characterised by different associations of minerals (Francis and Dawson, *in* Francis and others, 1970).

A plot of the recorded mineral veins shows the NW–SE trend (A in Figure 3) to be the most common. This trend has a dominantly baryte-copper association with iron and lead occurring in small quantities and calcite and quartz as less common gangue minerals. Most of the iron occurs as pyrite.

The NE–SW trend (B in Figure 3) has a dominantly calcite-iron association with the iron occurring as an oxide. Silver with minor cobalt, copper and lead occur, and baryte and quartz are less common gangue minerals.

The E–W trend (C in Figure 3) is the least common and least well defined in direction. This trend also has a dominantly calcite-iron association but in this case the iron occurs mostly as pyrite. Silver and copper, with subordinate lead, arsenic and cobalt also occur, with quartz and minor baryte as gangue minerals. The Ochil Fault also follows this trend but there is no mineralisation visible or recorded at the few localities where it is exposed.

It has been suggested (*op. cit.*) that the NE–SW and E–W trending faults (i.e. the calcite-iron associations) were mineralised during the Permo-Carboniferous and the NW–SE trend was mineralised in Tertiary times. K-Ar ages on illite-rich concentrates from the mineralised rocks of the Alva area are late Carboniferous to early Permian (260–300 Ma) (Ineson and Mitchell, 1974).

LITHOGEOCHEMISTRY

Analyses of 31 selected core samples and 12 channel samples for selected minor and major elements are given in Appendix II. On the basis of the core analyses, average metal values have been calculated for the three main volcanic rock types in Table 2. A fourth category of brecciated and veined core samples is also represented.

Despite the small sample populations, compositional variability between samples of the same lithological class, and the effects of calcite and baryte veining, several elements are appreciably enriched in the volcanics when compared against crustal abundance values for basaltic rocks (Turekian and Wedepohl, 1961; Taylor, 1964) notably As, Rb, Zr, Mo, Ag, Sb, Pb, Th and U. These metals most probably respresent inherent enrichments whereas the high Ba content of the tuffs is attributable to veining. On this basis, it can be inferred that the rocks of the Ochil Volcanic Formation represent suitable source-rocks for most of the metals now found in the vein structures. The exceptions are Cu and Co, for which the values given in Table 2 are only about one-half of those of the average basalt, and possibly also Ba which is present at only normal levels in the lavas and fragmental volcanic rocks.

The brecciated and veined volcanic rocks are characterised not only by high Ca and Ba values due to carbonate and baryte veining but also by slightly enhanced values of As, Ag and Sb compared with the other groups in Table 2. In BH 2 (Balquharn) a 4.74 m intersection in brecciated rocks averages 2.3% Ba (Appendix II, Table II). The rather high uranium content of the material recovered from the radioactive intersection in BH 1 (Burnside) is also of note (CXD 119, Appendix II, Table I).

The most significant values for economic metals were those of Cu, Ag and Co obtained from channel samples taken in the workings at Alva Silver Glen (Appendix II, Table IV). Up to 1.46% Cu with 27 ppm Ag is present over 0.9 m (CXD 202) and 0.085% Co with 0.07% Cu over 2.5 m (CXD 209).

GEOLOGY OF THE BURNSIDE DISTRICT

GENERAL

This district is one of complex geology where interbedded andesitic lavas and agglomerates have been affected by faults, intrusions and hydrothermal veins. Apart from a thin cover of hillwash and talus in places, the area is largely drift-free, but natural exposure has been modified by spoil from the old mine workings and opencast trenches dug along mineralised structures.

Along the southern margin of the district quartz-dolerite has been intruded along the line of the Ochil Fault (Figure 4a). This intrusion has a pod-shaped outcrop which is about 80 m wide in Silver Glen and the agglomerate which it cuts is bleached, brecciated and contains a little disseminated pyrite near the contact. To the north of the intrusion the succession comprises alternations of thin andesitic lavas and agglomerates which are overlain by a thick sequence of andesitic lavas seen in the northern part of the district. The lowest part of the sequence, seen only in the borehole (Figure 4b), comprises a minimum of 30 m of fragmental volcanic rock which includes tuffs and agglomerates.

FORMER MINE WORKINGS

The main mineralisation occurs in the central part of the district, between the ENE–WSW fault (K in Figure 4a) and the NW–SE fault H. No mineralisa-

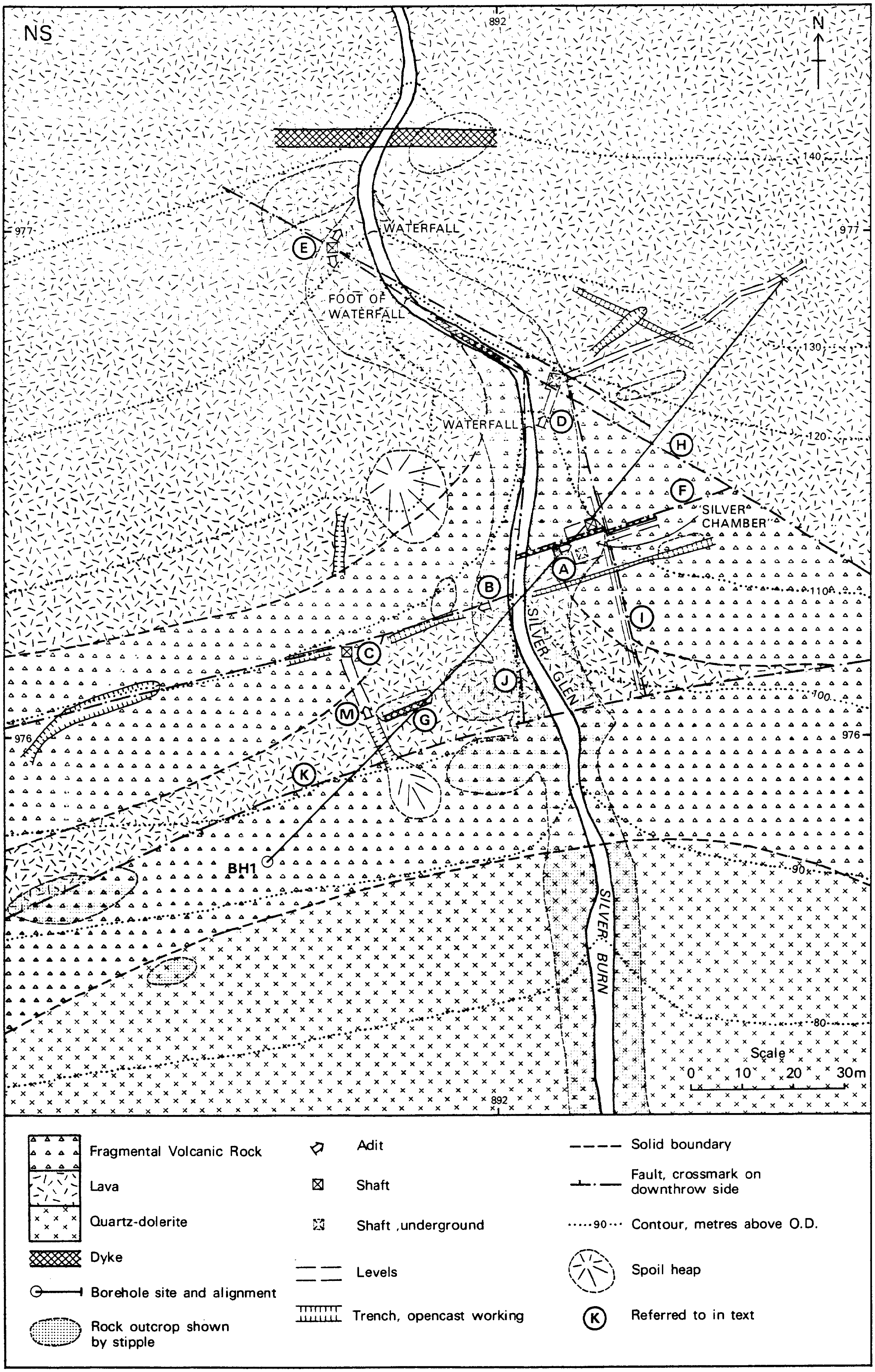

Fig.4a Geological plan of Burnside, Borehole 1

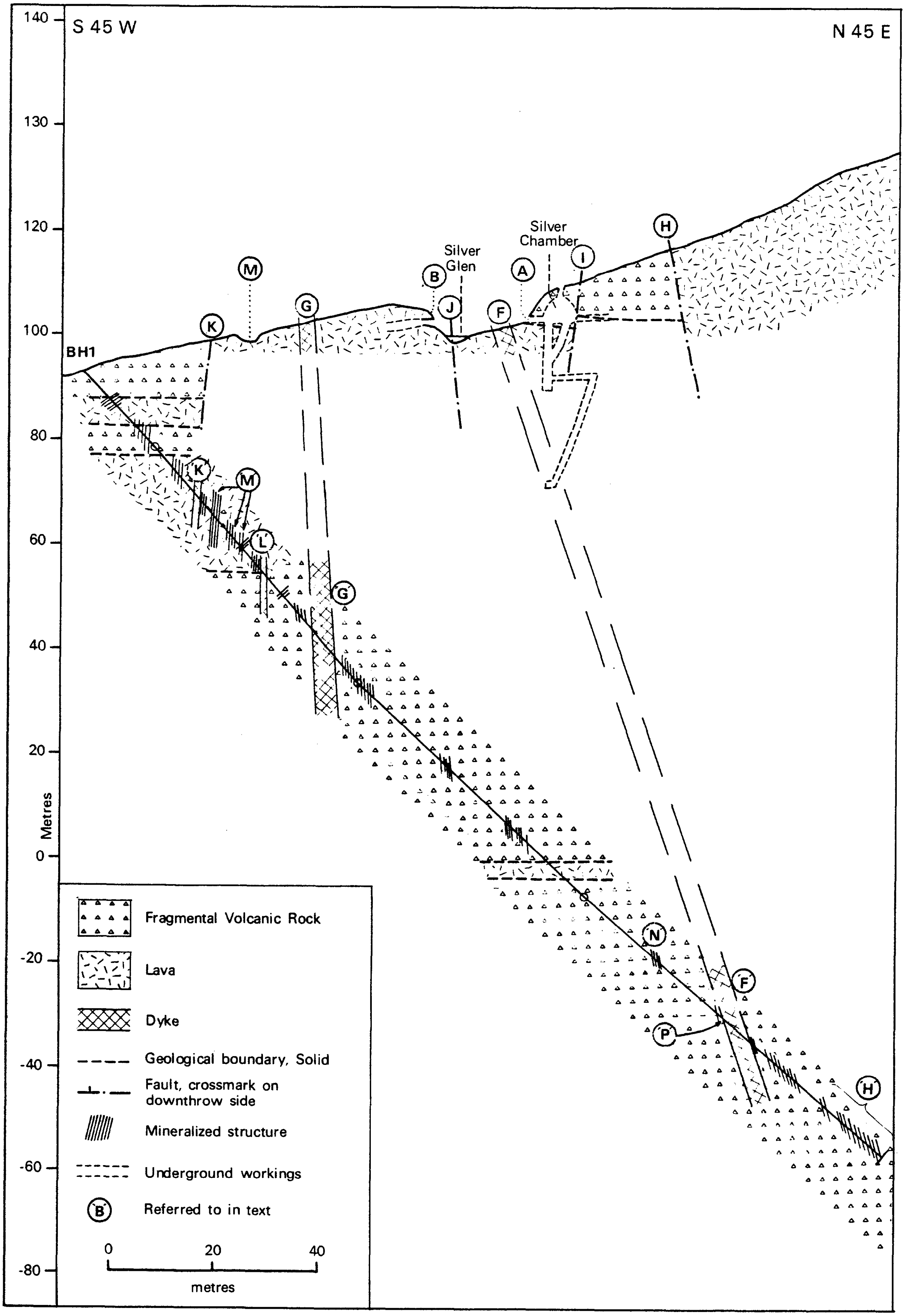

Fig.4b, Section of Burnside, Borehole 1

Table 2 Average compositions of rock types from the Ochil Volcanic Formation

	Lavas	*Fragmental volcanic rocks*	*Tuffs*	*Brecciated and veined rocks*
No. of samples	11	5	7	5
%				
Ca	3.0	4.1		*11.4*
Ti	0.73	0.64		0.36
Mn	0.079	0.083		0.20
Fe	5.8	5.5		4.0
ppm				
Co	26	23	26	26
Ni	55	35	44	36
Cu	36	53	31	22
Zn	*97*	62	62	45
As	22	11	12	*34*
Rb	63	66		26
Sr	370	260		250
Y	26	24		20
Zr	270	250		160
Nb	14	9.6		6.8
Mo	2.6	3.0		3.0
Ag	1.1	1.0	1.4	1.8
Sn	1.8	2.0		0.8
Sb	2.8	2.4		3.6
Ba	470	370	*1650*	*1150*
Ce	57	46		28
Pb	12	11	20	12
Th	9.2	8.8		6.8
U	3.6	3.6	3.6	2.8

The values given in italics are regarded as high-anomalous

Individual rock analyses are given in Appendix II

tion is seen along fault K but the parallel fault F, some 30 m to the north, is one of the most important mineralised structures in the district. Adit A into the east bank of Silver Burn and adit B driven into the west bank follow this structure, which has been offset by north-south fault J. A narrow trench which has been cut on the east bank due east of B is believed to have been a barren trial dug in an attempt to follow F on the east side of the stream. The mineralisation is in a breccia c. 0.6 m wide and comprises calcite, quartz, pyrite, chalcopyrite, malachite, arsenopyrite, argentite, galena, erythrite, ferruginous gouge and botryoids of hydrocarbon. Adit A, on the offset continuation of F, is the entrance to a chamber 6 by 4 m which was the site of the rich silver lode now known as the 'Silver Chamber'. The mineralised fault and an associated altered thin basic dyke are seen in the chamber where they are offset by another roughly north-south fault (I) which has also been mineralised. Structure I is more variable in thickness (maximum 0.4 m) and carries baryte, quartz, chalcopyrite and malachite. Levels have been driven along the extensions of these structures from the chamber. From the south-east corner a level has been driven for about 30 m trending 164° where the structure dips 78°W and a drivage has been made on the continuation driven from the north-east corner of the chamber for c. 5 m trending 350°. From the eastern side of the chamber a level has been driven for c. 10 m along the extension of the main structure (F) trending 064° and dipping 78°S. An irregular, subvertical structure, which appears to be the remnant of the silver lode, is intersected in the north-east corner of the chamber and also in the shaft which has been sunk in the south-west corner of the chamber. This mineralised breccia appears to be developed at the intersection of the two main structures and has a pipe-like form with a variable diameter depending on the host rock (Figure 8). It is thought that the silver lode may have been a node on this pipe and that the cobalt ore, reputedly mined from the lower level, constituted another node with the intervening section being formed largely of gangue minerals. Where seen the pipe is

1 m wide and contains baryte, pyrite, chalcopyrite, malachite, ferruginous gouge and botryoids of hydrocarbon. Calcite, quartz, arsenopyrite, argentite, galena and erythrite have also been recorded previously (Francis and others, 1970). The shaft in the chamber is about 2.5 m square and descends for about 12 m. A small trial has been driven to the south about 2 m below the floor of the chamber and another level has been driven to the east at about 10 m down. A 20 m winze led down from this intermediate level to a lower level which in turn had access to the surface by an unlocated adit (Wilson and Flett, 1921) in Silver Glen some 60 m to the south of the northern margin of the quartz-dolerite. There is also access to the shaft from a winze in the north-east corner of the chamber and above this is another shaft from ground level into the chamber.

Channel samples were collected from the mineralised structures in the Silver Chamber and analysed, Appendix II, Table IV. The east and south drivages gave anomalously high copper and silver and higher than normal cobalt values; the north drivage gave anomalously high copper but neither adit A, the trial from the shaft, nor the intersection gave any high values.

Adit B was driven west along structure F, to join shaft C, which is also connected to adit M. Surface trenching along the crop of F has been carried out between B and C and at intervals for some 50 m west of C.

About 20 m upstream from adit A is adit D which is driven on a mineralised vein trending 020°. At 6.5 m in from the entrance a small chamber 2.5 m square has been developed with a water-filled shaft at least 20 m deep in the north-west corner. Thin cross-cutting veins, trending 300°, seen near the shaft are probably related to the NW–SE fault (H) seen at the surface. From the north-east corner of the chamber a level has been cut in mineralised breccia on an average trend of 065° for about 50 m. The mineralisation is calcite, quartz, ferruginous gouge, pyrite, chalcopyrite, argentite and botryoids of hydrocarbon (Francis and others, 1970). Trenching at the surface probably followed the crop of the vein and is crossed by a narrow trench running NW–SE parallel to H.

Channel samples taken at intervals along this drivage gave high copper values at 10 m in from the entrance at the approximate intersection with the cross-cutting structure H.

Sixty metres to the north-west of adit D another working, E, is developed on the NW–SE fault (H) and in a similar tectonic setting to the workings at D. It comprises an opencut 10 m deep, or possibly a collapsed shaft, an adit driven south on a 170° trend, and adits driven to the north trending 030° at three different levels. The lowest of the north drivages is accessible and shows the vein splitting into two sections 5 m from entrance. The mineralisation is dominantly baryte with some calcite and traces of copper. The drivage to the south is blocked near the entrance but some baryte veins are seen on its projection in the drivage between adit B and shaft C. Some surface trenching to the north of shaft C follows a similar trend.

Channel samples (Appendix II, Table IV, CXD 210–211) collected from both branches of the drivage to the north show high copper values. The sample collected from the drivage to the south shows high cobalt and nickel values and moderately high copper values.

BOREHOLE DATA

The Burnside borehole (Table 1) was sited at the point of nearest reasonable access to the Silver Chamber (A) and aligned so that the mineralised structures seen in the chamber would be encountered at depth (Figure 4). The sequence encountered in the borehole was essentially lavas (Appendix III, PTS 50006–10) with thin beds of agglomerate in the top 50 m*, overlying a thick development of fragmental volcanic rock. The lavas are thin altered andesites, mostly feldsparphyric, but occasionally contain pyroxene phenocrysts. They are typically vesicular with infillings of chlorite and calcite. The fragmental volcanic rock is very variable both in fragment size and type of contents. Many of the fragments are reddened, others have reaction rims and a few have the very irregular outline typical of spatter. The matrix is also variable, being typically crystal-lithic but in places it is crystalline (Appendix III, PTS 5015) and in others it is bedded with scattered clastic quartz grains. The volcanic rocks are cut by several thin dykes and complex hydrothermal breccia zones, the latter being confined to the top 50 m of the borehole section. A little above the thickest of the dykes, at 175.63 m, 0.91 m of brown, only slightly consolidated, calcareous silt with shell fragments occurs ('P'). This silt appears to have partly or loosely filled a cavity. This cavity is thought not to relate to old workings, the lowest of which is about 100 m higher, but to be possibly contiguous with the post- and late-Glacial alluvial deposits which occur 200 m to the south.

Mineralisation occurs at intervals throughout the core, mostly as thin veins and veinlets in rather disperse zones. Thin veins and veinlets are scattered throughout the top 15 m. Calcite is the gangue mineral and there are occurrences of pyrite, occasionally of galena (Appendix V, XE 227) and rarely of sphalerite (Appendix V, XE 228). Between 26 and 55 m there are frequent thin veins and joint coatings which have calcite and chlorite as gangue; many have pyrite, some chalcopyrite (Appendix III, PTS 5006, 7) and a few contain galena in small quantities. This zone is cut by intrusions at 31.00–32.96 m ('K') and at 50.56–51.38 ('L'), both of which have altered selvages along their margins, and by complex hydrothermal

*Depths are not corrected for borehole inclination

breccia veins ('M') at 35.00–38.75 m (Appendix III, PTS 5011), 43.30–43.80 m and 44.63–45.60 m. Visible sulphides are more abundant in the vicinity of the intrusions and the hydrothermal zones. This suggests a possible genetic link. Another intrusion ('G') at 65.20–71.75 m (Appendix III, PTS 5012–4) has calcite veins above and below it and chalcopyrite (Appendix III, PTS 5014) occurs in a second generation of cross-cutting quartz-calcite veins within it. Calcite veins, occasionally with pyrite, occur at intervals, becoming less common between 125 and 157 m. Between 158.60 and 159.30 m a bleached breccia ('N') occurs with a network of calcite veins carrying some chalcopyrite. Analysis (Appendix II, Table I) shows that this zone is somewhat enriched in uranium, although no discrete uranium phase was recognised, and the down-hole spectral gamma log gives a pronounced anomaly at this level. An apparently composite intrusion ('F') at 175.63–181.00 m exhibits feldsparphyric margins and a fine-grained vesicular centre. Below 181 m there is a zone of thin calcite veins, carrying a little pyrite and galena, the veins becoming less frequent below 182 to 194 m. From 194 m to the bottom of hole there are scattered thin calcite veins with traces of pyrite, chalcopyrite and galena (Appendix V, XE 282). The veining of basal zone ('H') has a consistent style of structure and mineralisation and appears to represent one dispersed zone.

Correlation between borehole and surface is difficult. Intrusions 'F' and 'G' probably correlate with dykes F and G seen at the surface, intrusion 'K' appears to lie along the line of fault K seen at the surface, but intrusion 'L' has not been recognised at outcrop. Hydrothermal vein 'M' may be represented by veining in the now overgrown trench leading to adit M. Of the other structures seen at the surface, fault H may be represented by the zone of disperse veins 'H', but faults I and J cannot be identified in the borehole although they may be present in the dispersed veining between 100 and 125 m. Breccia 'N', which gave the highest copper and uranium values encountered in the borehole, cannot be satisfactorily correlated with any surface feature.

GEOLOGY OF THE BALQUHARN DISTRICT

GENERAL

This district is one of fragmental volcanic rocks, for the most part covered by a veneer of boulder clay (Figures 2 and 5). The Balquharn Burn, flowing along the western margin of the site, has cut down through the boulder clay to expose tuffs, lapilli tuffs and agglomerates which are seen again on the higher ground to the north-east of the site. The quarry to the south of the site has an exposure of about 8 m of boulder clay with coarse fragments mostly of volcanic rock in a sandy matrix. Several mineralised structures are seen in Balquharn Burn, three of which are present in the area of the borehole. Vein A (dip 80°E, trend 012°), vein B (vertical and trending 100°) and veining along fault C (which downthrows to the south-west and trends 22°) all have baryte with quartz, calcite and some copper and iron minerals. Adits have been driven about 10 m along B just to the north of present site, and about 50 m along C on the west bank of the Balquharn Burn about 1000 m to the north of present site.

BOREHOLE DATA

The borehole, Table 1, was drilled with the intention of intersecting mineralised structure C at depth. The sequence proved in the borehole is largely fragmental volcanic rock with a thin lava near the top (Appendix III, PTS 5016) and two thicker flows between 67 m* and 97.12 m. The lavas are all altered feldsparphyric andesites, vesicular and purplish-brown coloured. The two thicker flows have irregular grey-green tuffaceous sandstone infillings indicating contemporary sedimentation. The fragmental volcanic rocks vary considerably in fragment size and content and include agglomerates (PTS 5017), lapilli tuff, fine-grained and glassy tuffs (PTS 5020–21). The fragments consist mostly of microphyric or aphyric lava and include both acidic and basic varieties though some are comparable in composition with the lavas seen in the borehole. The majority of fragments are angular but reddened and rounded fragments associated with crude bedding occur at different levels. A few have very irregular lobate outlines of spatter. The matrix also varies from very coarse to cryptocrystalline devitrified glass. Intrusions are restricted to two very thin (1 cm maximum), pale coloured and altered acidic injections associated with complex veining.

Mineralisation occurs in zones of veins at several levels with scattered thin veins and veinlets cutting the intervening strata (Figure 5). In the top 20 m there are scattered thin anastomosing carbonate veins. Between 20 and 24 m, 'G' is a zone of carbonate-baryte veining with veins up to 20 cm thick. Below this to 50 m, are scattered thin veins mostly of calcite and a 1 cm injection of pale acidic material with quartz selvages at 42 m. Between 50 and 55 m there are several complex veins of calcite and baryte with occasional flecks of pyrite and some hematite ('F'). A very thin injection occurs at 54.50 m. From 55 to 108 m there are sporadic thin veins of carbonate and baryte, some with hematite, which in places are concentrated into minor zones (Figure 5). Below 108 m a network of calcite and dolomite veining passes into stockwork veining of breccias ('C') at 112.11–114.98 m and 115.73–116.85 m (Appendix III, PTS 5019) with hematite and

*Depths are not corrected for borehole inclination

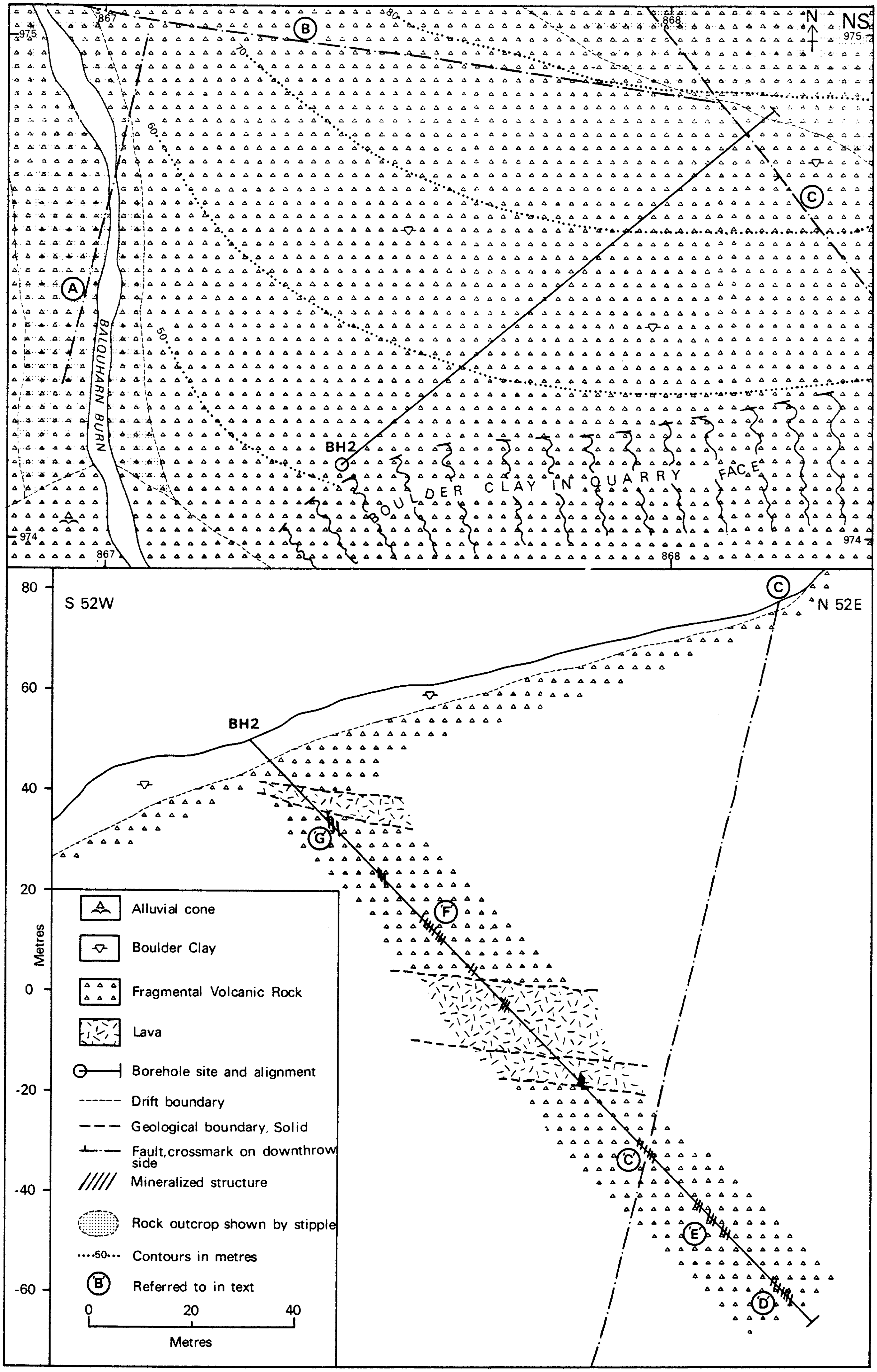

Fig.5. Geological plan and section of Balquharn Borehole, 2

occasional pyrite. Veining between 120 and 149 m, comprising sporadic calcite and dolomite (Appendix V, XE 279), forms a rather disperse zone ('E') which between 127 and 135 m occasionally contains pyrite. Between 149.54 and 155.96 m (Appendix III, PTS 5022) carbonate and baryte veins up to 7 cm thick constitute mineralised zone 'D'. Pyrite and hematite occur in the main veins and a little chalcopyrite is associated with cross-cutting veinlets. Analyses (Appendix II, Table II) yielded low metal values except for a small intersection of baryte-bearing breccia (see 'Lithogeochemistry').

Correlation between structures seen at the surface and those seen in the borehole is straightforward in the sense that structure C, which is the projected line of a fault with a throw of c.80 m, was the only structure anticipated in the borehole, and only one good breccia zone ('C') was encountered. Mineralised zone 'D' in the core may correlate with the continuation of vein B across fault C, but the other zones are not visible at the surface.

GEOLOGY OF THE BLAIRLOGIE DISTRICT

GENERAL

The Blairlogie district is characterised by thick beds of coarse fragmental volcanic rock alternating with sequences of andesitic lavas (Figures 2 and 6). Within the lava groups there are thin agglomerates and thin lavas also occur within the fragmental volcanic rock. The lavas are mostly altered feldsparphyric andesites though pyroxene-andesites occur in the higher groups. They show typically rubbly vesicular tops and bases and are autobrecciated in places with some tuffaceous sandsstone infillings. The fragmental volcanic rocks are largely agglomerate and lapilli tuff. The agglomerate contains many 0.5–1.5 m blocks and some larger ones, suggesting that this is an area proximal to a vent. The area is traversed by several NW–SE faults which are well exposed on the higher ground to the north of the present site. Mineral veins occur along all the faults, and adits and trials have been made along most of them. The most extensive workings are on fault A (Figure 6) along which adits and winzes have been made at several levels and an adit driven for 18 m in an easterly direction along a cross-cutting vein (Dickie and Forster, 1976). Traces of copper minerals are present in a gangue of baryte with patches of silica and fragments of country rock. Native copper, tetrahedrite, chrysocolla, chalcocite and malacite have been recorded from this area (Francis and others, 1970).

BOREHOLE DATA

This borehole was aligned to intersect structures B, C, D and E at depth (Figure 6). Difficult terrain and proximity of dwellings precluded intersection of the major fault A. The sequence encountered was composed mainly of altered andesitic lavas with two thin bands of fragmental volcanic rock interbedded near base. Purplish feldsparphyric lava (Appendix III, PTS 5023) and microphyric lavas occur which are very vesicular, particularly near the tops of flows, but often throughout, and show well developed flow structures particularly near the bases of flows. The vesicles are normally filled by chlorite and calcite but some of the larger examples containn quartz, dolomite and a little baryte. Throughout the sequence irregular patches of greyish-green tuffaceous sandstone occur both between and within the lava flows. The fragmental volcanic rocks seen near the base of the hole include agglomerate (Appendix III, PTS 5024) and lapilli tuff. Occasional fragments of pre-existing tuff can be seen in the agglomerate, which in places has a finely comminuted crystal matrix.

Veins of quartz and calcite up to 2 cm thick ('B') are seen between 8.25 and 8.50 m*. Broken core at 50.60–51.50 m and 53.10–54.10 m, with some loss of recovery, probably represents a structure ('C') though the only mineralisation seen is some hematite staining on broken surfaces. Broken and jointed core ('D'), with thin calcite veinlets, occurs between 70.25 and 71.75 m. Structure 'E' is also seen as broken core with brown weathered areas and thin calcite veins and veinlets between 102.25 and 103.36 m. Below this a 0.5 cm calcite-baryte vein is developed at 107 m. Though none of the core from structures 'B', 'C', 'D' or 'E' contains any significant mineralisation, the structures probably correlate with the projected positions of surface structures B, C, D and E. The lack of mineralisation at depth and the occurrence of calcite and quartz rather than the baryte seen at the surface is enigmatic but may be due to the fact that the lavas are less accommodating as host rocks than the fragmental volcanic rocks higher in the sequence.

CONCLUSIONS

All three boreholes are considered to be successful in that they intersected the target structures at or near their projected positions. Though the amount of mineralisation encountered in the cores was disappointing, the information they provide, together with related surface studies, suggests certain controls on mineralisation.

The overall structural control and relationship with intrusions has already been described (Francis

*Depths are not corrected for borehole inclination

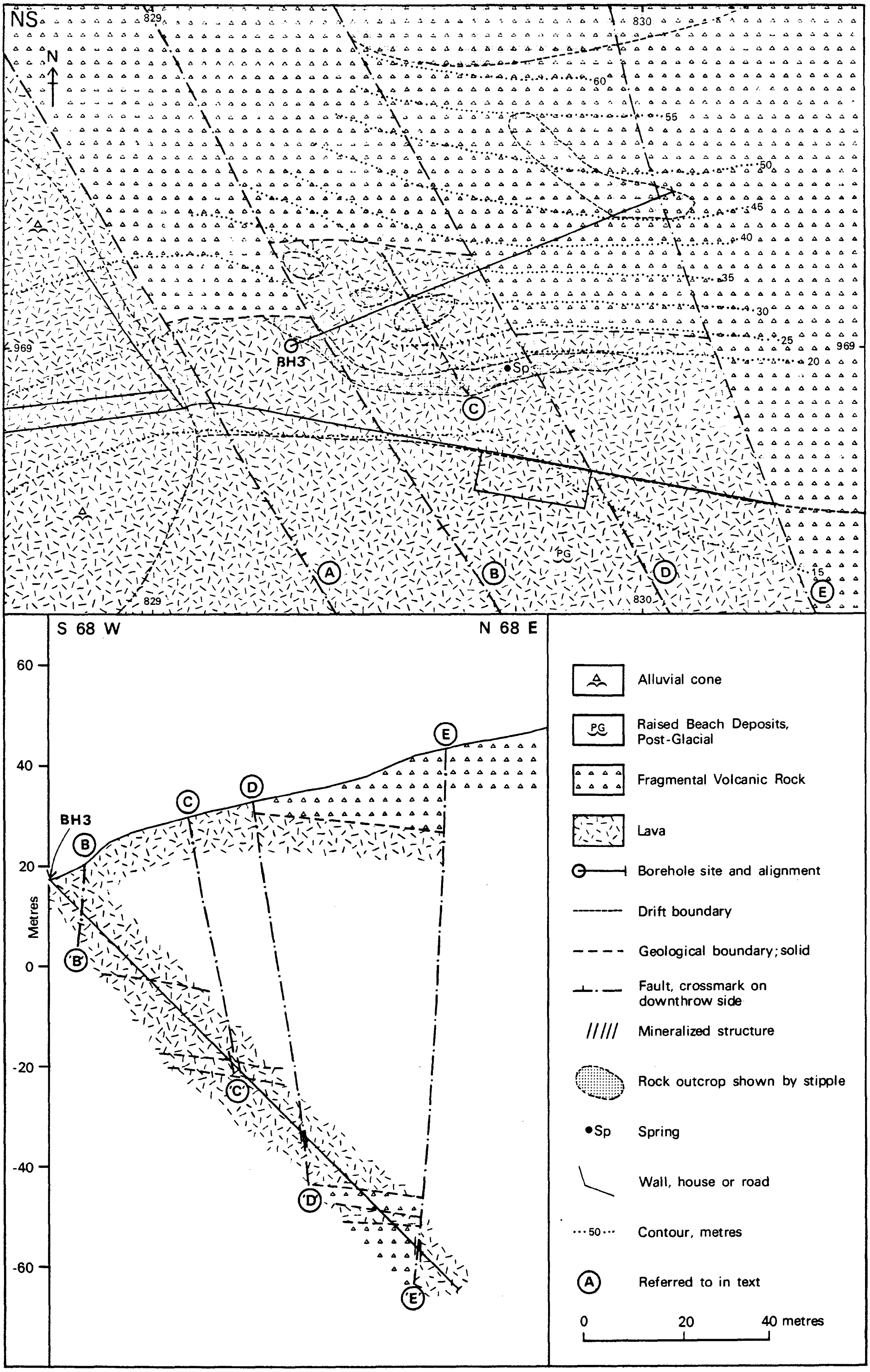

Fig.6. Geological plan and section of Blairlogie Borehole, 3

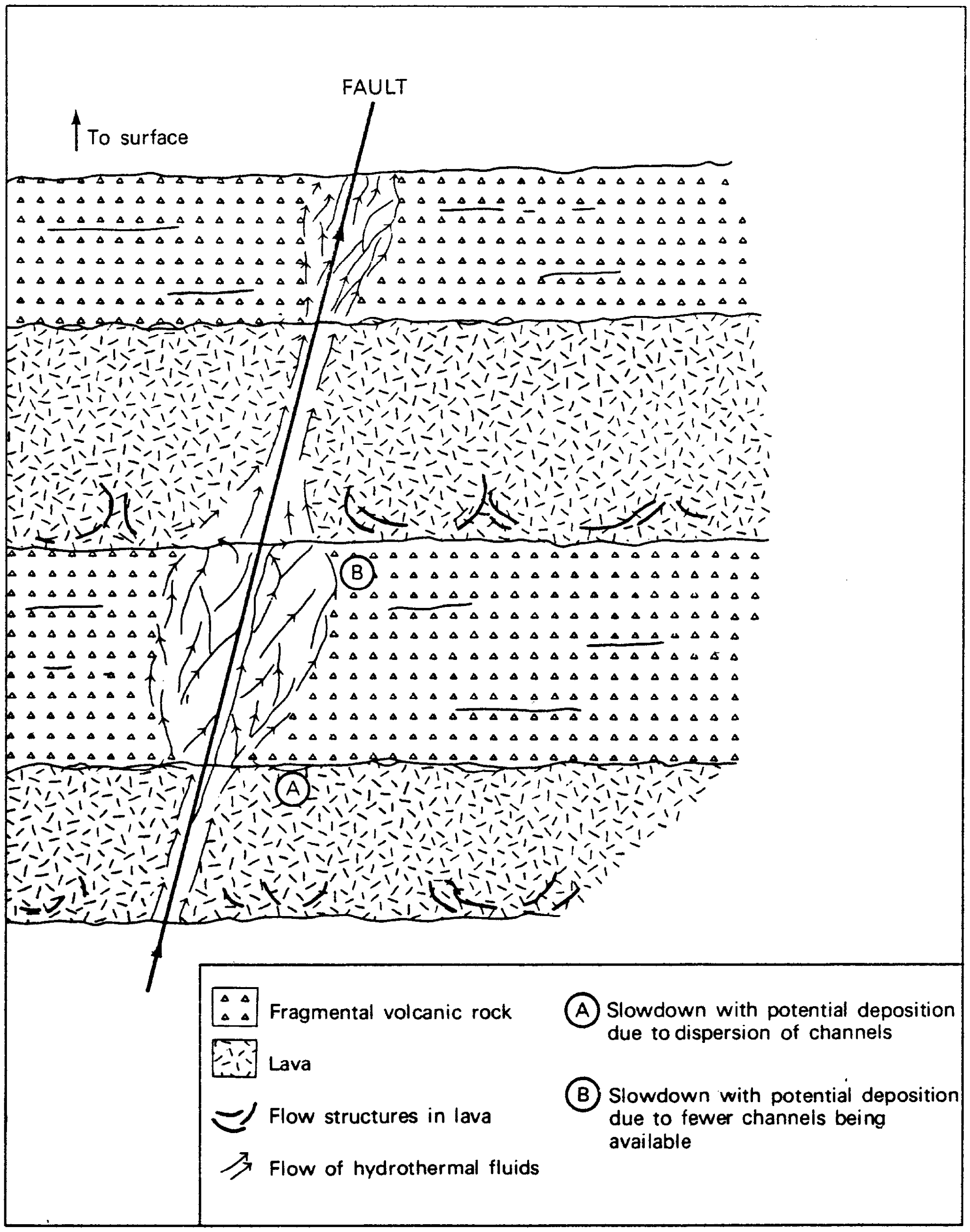

Fig. 7 Diagrammatic representation of differential flow in alternating lavas and fragmental volcanic rocks

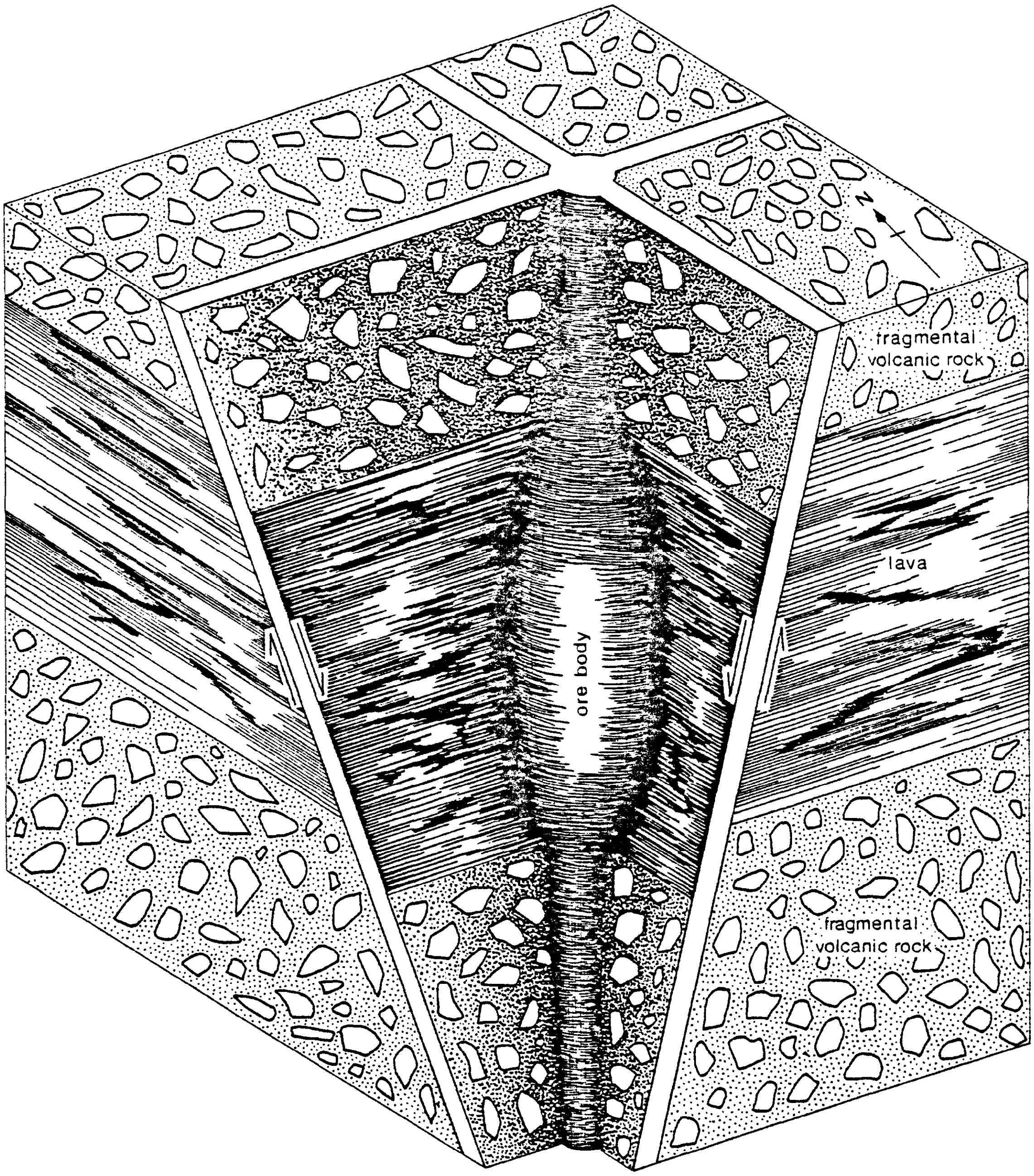

Fig 8 Schematic diagram of silver lode formerly worked at Silver Glen, Alva

and others, 1970). The present work suggests that, within that framework, concentration may be controlled by two main factors. Firstly, because of the very uneven texture of the fragmental volcanic rocks, fracturing is more diffuse and irregular than in the more homogeneous lavas (Figure 7). This gives a wider zone of weakness in the former to act as host rock and also a mechanism for differential rates of flow of the rising fluids. Thus concentrations may be expected to occur in the tops of thick fragmental volcanic rock units (B in Figure 7) by blockage in the overlying lavas where there are fewer fractures. A reduced rate of flow, with potential deposition, will also occur in the tops of thick lavas and at the base of overlying units of fragmental volcanic rock (A in Figure 7) where there is dispersal into a larger number of narrower and less continuous channels. This may account for the apparently anomalous distribution of mineralisation at Blairlogie. The other factor which appears to affect concentration is the increase in brecciation on the line of intersection of two structures. This would accentuate the difference in fracturing between the different rock types giving a nodal distribution where there is interbedding. This is the model postulated for the silver-cobalt concentration at Burnside (Figure 8).

At Burnside the main mineralisation is associated with very altered minor intrusions which appear to be integral parts of the complex hydrothermal veins. The presence of quartz-dolerite at Burnside may be significant, but, since silver was also mined at Airthrey [NS 815 972] at a considerable distance from any known quartz-dolerite, its role here is more likely to be secondary remobilisation than genetic.

The suggested principal controls of polymetallic mineralisation in the Western Ochils may be summarised as:

1 Deposition of Lower Devonian volcanic rocks containing traces of copper, barium, silver and cobalt and therefore favourable as source rocks.

2 Emplacement of calcite-pyrite mineralisation with associated silver and cobalt along east-west structures, probably part of the Ochil Fault system; development of penecontemporary north-south structures with concentration of mineralisation at the intersections of these and the east-west structures.

3 Later copper-barium mineralisation associated with NW–SE and NE–SW faulting of Upper Palaeozoic or younger age.

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APPENDIX I

BOREHOLE LOGS

Detailed logs of the three Alva boreholes are given here. Reference should be made to Appendices II–III for supplementary geochemical and petrographical information.

Inclined depth m	Inter-section m	Lithology	Mineralisation
0.00			
5.40	5.40	Superficial deposits	
7.90	2.50	Fragmental volcanic rock (agglomerate) with fragments of feldsporphyric lava. Some dark green, microphyric with chlorite-filled vesicles. Some pale pink microphyre with chlorite-filled vesicles. Little rock matrix (cored in small pieces - recovery 20%)	Ramifying veinlets of calcite. Traces of pyrite.
8.15	0.25	Lava (basaltic andesite) pale grey with small feldspar phenocrysts. Possibly a block at base of agglomerate. Jointing at 60° and 65°*, broken near base with displaced veins	Calcite veinlets up to 1 mm with traces of pyrite
		Lava (pyroxene andesite) grey, vesicular with chlorite and calcite infilling. Top ground away. Jointing 60-65°. Ferromagnesian phenocrysts below 8.50 m. Calcite veins show cut-off and displacement along minor 50° faults. Broken at 9.21 m. Jointing at 80° and 55° below 9.0 m. Core broken along joints 9.50-9.90 m with pyrite films. Base irregular with vein of calcite. Dip of base 20-25°	Calcite veinlets up to 2 mm at 70° Vein with galena at 65° Joints at 70° with traces of pyrite.
11.28	0.44	Lava, grey with small, altered feldspar phenocrysts. Calcite and chlorite-filled vesicles in places. Joints 75° and 60°. Possibly a lava block. Dip, possibly faulted, at 5°	Calcite streaks
15.00	3.72	Fragmental volcanic rock. Lava blocks, jointed. Vesicular, streaked out with calcite and chlorite infills. Irregular, brownish-rimmed patches of lava with feldspar phenocrysts. Joints 50°, 60° and 20°.	Pyrite on 25° joint at 11.43 m calcite and chlorite on 50° joints. Thin, broken calcite veins, cored as pieces 14.48-14.80 m
22.42	7.42	Fragmental volcanic rock. Apparent bedding at 15°. Joints at 45° broken at base	Calcite stringers near base
24.28	1.86	Lava (pyroxene andesite) with small, ferromagnesian phenocrysts. Predominant jointing at 40-50°. Joints at 60° and 85° from 18.20 to 19.0 m. Fracturing 21.20-21.93 m. Strong jointing at 64° and 80° below 22.80 m to 23.10 m. Broken near base. No alteration. ?fault or natural.	Calcite and dolomite veins 22.47-22.60 m
28.90	3.62	Lava (basaltic andesite) with frequent feldspar phenocrysts and some olivine pseudomorphs in vesicular matrix. Broken at top. Dominant jointing 45° and 80° with slickensides on 80°. Bleached vesicular pale brownish matrix in basal 70 cm. Dip of base 55°	Chlorite and pyrite on various joints. 26.06-26.41 m traces of pyrite along joints 27.65-27.90 m traces of disseminated pyrite
31.10	2.20	Lava. Feldspars present but not obvious. Greenish grey. Occasional pyroxene or olivine pseudomorphs in lower part. Banding at 55°. Pale, bleached "incipient hornfelsing" for 10 cm at base. Base in contact with injection at 85°	Pyrite (?chalcopyrite) infilling 3 mm cracks at high angles and also parallel to banding at 55°. Thin calcite veins at similar dip but oblique to thin feldsparphyric bands. Thin barytes, calcite-chlorite-pyrite vein (2 mm). Galena at 30.25 m
31.60 to 32.96		Lava injection; cuts both preceeding and succeeding items, feldsparphyric. 10 cm bleached zone at top and below. Intrusive lower contact at 85-90°	Bleached zone contains stringers and veins of pyrite up to 1 cm with chlorite and barytes. 7-8 mm vein of chlorite-calcite-pyrite (?some haematite) at base.
35.00	3.90	Lava, pale and bleached at top; vesicular; feldspars present but not obvious; jointed.	Veined with calcite to 32.62 m. Little pyrite along thin veins. 2 mm calcite pyrite vein 33.40-33.75 m. Thin veins with spread of pyrite and blebs up to 8 mm diameter to 34.93 m. Veins and veinlets in greenish matrix below.
38.85	3.85	Lava; feldsparphyric; pinkish. Brecciated, veined with vugs. Pink aphyric lava below 36.50 m	Pyrite along top margin up to 1.5 cm. Cut by complex hydrothermal breccia veining from top to 38.75 m.
41.56	2.71	Fragmental volcanic rock with pale and darker fragments. Jointing 55°. More massive below with thin veins and stringers. Bedding irregular, with broken pieces above base 45°	Calcite veins 2-3 mm with pyrite edges. Broken band at 39.70 m. Calcite-pyrite-galena stringers, top to 39.62 m. 40.20 m - breccia zone - calcite-pyrite-galena and purplish quartz. Calcite in bands up to 5 cm
47.02	5.46	Lava. Feldspar and small ferromagnesian phenocrysts. Broken band at 43.02 m. Dip of base 48°	Veins and stringers of calcite and pyrite. Injection veins 43.30 to 43.80 m. Pyrite and calcite-pyrite veinlets and stringers below. Injection zone with pale 10 cm band at top with selvages of chlorite-calcite-pyrite at 44.63 to 45.65 m. 90° stringers at 45.02 m, 45.20-45.30 m and 46.33-46.50 m of calcite-pyrite. Calcite-chlorite-pyrite vein at bottom.
50.68	3.66	Lava; abundant small to medium feldspars and some ferromagnesian phenocrysts. Pale and altered below 50.38 m. (Thin selvage of altered rock at base.) Dip of base 36°.	Calcite and pyrite veinlets at 65°. 3 cm calcite-pyrite vein at 48.33 m. Frequent chlorite-calcite-pyrite veinlets in altered zone.
51.38	0.70	Injection; fine, baked and pale top margin. Pale reaction rim at 0.5 cm basal margin. (Thin selvage of altered rock at base.) Dip of base 40°	Some pyrite films.
59.83	8.45	Fragmental volcanic rock. Fine to medium grained at top; coarser below with fine, aphyric, grey fragments; some vesicular, coarser brown; some red aphyric and some with microphenocrysts (wide range of types and weathering). Many of fragments vesicular and brownish below 56.00 m. Jointing sporadic - 75°-80° and occasionally 20°. 45° joint with limonite staining and some slickensides across planes from 56.97-57.30 m. Larger, sub-rounded fragments below 57 m. Sporadic 45° and 80° joints, mostly with limonite staining below 58.35 m. Core broken 59 m to 59.83 m. Dissociated block of lava with small feldspars 58.45 to 58.60 m. Broken at base - possibly small fault.	Occasional films of pyrite and calcite. Thin 70° calcite-quartz veins from 55.50-55.72 m. Broken and jointed with calcite and clay mineral films and some iron-staining between 56.10-56.58 m. Thin 2 cm veins of quartz-calcite with pale green ?chlorite veins in places. 80-85° at 57.33 to 58.35 m
65.20	5.37	Fragmental Volcanic Rock; fragments of vesicular and non-vesicular aphyric lava in matrix of lava with small felspar phenocrysts. Fragments often show reaction rim to matrix which in turn is more purplish with round fragments - others more irregular on a small scale but still show reaction rims to matrix. Some reddish, angular fragments, others with very diffuse margins, 20°, 45° and 85° joints at intervals. Core broken 61.30-61.80 m. 20 cm block of vesicular, aphyric lava at 62 m.	Thick calcite veins and stringers below 62 m

Inclined depth m	Intersection m	Lithology	Mineralisation
71.75	6.55	Lava, injection with abundant feldspar phenocrysts. Brecciated near top. Phenocrysts obvious in places but difficult to see in others. Lower margin with veining, 2 cm wide; some alteration on both sides. Oblique to core length over 30 cm	Quartz-calcite-chlorite veins, often with flesh-coloured inner margins near top. Occasional blebs of pyrite, both in veins and matrix, less frequent below 66.20 m
129.92	64.72	Fragmental volcanic rock. Vesicular "lava" matrix with vesicles and small feldspar phenocrysts. Fragments of similar material, slightly reddened; others very vesicular; some with reaction rims; others without. Wide variety of fragments to 80.00 m - below mostly buff-grey vesicular rock with small feldspars. Matrix becomes tuffaceous downwards; composed of small fragments and lapilli. Most large fragments, up to 25 cm, have well-defined margins and chilled selvages but no reaction in the matrix. Some larger fragments with more fluidal margins downwards. Pale brown, coarse, vesicular fragments predominate below 90.00 m. Large block of pinkish brown, fine lapilli tuff with well-defined top and bottom, 105.02 to 105.75 m. Mixed fragments below with some calcite infill. Finer with frequent lapilli below 107.96 m to 108.95 m. Large block of pinkish tuff with stilbite in matrix at 109.05 m. Well-defined lapilli below, some reddened, others with reaction rims. Some quartz grains in matrix below 110.80 m to 113.10 m. Broken near base.	Some irregular patches of calcite infilling gaps around some fragments. 3 cm calcite vein at 76.94 m and ½ cm vein at 77.04 m Rare thin veinlets of calcite below 80.00 m but still with irregular infills. 1 cm calcite vein, 30°, to core length, at 102.44 m with pyrite film on joint surface cutting vein at 102.45 m 0.5 cm calcite vein at 104.93 m Occasional thin calcite veins and infillings 118.20 to 118.50 m. Broken with thin calcite veins 122.10 to 122.60 m. Calcite up to 1 cm at 124.20 to 124.46 m; occasional thin veins below
133.06	3.14	Basalt with small to medium feldspars near top, becoming progressively smaller and finer down. 5 cm bleached zone 20 cm from top. Feldspars more frequent towards base.	
171.19	38.13	Fragmental volcanic rock with lapilli (1-2 cm). Irregular and broken 143 to 144.10 m. Larger and fewer fragments below 157.50 m in fine-grained matrix. Bleached to pale brown below 158.47 m. Brecciated below 158.62 m to 159.30 m. Many pink and red, sub-rounded and sub-angular fragments below to 168.20 m. Coarser below with scattered, reddened fragments to base	Few thin calcite veins in broken core 143 to 144.10 m. Rather broken below with irregular calcite veins in places. Network of thin calcite veins 157.50 m. Brecciated with calcite veins and occasional films of chalcopyrite below 158.62 m to 159.30 m
174.72	3.53	Tuff; fine. Irregular diffuse patches of calcite in matrix. Broken and cored in pieces. ?Core loss.	Thin calcite and calcite-quartz-chlorite veins and scattered small, calcite infills in matrix.
175.63	0.91	Silt; brown; very calcareous. Some small indeterminate shell fragments, grey and lightly-consolidated in places.	Partly infilled cavity.
176.20	0.57	Lava; abundant medium feldspar phenocrysts. Base very irregular with bleached zone. Probably a dyke.	Thin, irregular calcite and zeolite veins.
176.65	0.45	Lava; fine, pale brown with chlorite-calcite vesicles.	Very thin irregular veinlets of calcite and stilbite.
181.00	3.35	Lava with frequent feldspar phenocrysts. Very broken with zones of pale green alteration. Brecciated 178.40 to 178.90 m. Veined margin at 10°. Probably dyke.	
215.15	34.15	Tuff; fine; reddened in places from 181.30 m. Coarser below 183.60 m, becoming paler and bleached below 184.10 m with many angular fragments with reaction rims. Matrix more abundant at 187.15 m. Broken 186.91 to 187.15 m. Bedded in places with dip at 55° to core length at 188.35 m. Matrix fine with small feldspars below 189.34 m enclosing discrete, very irregular fragments; some reddened. Broken 193.70 to 193.86 m. More compact with no visible clasts to 194.46 m. Few below to 195.85 m, then scattered to 197 m. Sharp junction at 197.60 m with very fine, purple ?lava above another sharp junction at 197.88 m; fragments in places below, becoming more frequent downwards. Pale, purple band with very irregular top at 202.56 m and sharp base at 203.20 m. Many fragments below, becoming larger below 214 m.	Veined with calcite and galena. Calcite and some pyrite veining 181.80 to 182.00 m. Occasional thin calcite veins at 45°. Thin film calcite 182 m to 183.28 m. Occasional films of calcite with specks of pyrite. Broken 186.91 m to 187.03 m with films of calcite and occasional specks of galena below. All carrying a little mineralisation to 194 m. Film with galena 201.90 m. Films of calcite with pyrite and rare chalcopyrite 204.25 and 204.70 m to 205 m. Calcite with galena at 206.48 m Calcite with pyrite at 207.24 m Calcite with chalcopyrite at 208.75 m Calcite with galena at 212.94 m to 213.72 m? Calcite with galena at 215.15 m
215.15		End of Borehole	

*All inclinations are given with respect to core length.

Inclined depth m	Inter-section m	Lithology	Mineralisation
0.00		Overburden of fragments and pieces of weathered, fragmental volcanic rock.	
5.04	5.04		
7.15	2.11	Fragmental volcanic rock (agglomerate): Frequent fragments (3-5 cm) of widely variable lava types (dark, aphyric with small feldspars; pale with large feldspars; purple, aphyric; greenish aphyric; some very vesicular; some pink, clastic fragments). Coarse matrix. Fragments smaller with less matrix to base. Sharp, stratigraphic base.	Calcite stringers at base at 70°.
8.40	1.25	Lapilli tuff; banded; red brown and greenish purple. Crudely bedded (inclined at 50°)* with scattered 0.5 cm fragments.	Thin calcite veins at 10° and 45°.
13.52	5.12	Fragmental volcanic rock (agglomerate). Abundant small fragments at top, mostly 2-3 cm but up to 10 cm (fragments widely variable as in overlying unit). Fragments mostly with rounded corners. Coarse matrix. Rare finer bands with crude bedding in places inclined at 70°. Stratigraphic base inclined at 50°.	Anastomosing dolomite/calcite veins from 13.62 to 13.85 m.
19.57	6.05	Lava (andesite): Purple with abundant small phenocrysts. Bands of angular fragments, mostly of similar type but with different weathering; also some exotics. Stratigraphic base inclined at 70°	
31.33	11.76	Fragmental volcanic rock (agglomerate); banded. Fragments, mostly over 5 cm, of microporphyritic lava and some very vesicular lava. ?Ignimbrite fragment near top. Coarse, pinkish matrix. Many aphyric and microphyric fragments below 20.40 m. Fragments mostly smaller and more varied below 23.88 m. Brown weathering 26.90 to 27.35 m. Mostly small fragments below 28.70 m passing down into lapilli tuff below.	1-2 cm dolomite veins with calcite patches 20.10 to 20.40 m at 20° to core length. Thick carbonate vein (calcite/baryte/dolomite) 23.24 to 23.88 m about 15° to core length. Occasional thin calcite stringers below. 3 cm calcite-limonite vein at 27.10 m, 30° to core length.
33.95	2.62	Lapilli tuff: pinkish with coarser fragments, some having lobate reddened outlines; crude bedding at 65°	Thin calcite veins and stringers.
61.52	27.57	Fragmental volcanic rock: abundant and varied fragments mostly exceeding 5 cm; some flow banded; not much matrix; abundant 2 to 5 cm fragments of very varied rock types below 37.25 m, including pale, buff and grey aphyric rocks; some darker rocks, one fragment of "acid" lava. 1 cm pale grey acidic "dyke" with quartz selvage 41.78-42.03 m. Large blocks of fine, pale buff, vesicular lava 47-47.20 m; blocky lava with small feldspars 47.50-47.75 m; purplish aphyric lava 48.30-48.45 m; smaller fragments below. Finer band at 47 m with bedding at 50°. Fragments smaller towards base.	Thin calcite vein parallel to core to 35.60 m. Core broken with irregular calcite veins below to 36.05 m. Irregular calcite veining 36.54-36.59 m. 1 cm calcite vein 37.15-37.25 m. Occasional thin calcite veins below. 0.5 cm calcite vein 44.75-44.85 m. Occasional thin calcite veins and stringers below 47 m. 1 cm calcite-quartz vein perpendicular to core at 48.64 m. 10 cm complex zone of veinlets of calcite and compound veins with calcite in centre and flecks of pyrite and some baryte on margins at 50.65 m. 2 cm irregular vein of calcite-haematite at 51.10 m. 4 cm compound vein with calcite, baryte and thin pinkish lava injection and 0.5 cm baryte vein at 54.55 m. Thin calcite veins at intervals below. 1 cm irregular calcite vein at 58.53 m. Scattered thin calcite veins at base.
67.00	5.48	Lapilli tuff: grey with crude bedding in places inclined at 50°. Bands of coarser fragments of aphyric lava, some very vesicular. Fine, pale, banded near base.	Thin calcite veins and veinlets. Heavy baryte veining at 70° between 63.18 and 63.70 m. Irregular baryte veining with some haematite near base.
83.95	16.95	Lava (andesite): purple, very vesicular. Many vesicles show elongation inclined at 50°. Dark red below 72.33 m. Irregular, pale infill of tuffaceous sandstone below 75.20 m. Autobrecciated in basal 30 cm. Porphyritic.	Scattered very irregular baryte veins (some with haematite). Broken with baryte and haematite veins up to 1 cm below 66.20 m. Haematite in vesicles below 71.50 m. Broken and ramifying calcite veins 72.85-73.15 m. Large haematite-infilled vesicles 73.80 m. Ramifying baryte veins 74.30-75.20 m.
97.12	13.17	Lava (andesite): brown, rubbly top. 10 cm of purplish brown vesicular lava below with infilled vesicles. Bands of pale grey sandstone at intervals to 84.70 m. Patches of grey green sandstone below 86.75 m. Very vesicular below 95.80 m. Some inclusions of tuff at base. Porphyritic.	Calcite, baryte, chlorite infilling of vesicles. Irregular baryte veins, some with central patches of calcite up to 1 cm. Fewer veins below 87.88 m. Heavily veined with baryte 95.37-95.80 m. Some veining below.
105.82	8.70	Fragmental volcanic rock: fragments of aphyric lava; some reddened; some with microphenocrysts of feldspar. Fragments are 3-4 cm at top but are smaller downwards. Core broken 102.10-104.30 m.	Occasional irregular veinlets of baryte and calcite. Baryte veins up to 0.5 cm 104.90-105.10 m.
112.11	6.29	Tuff: fine, compact; some lapilli and fragments below 105.50 m.	Some irregular baryte veining 108.15-108.25 m. Network baryte and some calcite veining 109.56 m with minor haematite below 111.20 m.
114.98	2.87	Breccia.	Heavy veining by baryte-carbonate. Some disseminated pyrite (?arsenopyrite) and a little haematite, mostly in basal 12 cm.
115.33	0.35	Fragmental volcanic rock: lava fragments	Heavily veined with baryte and haematite.
116.85	1.52	Breccia.	Heavy baryte-carbonate. Haematite throughout.
126.95	10.10	Tuff: fine, compact. Coarser near base.	Fine network of baryte veining. More frequent below 118.65 m. Thin baryte veinlets and occasional calcite-baryte at 122.05 m. Some haematite at intervals below. More regular calcite-baryte veins at 75° below 125.50 m.
128.20	1.25	Fragmental volcanic rock (lapilli tuff): fragments about 1 cm	Scattered, thin, irregular baryte veins.
131.65	3.45	Tuff: fine, compact.	Occasional irregular baryte veins up to 1 cm wide throughout. Occasional specks of pyrite.
137.04	5.39	Lapilli tuff: calcareous tuff at base. Fragmentary in basal 50 cm.	Scattered calcite and baryte veins up to 0.5 cm wide. Frequent calcite veining from 136-137.04 m.

Inclined depth m	Inter-section m	Lithology	Mineralisation
		Fragmental volcanic rock: fragments of aphyric green, red and brown lava; some with microphenocrysts of feldspar; a few with microphenocrysts of pyroxene; some vesicular, some not; occasional fragments of tuff cut by veins. Fragments smaller at 149.19 m.	Tuff fragments cut by diffuse network of calcite and calcite-baryte veins up to 0.5 cm wide. Some haematite around 149.19 m. Network of calcite and baryte veining 149.54-149.74 m. A few thin veinlets of calcite at 149.90 m. Scattered veinlets and veins up to 1 cm wide of baryte and a little calcite to 152.36 m. Scattered veins of baryte up to 1 cm wide below. Calcite to 154 m. Veins are displaced and cut by other veins or veinlets. Veinlets of calcite and 7 cm calcite-baryte vein at 155.04 m at 45°. Frequent baryte-calcite veining with traces of pyrite, chalcopyrite and haematite apparently within vein; chalcopyrite on films traversing vein at right angles, 155.44-155.96 m. Scattered thin veins less than 0.5 cm and veinlets of baryte, often traversed or displaced by others. Thin calcite veins 160.22-160.74 m.
160.74	23.70		
160.74		End of borehole	

*All inclinations are given with respect to core length.

Inclined depth m	Inter-section m	Lithology	Mineralisation
0.87	0.87	Overburden: pieces of weathered lava	
2.47	1.60	Lava: purplish grey; frequent small feldspar microphenocrysts; some irregular joints at 20°. Scattered calcite and chlorite-filled vesicles frequent in basal 5 cm. Stratigraphic base irregular and balled at 40°.	Some irregular haematitic banding to 1.35 m.
17.30	15.33	Lava: 2 cm brown "bole" at top. Purplish; abundant, small, lath-like phenocrysts of feldspar. Very vesicular with infillings of calcite, chlorite and rare quartz. Irregular sandstone infill at 11.60-11.70 m, may be base of flow unit. Reddened below with quartz and calcite-chlorite infills to 11.90 m. Pale, bleached 15 cm zone associated with parallel infill of sandstone at 13.65 m. Core broken below 15.30 m. Grey-green, 3 cm sand and ash band at 16.20 m. Lava below has fewer and smaller feldspars. Brown-grey vesicular flow unit (as above); darker with larger phenocrysts below joint at 17.12 m. Balling structures below 17.45 m with sandstone infilling to 17.80 m. Reddening along margins.	Occasional thin veins and stringers of calcite. 2 cm aphyric band at 7.02 m with quartz-haematite infillings. Quartz-calcite veins at 8.25 m (1 cm) and 8.50 m (2 cm) at 90°. Irregular quartz and calcite-chlorite veins in places. 4 joints with calcite films below 15 m.
21.10	3.30	Lava: grey; purplish bands with greenish ash infill in ball structures to 18.30 m. Abundant platey feldspar phenocrysts and frequent small chlorite and calcite vesicles. Feldspar distribution patchy. Jointing approximately parallel to core length from 20.10 to base. Flow base structural with greenish "sandstone" infill in basal 25 cm.	Chlorite and calcite in vesicles.
26.20	5.10	Lava: purplish with "sandstone" infilling in top 12 cm. Frequent small laths of feldspar. Vesicular with calcite, chlorite infillings. 80° jointing from 21.90-22.25 m. Irregular "sandstone" infilling at 22.50-23.08 m. Elongation of vesicles, linearity of inclusions and laths orientation suggests a dip of 50° at 24.00 m. Elongate, 1 cm green "lava" inclusion causing a buff-coloured reaction rim in host at 23.85 m. Rounded, quartz-infilled vesicles from 24.10-24.50 m. Vesicles elongate below. Large calcite and chlorite-filled vesicles on reddened zone at 25.85 m. Basal 30 cm consists of infilled buff and purple lava (as above) with "sandstone". Vesicular with chlorite-calcite, with greenish ash wedge at 26.15 m. Broken at base	Chlorite and calcite in vesicles.
28.20	2.00	Lava: brownish grey; frequent small platey feldspars. Vesicular with calcite, chlorite and quartz infills. Paler in basal 10 cm. Greenish, chloritic junction.	Calcite, chlorite and quartz in vesicles.
35.05	6.85	Lava: purplish; more red at top. Frequent, small, lath-shaped feldspar phenocrysts. Some mafics. Vesicular; mostly chlorite and calcite. Very vesicular green-red mottled zone with flow banding (?base of flow unit) at 30.90-31.00 m. Lava (as above) below banded unit. Irregular "sandstone" infills at 32.52-32.85 m and 34.80-35.05 m.	Calcite and chlorite in vesicles.
39.00	3.95	Lava: purplish near top, grey below. Abundant small, platey feldspars and a few small, scattered, irregular, chlorite-filled vesicles. Bands of brownish weathering. Broken in basal 75 cm. Pale near base.	Chlorite in vesicles.
42.05	3.05	Lava: purplish; red-purple at top, brownish in lower part. Frequent small laths of feldspar. Vesicular with irregular "sandstone" infills. Flow-top structures present. Calcite and chlorite infills. "Sandstone" infills at intervals to base.	Calcite and chlorite in vesicles.
50.38	8.33	Lava: brownish at top, grey-brown below. Few patches of "sandstone". Abundant small platey feldspars. Some vesicles infilled by calcite, quartz and chlorite up to 75 mm. Green tuffaceous sandstone 46.13-46.30 m with bedding at 70° to core length. Sandstone at 46.40-46.47 m and 47.00-47.12 m with reddened lava between. Pale brown flow base.	Calcite, quartz and chlorite in vesicles.
51.50	1.12	Lava: red brown; scattered, small feldspar phenocrysts. Vesicular with calcite and chlorite. Broken below 50.60 m	Chlorite and calcite in vesicles.
54.04	2.54	Lava: grey-brown-green; aphyric; compact. Calcite and chlorite vesicles. Rather broken with haematite staining 53.90-54.04 m.	Calcite and chlorite in vesicles. Haematite staining. Red zeolite-chlorite veining near base.
63.90	9.86	Lava: purplish at top, grey below. Frequent feldspar microphenocrysts. Scattered large vesicles and frequent smaller calcite and chlorite-filled vesicles. Phenocrysts more numerous downwards to 58 m, becoming more vesicular below with fewer microphenocrysts in places. Broken below 62.90 m. Large calcite vesicles near base. Basal balling structures 63.78-63.90 m.	Calcite-chlorite-haematite in vesicles.
66.56	2.66	Lava: abundant small feldspar microphenocrysts. Purplish at top, pale buff near base. Scattered, largish chlorite-calcite filled vesicles. Dip at 50° to core length.	Chlorite and calcite in vesicles.
67.17	0.61	Lava (as above): dark red at top. Scattered, irregular calcite infills. Bleached zone 67.10-67.17 m (base of flow unit) at 45°.	Irregular calcite infills.
71.75	4.58	Lava: frequent small feldspars and microphenocrysts. Scattered chlorite and calcite vesicles. Also diffuse calcite patches in matrix and irregular veins. Broken below 70.25 m with jointing at 15° to core length. Chlorite-filled vesicles more frequent below 71.40 m. Bleached in basal 10 cm.	Chlorite and calcite in vesicles. Calcite in diffuse patches and as irregular veins.
89.68	17.93	Lava (as above): very vesicular throughout with calcite and chlorite infills. Irregular, grey-green sandstone-tuff infilling 72.05-72.80 m, 82.85-83.23 m, 84.20-84.40 m and 86.80-87.60 m Slickenside surfaces and flow-base structures below 87.20 m. More reddened at base of flow unit.	Calcite and chlorite in vesicles. Occasional thin veinlets of calcite 75.90-76.22 m. Calcite veinlets and stringers below.
91.15	1.47	Lava (as above): purplish at top. Vesicular with calcite chlorite infills. Greenish sandstone infill from top to 89.90 m. Pale brownish basal 20 cm with flow base structures.	Calcite and chlorite in vesicles.
93.85	2.70	Fragmental Volcanic Rock: irregular blocks of lava, mostly aphyric; some greenish, others reddish purple; some with abundant small chlorite vesicles.	Chlorite in vesicles.

Inclined depth m	Inter-section m	Lithology	Mineralisation
95.83	1.98	Lava: grey with frequent small feldspars. Flow balling with reduction of lava to buff rim and green inside. Associated green siltstone from 95.05 m to base.	Occasional thin calcite veins.
103.36	7.53	Fragmental volcanic rock: lapilli and fragments of different lava types. Irregular, green tuff inclusions 101.35-101.95 m; fine tuff below to 102.25 m, rather broken below with pale brownish patches.	Occasional thin, irregular calcite veins up to 0.5 cm. Occasional calcite infill in matrix.
115.23	11.87	Lava: grey with frequent small feldspars; purple patches below 113 m to base.	0.5 cm calcite-baryte vein 106.70-107.80 m.
115.23		End of borehole	

*All inclinations are given with respect to core length.

APPENDIX II

GEOCHEMICAL DATA FOR CORE AND CHIP SAMPLES

Samples of core (31) from the three Alva boreholes were selected for analysis on the basis of the presence of visible mineralisation and in some instances as being representative of particular rock types. A small group of chip samples (12) from the old mine workings in Silver Glen was also analysed.

The sample material was crushed to 1–2 mm particle size, quartered and approximately 200 g ground in a tungsten carbide tema mill to less than 50 μm size. Most of the analyses were performed by X-ray fluorescence spectrometry using a Philips 1450/20 spectrometer (analyst T. K. Smith). The Cu, Zn, Ag and Pb analyses shown in parentheses in Tables I, II and III were obtained by atomic absorption spectrophotometry using a hot HNO_3 attack. Those U analyses reported in parentheses were determined by XRF, the remainder by delayed neutron activation analysis.

The underlined values in Tables I–IV are regarded as high-anomalous.

APPENDIX II TABLE I BOREHOLE 1

Sample No. CXD	Depth, m From	To	Inter-section m	Summary description	Ca (%)	Ti (%)	Mn (%)	Fe (%)	Co (ppm)	Ni	Cu	Zn	As	Rb	Sr	Y	Zr	Nb	Mo	Ag	Sn	Sb	Ba	Ce	Pb	Th	U
110	26.39	27.78	1.39	Basaltic andesite lava	2.556	0.956	0.086	7.002	30	(30) 30	(65) 60	(90) 81	13	57	552	41	430	16	4	(1) 2	4	1	614	75	(20) 15	12	5
111	28.90	29.65	0.75	Lava	1.278	1.025	0.057	6.076	25	(35) 25	(120) 124	(70) 55	75	90	416	46	480	16	4	(1) 0	2	5	501	83	(30) 26	15	6
112	31.65	33.25	1.60	Lava	9.072	0.520	0.130	4.340	30	(60) 48	(75) 61	(370) 287	27	74	323	22	166	8	3	(2) 1	0	0	389	50	(50) 32	6	2
118	35.00	36.20	1.20	Breccia veined lava	1.754	0.957	0.063	6.199	25	(35) 26	(70) 62	(30) 13	103	71	152	38	388	17	0	(1) 1	0	7	269	69	(20) 9	14	5
113	36.50	38.31	1.81	Breccia veined lava	15.594	0.394	0.138	3.905	25	(50) 33	(38) 50	(120) 95	37	37	308	30	222	8	3	(3) 2	4	9	257	57	(60) 48	9	3
114	40.20	41.55	1.35	Fragmental volcanic rock	5.884	0.514	0.106	4.373	15	(35) 21	(22) 30	(60) 37	8	85	208	21	165	7	5	(1) 1	3	4	248	31	(80) 20	5	2
115	65.19	66.54	1.35	Lava	9.527	0.574	0.131	3.437	20	(45) 39	(45) 38	(70) 64	5	108	233	29	256	13	2	(2) 1	3	7	353	63	(20) 0	10	3
116	68.35	69.60	1.25	Fragmental volcanic rocks	3.319	0.965	0.068	6.826	30	(40) 28	(61) 70	(100) 105	5	70	372	39	433	18	4	(2) 2	6	5	551	73	(20) 17	13	5
117	95.66	96.92	1.26	Fragmental volcanic rocks	1.528	0.705	0.057	6.227	30	(65) 60	(119) 135	(70) 73	5	72	437	22	241	8	3	(1) 1	2	2	755	43	(20) 9	10	3
119	158.62	159.30	0.68	Brecciated and veined fragmental volcanic rock	3.406	0.356	0.077	3.766	35	45	(1200)	(40)	32	80	361	25	205	11	17	(2) 3	0	2	701	33	(20)	9	52
126	190.68	191.33	0.65	Tuff					25	45	(50)	(50)	9							(0)			750		(15)		(3)
127	196.84	197.20	0.36	Tuff					20	15	(15)	(60)	8							(1)			716		(15)		(5)
128	208.60	209.10	0.50	Tuff with calcite veins					30	30	(85)	(80)	14							(1)			719		(25)		(4)
129A	212.70	213.20	0.50	Tuff with calcite veins					30	45	(15)	(50)	5							(2)			147		(22)		(3)
130	214.55	215.15	0.60	Tuff with calcite veins					35	70	(30)	(80)	12							(1)			575		(20)		(5)

APPENDIX II TABLE II BOREHOLE 2

Sample No. CXD	Depth, m From	To	Inter-section m	Summary description	Ca (%)	Ti (%)	Mn (%)	Fe (%)	Co (ppm)	Ni	Cu	Zn	As	Rb	Sr	Y	Zr	Nb	Mo	Ag	Sn	Sb	Ba	Ce	Pb	Th	U
101	20.55	23.24	2.69	Agglomerate	2.386	0.432	0.055	3.887	15	(25) 34	(5) 8	(40) 36	47	53	96	19	222	10	4	(1) 1	1	6	56	23	(10) 8	9	3
102	23.24	23.88	0.64	Carbonate-veined agglomerate	12.284	0.178	0.232	3.454	20	(20) 17	(5) 0	(20) 14	15	11	283	9	84	5	2	(2) 1	0	0	1.07%	0	(20) 0	4	1
103	41.32	42.96	1.64	Fragmental volcanic rocks	4.833	0.467	0.085	5.080	20	(30) 24	(10) 13	(50) 55	21	51	158	18	192	7	2	(1) 1	0	0	149	40	(20) 6	8	3
104	44.98	47.17	2.19	Fragmental volcanic rocks	4.716	0.526	0.098	4.818	20	(30) 42	(20) 19	(45) 42	16	54	126	21	195	8	1	(1) 0	0	1	129	43	(20) 4	8	3
105	79.77	81.10	1.33	Vesicular lava	5.084	0.544	0.104	5.946	25	(40) 48	(20) 22	(50) 48	37	34	132	19	157	6	3	(1) 1	2	7	84	64	(20) 9	8	2
106	112.11	114.98	2.87	Breccia with baryte veining	18.049	0.122	0.308	2.957	30	(40) 31	(10) 0	(40) 31	5	9	143	11	49	3	3	(3) 2	0	0	5223	12	(20) 1	2	1
107	114.98	116.85	1.87	Breccia with baryte veining	9.048	0.128	0.257	3.232	30	(50) 74	(15) 0	(80) 74	8	3	375	12	58	1	7	(2) 3	0	2	5.03%	0	(20) 2	5	1
108	120.50	121.60	1.10	Tuff	7.487	0.273	0.183	3.421	20	(40) 70	(10) 10	(75) 70	24	11	56	15	98	5	0	(2) 2	0	16	79	24	(20) 7	4	1
109	135.95	137.04	1.09	Lapilli tuff with calcite veins	16.807	0.264	0.161	2.610	20	(35) 31	(15) 8	(40) 31	10	26	214	13	98	5	0	(3) 2	0	2	8570	4	(20) 2	4	1
129B	155.44	155.96	0.52	Fragmental volcanic rock with baryte veins					35	(30)	(20)	(70)	9							(1)					(20)		(1)

APPENDIX II TABLE III BOREHOLE 3

Sample No. CXD	Depth, m From	To	Inter-section m	Summary description	Ca (%)	Ti (%)	Mn (%)	Fe (%)	Co (ppm)	Ni	Cu	Zn	As	Rb	Sr	Y	Zr	Nb	Mo	Ag	Sn	Sb	Ba	Ce	Pb	Th	U
120	13.95	14.75	0.80	Lava	1.001	0.828	0.065	6.863	25	(80) 71	(30) 19	(90) 87	14	28	446	25	257	17	3	(1) 1	3	3	432	51	(20) 9	9	2
121	22.15	23.15	1.00	Lava	0.408	0.431	0.046	3.827	30	(55) 45	(15) 16	(70) 65	32	94	322	15	222	11	0	(1) 1	0	5	654	34	(10) 2	7	2
122	23.71	24.62	0.89	Lava	0.680	0.844	0.069	7.068	25	(75) 76	(20) 21	(90) 99	11	39	507	24	260	17	2	(1) 1	0	0	634	54	(10) 8	8	2
123	28.60	29.57	0.97	Lava	0.670	0.781	0.061	6.711	25	(75) 73	(20) 20	(70) 75	10	24	404	23	250	15	2	(1) 0	3	2	331	46	(20) 7	8	2
124	51.90	52.70	0.80	Lava	0.829	0.757	0.056	6.566	25	(70) 73	(10) 6	(90) 97	5	82	274	21	260	17	2	(1) 1	0	0	496	57	(10) 11	10	2
125	58.25	59.26	1.01	Lava	1.562	0.753	0.059	6.335	30	(80) 75	(15) 5	(110) 112	14	68	464	23	247	17	3	(1) 3	3	1	717	53	(20) 11	8	2

APPENDIX II TABLE IV Vein samples Silver Glen

Sample No.	Group	Location	Intersection m	Trend	Co	Ni	Cu	Zn	Ag	Pb
201	A	Winze	1.00	80W 022	30	20	85	50	2	30
202	A	East drive	0.90	78S 054	50	35	14600	40	27	40
203	A	South drive	0.12	78W 164	65	50	8000	60	16	30
204	A	North drive	0.40	78W 350	15	20	1165	20	4	20
205	A	Lower south drive	0.65	80W 165	20	35	175	40	2	30
206	A	Entrance adit	0.70	75S 240	40	40	230	50	3	60
209	E	South drive	2.5	80W 350	850	100	675	20	5	20
210	E	North drive (west)	0.80	80S 020	15	30	2000	20	2	10
211	E	North drive (east)	0.45	75S 030	25	30	1800	30	3	10
212	D	60 m from entrance	1.50	75S 242	20	25	160	60	1	10
213	D	10 m from entrance	1.50	80S 065	25	40	1150	60	3	20
214	D	20 m from entrance	1.0	65S 252	20	35	165	60	2	10

APPENDIX III

PETROGRAPHICAL DESCRIPTIONS OF SELECTED CORE SPECIMENS

General

Selected lengths of core were examined optically by polished thin sections in transmitted and reflected light following preliminary examination of hand-specimens with a stereoscopic microscope. Carbonate determinations were accomplished by staining with Alizarin-Red solution.

Bulk XRD scanning of crushed (-120 mesh) rock was carried out by D. J. Morgan (Appendix IV). Qualitative XRF analysis of mineralised samples was carried out by D. J. Bland to elucidate the association of base metals present and results are incorporated in descriptions.

Depth in m	Section (PTS)	Description
Borehole 1, Burnside		
28.90	5006	Altered andesitic lava
28.90–29.00	5007	Altered andesitic lava
35.60	5008	Altered andesitic lava
36.60	5009	Altered diabase
37.70	5010	Altered andesitic lava
38.00–38.13	5011	Altered fault breccia
65.57	5012	Altered fault breccia
66.00	5013	Altered andesitic lava
70.90	5014	Altered andesitic lava
112.52	5015	Hyaloclastite
Borehole 2, Balquharn		
9.30	5016	Porphyritic lava/tuff/altered andesite
91.85	5017	Agglomerate
74.64	5018	Andesitic lava
115.83	5019	Explosion breccia
148.62	5020	Glassy tuff
155.10	5021	Glassy tuff
155.90	5022	Carbonate vein rock
Borehole 3, Blairlogie		
63.78	5023	Altered andesitic lava
101.54–101.73	5024	Agglomerate

Altered andesitic lava (PTS 5006)

In hand specimen, a greyish-green porphyritic rock. Although alteration has been marked, a remnant igneous texture may be discerned in the form of phenocrysts of plagioclase set in a cryptocrystalline matrix. The feldspar phenocrysts display a distinct colour change; in areas where hydrothermal alteration has been intense, the phenocrysts are yellowish in colour whilst in areas only mildly altered, the feldspar retains its more usual creamish white colour. In thin section, this observation reflects a difference in mineralogy. The strongly altered plagioclase grains have been broken down into a microscopic aggregate of chlorite and clay minerals whilst those phenocrysts of 'fresher' aspect are strongly sericitised. The form of the original feldspar crystal is commonly preserved.

It is not possible to determine the exact nature of the fine-grained matrix by optical means. Its cloudy character is probably due to the presence of a clay mineral although no clay minerals were detected by bulk XRD examination of duplicate material. The rock is traversed by a series of veins which contain calcite, ferroan dolomite, quartz, hematite, chlorite and a trace of epidote. The calcite bearing veins postdate the sulphide phase of mineralisation. The rock is strongly mineralised with intergrowths of pyrite, marcasite and occasional flecks of chalcopyrite. The mineralisation is probably epigenetic in origin, belonging to veins produced during a possible episode of faulting.

Altered andesitic lava (PTS 5007)

An overall greenish-grey coloured rock in hand specimen. The rock has suffered strong hydrothermal alteration, but in areas where alteration has been less intense, phenocrysts of plagioclase set in a fine-grained matrix can be made out. In thin-section the euhedral feldspar crystals are seen to be broken down into microscopic aggregates of chlorite and clay minerals with small patches of sericite. The fine-grained matrix appears turbid and this is probably due to the presence of a clay mineral and fine hematitic dust. Two generations of veining can be recognised; infilling minerals are chlorite, quartz, calcite and a trace of epidote. Some tiny, quartz-rich veins postdate earlier, chlorite veins. Sulphide mineralisation is largely confined to a single fracture surface and consists of a superficial aggregate of pyrite with occasional blebs of chalcopyrite.

Altered andesitic lava (PTS 5008)

In hand specimen, a grey-coloured, minutely vesicular, porphyritic rock with phenocrysts of plagioclase distributed throughout a fine grained matrix. A vague flow structure is present. In thin section, euhedral outlines of the original feldspar crystals are preserved in microscopic aggregates of sericite and chlorite (penninite). The matrix is fine-grained and appears to consist of chlorite and clay mineral. A narrow vein, containing calcite, quartz and hematite cuts the rock. Pyrite is contained within this vein and, in addition, forms small, superficial, scaly masses on fracture surfaces.

Altered diabase (PTS 5009)

In hand specimen this is a fine-grained, brownish-coloured, vesicular rock of dense, homogenous aspect suggesting that it is of hypabyssal intrusive type. There is a faint dark to light colour change across the rock. In thin section, the rock displays a relict ophitic fabric in which large sub-idiomorphic crystals of pyroxene are moulded around and completely envelope idiomorphic crystals of strongly sericitised and chloritised plagioclase. The pyroxene (possibly augite) phenocrysts are strongly decomposed to an aggregate of chlorite and clay minerals but their sub-idiomorphic character is emphasised by an internal mesh-work of iron oxide rodlets. The matrix is too fine grained to be resolved by optical methods but appears to be highly chloritic. Some particularly conspicuous patches of green chlorite may have replaced biotite. The many small vesicles that disrupt the fabric of the rock are commonly infilled with quartz, chalcedony, calcite and chlorite; in some instances pyrite totally replaces these minerals and two pyrite growth stages can be recognised.

Altered andesitic lava (PTS 5010)

In hand specimen, the rock is purple-green in colour and exhibits a porphyritic texture with large (up to 1 cm in length) phenocrysts of altered plagioclase distributed throughout a fine-grained matrix. In areas where alteration has been most intense the overall purplish colour of the rock becomes green with total obliteration of the original igneous texture.

In thin section, the plagioclase phenocrysts are present as euhedral crystals but are strongly sericitised and contain irregular patches of clay and amorphous iron oxide. The matrix is microscopically fine grained but probably contains chlorite and clay minerals and hematitic dust. The rock is cut by two large veins of identical mineralogy and of probable coeval age. The country rock in areas immediately adjacent to these veins is noticeably bleached and highly chloritic. The infilling vein minerals are quartz, calcite, chlorite, goethite, a trace of epidote and pyrite.

Altered fault breccia (PTS 5011)

In hand specimen, an overall greenish-grey coloured rock consisting of sub-angular, calcite-rimmed, fine grained, green rock fragments set in a pale grey coloured crystalline matrix. In thin section, the rock fragments are highly chloritised but occasionally show a fine-grained porphyritic texture, suggesting altered lava. The matrix consists of coarse, platy calcite, a little chlorite and a trace of muscovite. There is a sparse distribution of marcasite, pyrite and pyrrhotite throughout the rock.

Altered fault breccia (PTS 5012)
In hand specimen, an overall greenish-grey coloured rock consisting of calcite-rimmed lenticular masses and sub-angular, fine-grained, green rock fragments set in a pale grey crystalline matrix.

In section, the rock fragments are highly chloritic and siliceous and do not display any particular textural characteristics. However, some tiny vesicles, rimmed with quartz and infilled with calcite and chlorite are present, and as bulk XRD examination of duplicate material indicates an appreciable amount of feldspar, it is suggested that the rock fragments probably represent an altered acidic lava. The matrix consists of finely crystalline calcite, a little quartz, chlorite, a trace of epidote and tiny diffuse patches of a radial aggregate of brown carbonate. A large vein, rimmed by chlorite and quartz, and containing coarse platy calcite, a trace of chlorite and specks of hematite, cuts the rock. In areas immediately adjacent to the vein, there is strong carbonate replacement. Sulphide mineralisation is limited to disseminated pyrite and occasional flecks of chalcopyrite.

Altered andesitic lava (PTS 5013)
This is a mottled, brownish-green coloured rock with phenocrysts of plagioclase (up to 0.5 cm in length) set in a fine-grained matrix. Strong hydrothermal alteration probably accounts for the rock's mottled appearance. In section, the idiomorphic feldspar phenocrysts appear strongly sericitised, and where alteration is more pronounced small patches of chlorite and kaolinite occur. The matrix is fine grained and cloudy but seems to consist of a fine meshwork of feldspar laths, chlorite, iron oxide and a (?) clay mineral. Some small irregular patches of chlorite may be after hornblende. A large vein, which contains quartz, chlorite, calcite and hematite cuts the rock. A series of tiny veins, filled with chlorite, (?) clinozoisite and calcite intersect the large vein and thus postdate it. With the exception of a trace amount of disseminated pyrite, the rock is devoid of sulphide minerals.

Altered andesitic lava (PTS 5014)
In hand specimen, a greenish-grey coloured rock with large phenocrysts of altered plagioclase (up to 1.0 cm in length) distributed throughout a fine-grained matrix. Where hydrothermal alteration has been marked, the rock has a bleached appearance.

In thin section, the plagioclase displays a wide spectrum of alteration. Some of the phenocrysts are relatively fresh and are andesine (an average composition is $Ab_{57}An_{43}$). In areas of intense alteration, the feldspars retain their idiomorphic form but consist of sericite and/or (?) kaolinite. Some subidiomorphic crystals of (?) pyroxene are apparent, now completely replaced by chlorite with tiny rodlets of iron oxide reflecting a ghost cleavage. The matrix is fine grained and consists of a mesh-work of small laths of plagioclase, chlorite, hematite and probable clay. The rock is cut by a large vein which in one area attains a width of 2.0 cm. The vein is infilled with fragments of volcanic glass which has been largely devitrified to spherulitic palagonite. The palagonite in some areas shows alteration to green chlorite. These devitrified fragments are distributed throughout an often replacive matrix of fibrous iron-rich calcite which has grown at right-angles to the walls of the vein. It is suggested that the vein is of tectonic origin and possibly related to an episode of faulting. The lack of correspondence between vein margins implies lateral movement during formation of the vein. The complex pattern of elongated patches of fibrous calcite and irregular areas of coarse calcite indicate that the vein developed by successive minor stages. Disseminated chalcopyrite is present throughout the rock, and in the carbonate-rich vein it occurs intergrown with bornite.

Tuff-breccia or hyaloclastite (PTS 5015)
In hand specimen, creamish-brown rock consisting of sub-angular fragments of chloritised, fine-grained igneous rock set in a pale grey coloured crystalline matrix.

In thin section, the rock fragments fall into two categories. The most common type is composed largely of yellowish palagonite, sometimes altering to fine green chlorite and patches of dark brown unaltered glass. Fragments of the second type display the more regular fabric of a porphyritic lava, with phenocrysts of kaolinised feldspar set in a dark glassy matrix. The fragments are distributed throughout a coarse, ferroan dolomite matrix which is largely replacive. The rock is barren of sulphide mineralisation.

Junction between extrusive rocks (PTS 5016)
The rock is composed of three components:

a. Altered andesitic lava. In hand specimen, this component is fine grained, vesicular and pale brown in colour. The texture is porphyritic with altered phenocrysts of feldspar set in a (?) clay matrix. In thin secton, the feldspars show strong sericitisation with alteration to kaolinite in many instances. The exact nature of the cryptocrystalline matrix is difficult to determine by optical means but it appears to be highly chloritic and cloudy due to a (?) clay mineral (XRD examination of duplicate material indicates an appreciable amount of kaolinite) and a fine hematitic dust. The rock is markedly amygdaoloidal with calcite, chalcedony and chlorite constiuting the infilling minerals. The lava is devoid of sulphide mineralisation.

b. Glassy tuff: the contact between this component and the underlying andesitic lava (a) is uneven. In hand specimen, the rock is of greenish-brown colour, with sub-angular fragments (up to 4 mm in length) set in a crypto-crystalline matrix. In section, the rock displays a brecciated texture with sub-angular fragments of chloritised extrusive rock (probably andesite), volcanic tuff and altered feldspar set in a largely devitrified, siliceous matrix. A few tiny vesicles are filled with chlorite. The rock contains minor disseminated pyrite. Some large irregular-shaped cavities in lava (a) are filled with material of this glassy tuff which is, therefore, of younger age than the lava (a).

c. Porphyritic lava. A linear (?) erosion surface separates component (b) from an overlying lava. In hand specimen the lava is chocolate coloured with uniformly sized feldspar phenocrysts set in a sparse, fine-grained matrix. In thin section, the feldspar phenocrysts show some evidence of kaolinisation but are almost totally replaced by calcite. The carbonate replacement has been selective, for the largely devitrified siliceous matrix is unaffected. The texture is somewhat unusual for a lava in that the distribution of generally equant phenocrysts exceeds 80% of the total rock. The rock is microscopically vesicular with infillings of chalcedony and chlorite and the presence of hematitic dust accounts for the overall brownish colour. Some tiny, discontinuous 'hair' veins contain chlorite and ferroan dolomite. There is no sulphide mineralisation. Of the three eruptive rocks present, this lava (c) is of youngest age, with glassy tuff (b) occupying an intermediate age between rocks (a) and (c).

Tuff-breccia (agglomerate) (PTS 5017)
In hand specimen a greenish-brown coloured rock with large unsorted, angular to sub-angular fragments (up to 5.0 cm in length) of fine-grained, porphyritic extrusive rock. In section the large fragments consist of chloritised lava, tuff, dark volcanic glass, devitrified glass shards and sericitised feldspar set in a devitrified glassy matrix. The rock is traversed by a series of veins containing ferroan dolomite which has resulted in marked carbonate alteration.

From vein cross-cutting relationships two distinct generations of carbonate growth can be recognised. The rock is barren of sulphide mineralisation.

Andesitic lava (PTS 5018)
In hand specimen, a dark grey to black porphyritic rock with phenocrysts of feldspar set in a fine-grained matrix.

In thin section the idiomorphic feldspar phenocrysts show strong alteration to kaolinite and occasionally contain wisps of green chlorite. Some of the larger feldspar phenocrysts are almost totally replaced by ferroan dolomite. The matrix consists of a mesh-work of kaolinised feldspar laths, a dark volcanic glass and minor goethite. A few small vesicles contain quartz, chalcedony, chlorite and calcite. With the exception of a trace of chalcopyrite, the rock is devoid of sulphide minerals.

Numerous veins cut the lava and two series can be distinguished:

1a discontinuous quartz-filled veins
1b later veins which contain ferroan dolomite, chlorite and a little epidote
2 a large vein (up to 3.0 cm wide) rimmed by quartz and containing banded ferroan dolomite, the growth history of which is visible from the distribution of hematite. This vein also contains tiny lenses of fine, crystalline quartz and an occasional fragment of the country rock. Its age relationships relative to veins 1a and 1b are uncertain.

Explosion breccia (PTS 5019)
In hand specimen, a pale brownish-green coloured rock consisting of angular to sub-angular fragments (up to 2.8 cm in length) of lava and tuff set in a cryptocrystalline matrix. In thin section the lava and tuff fragments show marked devitrification and are highly chloritic. Some phenocrysts of feldspar show alteration to kaolinite but the majority are totally chloritised. Hematite is present in accessory amount. The rock is strongly silicified but an episode of carbonate (ferroan dolomite) veining with marked carbonate alteration postdates the silicification. The rock is devoid of sulphide mineralisation.

Glassy tuff (PTS 5020)
In hand specimen, a brownish-green coloured rock consisting of fragments of altered fine-grained extrusive rock set in a cryptocrystalline matrix. In thin section, the angular fragments consist of chloritised lava and tuff, fragments of dark volcanic glass and kaolinised feldspar. The glassy matrix shows strong devitrification with marked replacement by chlorite and contains abundant hematite and a patchy distribution of chalcedony. A large vein cuts the rock, composed of ferroan dolomite, quartz, small angular fragments of country rock, hematite and chlorite. The introduction of this vein has resulted in strong carbonate replacement of the host rock. Along the marginal areas of the carbonate vein and the host rock, baryte occurs in slender, elongated crystals. The baryte is totally confined to a narrow zone and has clearly formed prior to the carbonate phase which largely replaces it. The rock is devoid of sulphide mineralisation.

Glassy tuff (PTS 5021)
In hand specimen, a brownish-green coloured rock, containing angular fragments of altered extrusive rock, set in a cryptocrystalline matrix. In thin section, the fragments consist of chloritised lava and tuff, fragments of dark volcanic glass and kaolinised feldspar. Some of the individual fragments contain amygdales which are commonly filled with chalcedony. The glassy matrix shows signs of strong devitrification with chlorite replacement and contains an appreciable amount of skeletal hematite. The rock has been invaded by a series of large carbonate veins. The veins are composed of ferroan dolomite, the growth history of which is frequently highlighted by zones of iron oxide staining, small fragments of chloritised country rock and a trace of quartz. The introduction of the carbonate vein has resulted in marked carbonate alteration of the host rock. From vein cross-cutting relationships, two episodes of carbonate mineralisation can be recognised. The rock contains blebs of chalcopyrite in trace amount.

Carbonate vein rock (PTS 5022)
The hand specimen of this rock consists almost entirely of pink coloured carbonate in which large, angular fragments of an altered, porphyritic, extrusive rock are embedded. In thin section the fragments consist of dark volcanic glass and chloritised lava which are set in a fine, devitrified, siliceous matrix. The carbonate phase consists of ferroan dolomite with small patches of calcite, and trace amounts of chlorite, quartz and hematite. The fragments of extrusive rock are extensively altered and replaced by the carbonate phase. There is an isolated deposit of chalcopyrite and pyrite on a fracture surface.

Altered andesitic lava (PTS 5023)
In hand specimen, a dark brown coloured, porphyritic, vesicular lava with phenocrysts of altered feldspar distributed throughout a glassy matrix.

In section, the phenocrysts of feldspar appear somewhat chloritised and compositionally fall within the oligoclase range (an average value is $Ab_{82}An_{18}$). Some idiomorphic crystals composed entirely of a blue chlorite (penninite) and which occasionally show a relict ophitic texture involving small laths of plagioclase, are probably pseudomorphs after a ferromagnesian mineral. Smaller patches of green chlorite are probably replacing biotite. The matrix consists of a fine mesh of tiny feldspar laths and devitrified volcanic glass. The lava is markedly vesicular with vesicle diameters ranging in size from 1.0 mm to 2.5 cm. The smallest vesicles are frequently filled with chlorite and calcite, but those of large dimensions are rimmed by hematite and quartz, and contain carbonate (both calcite and ferroan dolomite), fragments of country rock, chlorite and baryte. The baryte is in the form of long slender crystals and its growth is confined to the centres of the vesicles. The edges of the baryte crystals are rimmed by hematite and the mineral is many instances is replaced by the carbonate phase. The rock is devoid of sulphide mineralisation.

Agglomerate (PTS 5024)
This rock is greenish coloured with large, angular, clasts of an altered extrusive rock set in a fine chlorite-rich matrix. In section, the clasts consist of strongly chloritised(?) andesitic lava and a glassy tuff. In the lava clasts, the phenocrysts of plagioclase display marked alteration to sericite and not infrequently to kaolinite. The phenocrysts are also heavily fractured but as they retain euhedral crystal outlines their deformation was probably a post-consolidation phenomenon. The matrix of the lava consists of a fine mesh of altered plagioclase laths and devitrified volcanic glass. Other clasts have a more tuffaceous character and contain fragments of quartz, volcanic glass, plagioclase and potassic feldspar, all of which are set in a devitrified glassy matrix. The agglomerate matrix consists of finely comminuted mineral fragments of which quartz is the major constituent, accompanied by fragments of devitrified volcanic glass, plagioclase, muscovite and chlorite. The rock contains a minor amount of hematite but is devoid of sulphide mineralisation.

APPENDIX IV

X-RAY DIFFRACTION SCANS ON ALVA CORE SAMPLES (Analyst: D. J. Morgan)

Depth in m	Major (⩾30%)	Moderate (10–30%)	Minor (⩽10%)
Borehole 1, Burnside			
28.90	feldspar	calcite, quartz, chlorite	
28.90–29.00	quartz	feldspar, chlorite	?mica
38.00–38.13	calcite		chlorite, ?mica
65.57	calcite, quartz	feldspar, chlorite	
66.00	quartz	feldspar	chlorite, mica
112.52	kaolinite, dolomite	quartz	
Borehole 2, Balquharn			
9.30	calcite	quartz, dolomite, kaolinite	feldspar
115.83	dolomite, quartz	kaolinite	

APPENDIX V

X-RAY DETERMINATIONS OF MINERALS FROM ALVA CORE SAMPLES (Analyst: R. I. Lawson)

Sample	Depth in m	Description	X-Ray Film	Determination
Borehole 1, Burnside				
CXD 21	8.45	Bright silvery flake	XE 227	galena
		Red brown mineral	XE 228	sphalerite
CXD 11	45.00	Circular radiating mineral	XE 336	pyrite
CXD 132	206.40	Black mineral in calcite	XE 282	galena
CXD 131	212.94	Metallic fragments embedded in fracture surface	XE 337, 343, 344	iron, possibly drill casing
Borehole 2, Balquharn				
CXD 39	120.90	Brown vein mineral	XE 279	dolomite

APPENDIX VI

GEOPHYSICAL SURVEYS

Introduction

In November 1977 geophysical surveys using VLF and magnetic methods were carried out around each of the three proposed borehole sites. The aims of these surveys were (1) to establish the geophysical response to known geological structures, (2) to give further structural information at ground surface and at depth, and (3) to detect possible mineralisation associated with the structures and thereby specify optimum positions for the boreholes. Subsequently in July and November 1978 the three boreholes were logged geophysically by BPB with caliper, resistivity, formation density, gamma ray, neutron-neutron, sonic, S P and temperature measurements. The principal result derived from the geophysical logs is the identification of a thin unit enriched in uranium on the gamma ray log of Burnside BH 1 between 158.60 and 159.30 m. This anomaly was confirmed by chemical analysis of the small amount of bleached breccia core recovered (CXD 119, Appendix II, Table I). Copies of the borehole logs are available on request from the Head of the Applied Geophysics Unit, Institute of Geological Sciences, Keyworth, Nottingham, NG12 5GG.

Regional geophysical coverage in the area includes the aeromagnetic survey (Institute of Geological Sciences, 1962), regional gravity surveys completed in 1976 by AGU, and a seismic reflection test carried out over the Devonian lavas of the Ochil Hills (Andrew, 1978).

Regional surveys

The aeromagnetic map shows a gradient of about 50 gammas/km associated with the Ochil Fault between Stirling and Alva. South of and parallel to the fault is an elongated 'low' which may be due to the buried river valley within the Carboniferous sediments. North of the fault positive irregular anomalies are associated with the Devonian lavas.

The regional gravity field is dominated by a broad negative anomaly which occurs on the southern side of the Ochil Fault, associated with a great thickness of low density Carboniferous sediments in the Clackmannan Syncline. The area of interest lies on the western flanks of this anomaly.

The seismic test line was located approximately 10 km north-east of the Alva survey area, within the Devonian lavas of the Ochil Hills. Low velocity layer refraction tests showed a weathered layer of approximately 16 m thickness, but reflections were too weak to be interpreted. Natural seismic activity near the Ochil fault implies that at depth the fault may be inclined to the north.

Detailed surveys

At each site, VLF and total magnetic field measurements were taken at 10 m intervals along parallel traverses 50 m apart, and up to 850 m in length. The traverses were orientated approximately north-south at Burnside and Balquharn, and east-west at Blairlogie, or approximately at right-angles to the structures under investigation.

Burnside (BH 1). The surveys were carried out to determine whether any westward strike extension of the polymetallic mineralisation in Silver Glen could be detected, and for information about the position, structure, and possible associated mineralisation of the Ochil fault and the quartz-dolerite intrusion on the fault.

No significant geophysical anomalies were found on strike from the old silver deposit. South of this the VLF profiles were inconclusive owing to topographic effects and distortion due to fences and a large water pipe running more or less along the line of the Ochil fault. Magnetic profiles were similarly distorted but indicated clearly the position of the Ochil fault by a sharp increase in background value from the south to north, and much greater irregularity over the lavas north of the fault.

Balquharn (BH 2). Geophysical surveys were carried out to determine whether any mineralisation associated with the intersection of the Ochil fault and a northwesterly trending subsidiary fault could be detected. VLF profiles were inconclusive owing to topographic effects and distortion by the road and fences. Magnetic profiles changed from smooth to irregular across the Ochil fault from south to north, with little change in background level.

Blairlogie (BH 3). Geophysical surveys were carried out to determine whether the Blairlogie copper-baryte veins could be detected geophysically and if there was evidence for significant mineralisation in the veins at depth. The extent of the survey lines was limited in the west by roads and buildings, and in the east by steep crags and thick vegetation. All profiles showed strong responses to fences and a water pipe. VLF in-phase profiles showed extreme topographic correlation. No significant anomalies could be correlated with mapped veins due either to limited depth extent or to insufficient conductivity and magnetic susceptibility contrast.

Conclusions

No geophysical evidence was obtained of the location of mineralised structures in the three districts proposed for drilling. It was possible to locate the exact position of the Ochil fault by magnetic surveys, but VLF surveys were inconclusive owing to greater distortion of profiles by fences, roads and pipes, and extreme topographic effects.

References

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