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. 26

Stratabound barium-zinc mineralisation in Dalradian schist near Aberfeldy, Scotland: Preliminary report

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Stratabound barium-zinc mineralisation in Dalradian schist near Aberfeldy, Scotland: Preliminary report

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26 Stratabound barium-zinc mineralisation in Dalradian schist near Aberfeldy, Scotland: Preliminary report.

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Summary

A zone of stratabound barium, zinc and lead mineralisation has been discovered in Middle Dalradian metasedimentary rocks of the Ben Eagach Schist Formation near Aberfeldy in the Scottish Highlands. Discovered in a regional geochemical drainage survey and proved by a co-ordinated geological-geochemical-geophysical programme, mineralisation occurs within a zone up to 50 m thick and at least intermittently over a strike length of 7 km. Shallow boreholes indicate that the mineralised zone can extend to 100 m below surface. Interbanded bedded baryte and quartz-celsian rock, together with sulphide-bearing carbonate rock, muscovite-schist and graphitic schist are the main components. Individual baryte bands range in thickness from 1.5 to 15.5 m and assay on average 85% $BaSO_4$. Zinc and lead concentrations reach a maximum in carbonate rocks with 8% Zn and 4% Pb over a 4 m thickness in one instance. Reconnaissance lithogeochemical sampling throughout the crop of the Ben Eagach Schist near Aberfeldy, utilising a portable X-ray fluorescence analyser for rapid barium determination, has demonstrated the presence of barium enrichments outside the mineralised zone. Within the zone itself, cryptic barium enrichment attributable to barian mica and microscopic baryte is widespread.

INTRODUCTION

Preamble

In June 1975 the Metalliferous Minerals and Applied Geochemistry Unit of IGS undertook a regional geochemical drainage survey over 350 km^2 of the Tay-Tummel watershed as part of the mineral reconnaissance programme being undertaken on behalf of the Department of Industry. The main target was a zone of stratiform pyritic mineralisation in the Middle Dalradian Ben Lawers Schist Formation which contains minor amounts of copper in the Loch Tay area (Smith and others, 1977). No significant copper values were obtained but anomalously high barium, lead and zinc concentrations were recorded in sediments derived from streams draining northwards from the watershed. Since the pyritic horizon lies to the south of the watershed the presence of a second mineralised horizon was inferred. A follow-up drainage survey in September 1975, employing a higher sampling density, established the Ben Eagach Schist Formation as being the most likely source of the mineralisation and at the same time a geological reconnaissance identified the presence of stratabound baryte with sphalerite and galena near the stratigraphic top of the Ben Eagach Schist. Further mineralised outcrops were known to be present along strike (Sturt, 1961) and a combined geological-geophysical-geochemical investigation was undertaken to determine the nature and general extent of the mineralisation.

Location and geographical setting

Straths Tay and Tummel lie in the northern part of Perth and Kinross District, Tayside Region, about 100 km north-west of Edinburgh. The locus of the investigation is the watershed between these two great glaciated troughs (see Fig. 1), the ENE trend of the ridge reflecting the grain of the underlying

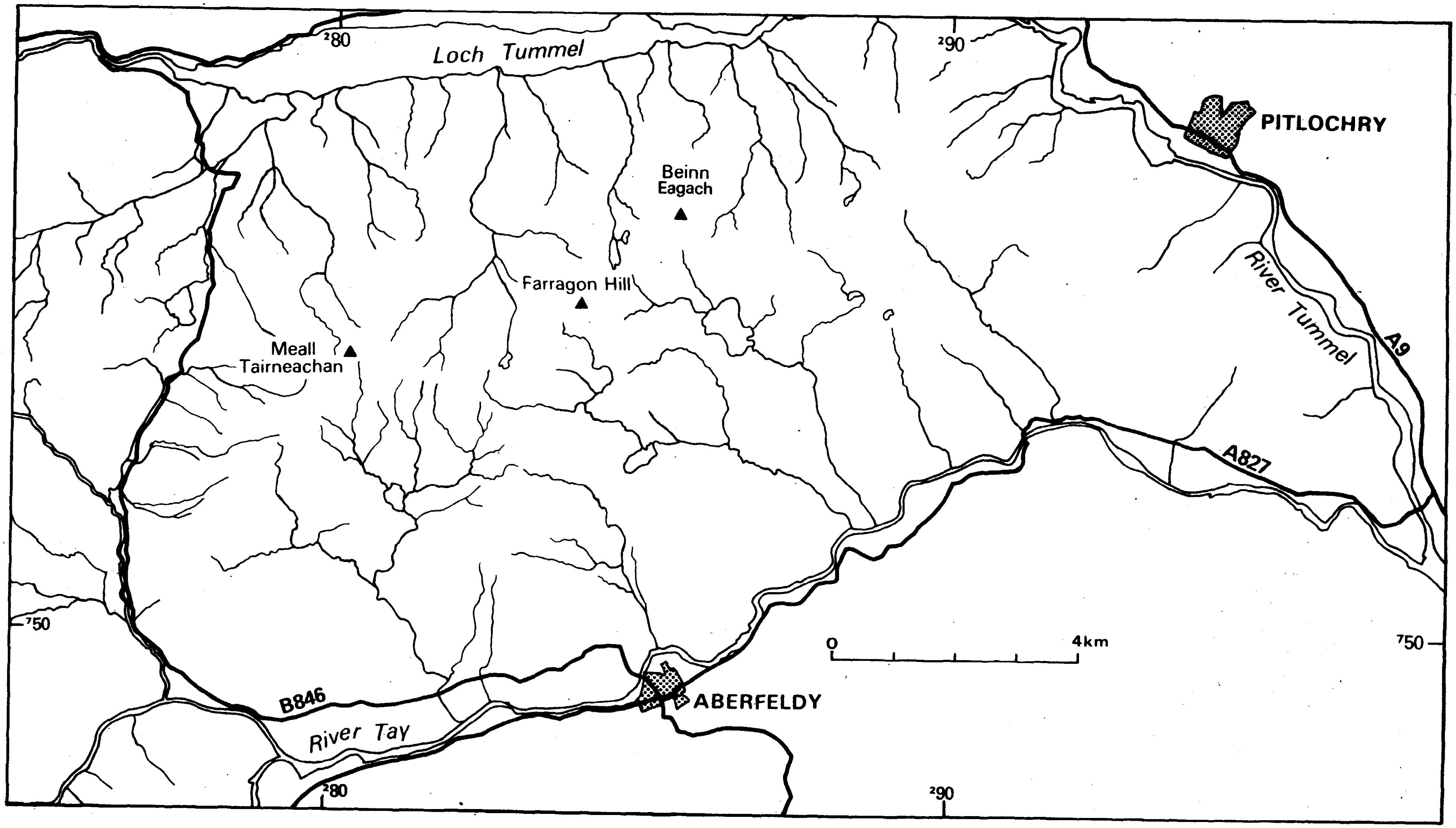

Fig. 1. Location, topography and drainage of the Tay-Tummel watershed

rocks. The ridge has a stepped profile, more noticeable on the south side, culminating in a dissected steep summit-ridge with a number of distinct tops - Meall Tairneachan, 787 m, Ben Eagach, 689 m, and Meall a'Charra, 617 m. The whole feature is, however, dominated by the domed summit of Farragon Hill, 780 m. At its western end the ridge is separated from the higher Rannoch-Lyon watershed by a narrow valley marking the NE trending Loch Tay Fault. The SE flowing River Tummel forms the eastern boundary of the area. The land is devoted almost wholly to sheep farming and, for a limited part of the year, to grouse and deer shooting.

Human settlements are restricted to the valley bottoms and lower slopes of the ridge. The main population centres are Aberfeldy (1589) and Pitlochry (2473), which is also the nearest railhead. A number of hill tracks give reasonable vehicular access to the flanks of the ridge and sections of the summit line can be reached using suitable hill vehicles, except after heavy rain or snow.

Scope of the present survey

Because of the difficult terrain, adverse winter weather conditions and sporting interests, the amount of field time was greatly restricted, with the result that the work extended over four years. The 1975 drainage surveys were supplemented in 1976 by soil surveys together with the collection of chip samples and trenching of the mineralised outcrops. To complete the geochemical survey, over 200 samples of basal till were collected in 1977-78 with a power auger mounted on a Muskeg tractor.

Geological mapping commenced in 1977 and led to the production of a 1:10,000 scale map of the Ben Eagach Schist Formation between the B846 Aberfeldy-Tummel Bridge road and Meall a'Charra (see Fig. 2). In the following year theodolite-controlled surveys at the 1:1,000 scale were made of the main districts of mineralisation to permit accurate correlation of surface geology with borehole intersections.

Despite initial doubts over the suitability of geophysical methods a pilot study by G.R. Marsden in 1977 demonstrated that the very low frequency electromagnetic method (VLF-EM) could distinguish between non-conducting bands such as massive baryte and quartz-celsian rock and the highly conductive graphitic schist. During the ensuing winter and spring almost the entire strike of the Ben Eagach Schist Formation between Meall a'Charra and Meall Tairneachan was surveyed by this method and full details will be presented in the final report.

In 1977 five shallow boreholes (1-5 in Appendix I) were sunk to obtain samples of the mineralised zone and the following year a further six bores were drilled to greater depths either to intersect the mineralised zone at depth or to determine the sources of geophysical and geochemical anomalies. Barium was determined in the drill cores and surface rock samples by means of a portable X-ray fluorescence analyser (the Mineral Analyser) using a ^{241}Am source (3mCi) to excite the Ba Kα X-radiation. A limit of detection of approximately 0.5% Ba is achievable when using this instrument on solid samples.

GENERAL GEOLOGY

The Aberfeldy area is situated in the southern flank of the Scottish Highlands within the bounds of 1 inch Geological Sheet 55. This part of the country is underlain almost exclusively by schists belonging to an immense late Precambrian to Cambro-Ordovician succession of marine sedimentary and volcanic rocks known collectively as the Dalradian Supergroup (Harris and Pitcher, 1975). For the purposes of this investigation detailed studies were restricted to the three formations of the Easdale Subgroup of the Middle Dalradian listed in stratigraphic order below.

Ben Lawers Schist: Calcareous mica-schist, commonly hornblendic, with thin bands of calcareous quartzite and with metabasic sheets.

Ben Eagach Schist: graphitic phyllite and mica-schist with thin bands of dark limestone and major bands of quartzite.

Carn Mairg Quartzite: thick beds of pebbly quartzite, commonly graded and separated by thin bands of graphitic phyllite.

The succession was strongly affected by movement and metamorphism during the Caledonian Orogeny and the Ben Eagach area is situated within a belt of steeply inclined strata which lies between SE-dipping rocks to the north of Loch Tummel and the gently-inclined inverted limb of the Tay Nappe to the south of Aberfeldy. Within the steep belt the general direction of younging is towards the SE (Sturt, 1961) but reversals caused by later folds also occur.

The early movements were accompanied by the development, in pelitic rocks, of a penetrative schistosity; later movements produced crenulations and strain-slip cleavage. The rocks are recrystallised and have metamorphic textures, although original sedimentary grains are easily recognisable in some psammitic rocks. The peak of metamorphism (amphibolite facies) was reached after the formation of the Tay Nappe with the growth of garnet in pelitic rocks and, in the calcareous Ben Lawers Schist, of spectacular porphyroblastic hornblende (garbenschiefer).

At the western edge of the area investigated the schists are truncated by the Loch Tay Fault, one of the 'Great Glen' suite of NE-SW trending wrench faults, which has a sinistral displacement of 5.5 km.

Exposure is generally good but there are extensive tracts of peat and the mineralised zone itself is poorly exposed. The predominant direction of glacial transport was to the south-east, but on north facing slopes the distribution of float has probably been modified by corrie glaciers and hill-wash.

GEOLOGY OF THE MINERALISED ZONE

Distribution of the mineralisation

A zone of barium and minor zinc mineralisation up to 50 m thick is exposed intermittently along a strike length of over 7 km between Meall Tairneachan [NN 8074 5438] and Creag an Fhithich [NN 8715 5644]. This zone lies close to the top of the Ben Eagach Schist (see Fig. 2) and consists of interbanded but essentially stratabound baryte rock, quartz-celsian rock and sulphide-bearing carbonate rock. From Ben Eagach eastwards quartz-muscovite-schist becomes an important component. Although the mineralised zone occurs mainly within the upper section of the Ben Eagach Schist, to the west of the mountain of Ben Eagach the upper boundary of the zone may be formed by the Ben Lawers Schist.

In places the mineralised bands within the zone are separated by units of dark phyllite up to tens of metres in thickness. Although devoid of easily recognisable barium minerals, semi-quantitative X-ray fluorescence analysis of core and rock samples has demonstrated substantial barium enrichment both in these phyllites and in others quite remote from the mineralised zone.

Lithology

The baryte rock is pale grey to white, with a granoblastic texture and a regular centimetre-scale banding picked out by slight colour and grain size variations and concentrations of pyrite. Individual layers within the baryte wedge out but unequivocal evidence of depositional structures have not been observed. Equant crystals of baryte 1 to 2 mm across normally make up over 90% of the rock, the remainder, in decreasing order of abundance, being quartz, dolomite, muscovite, pyrite, magnetite, sphalerite, galena, chalcopyrite and fuchsite.

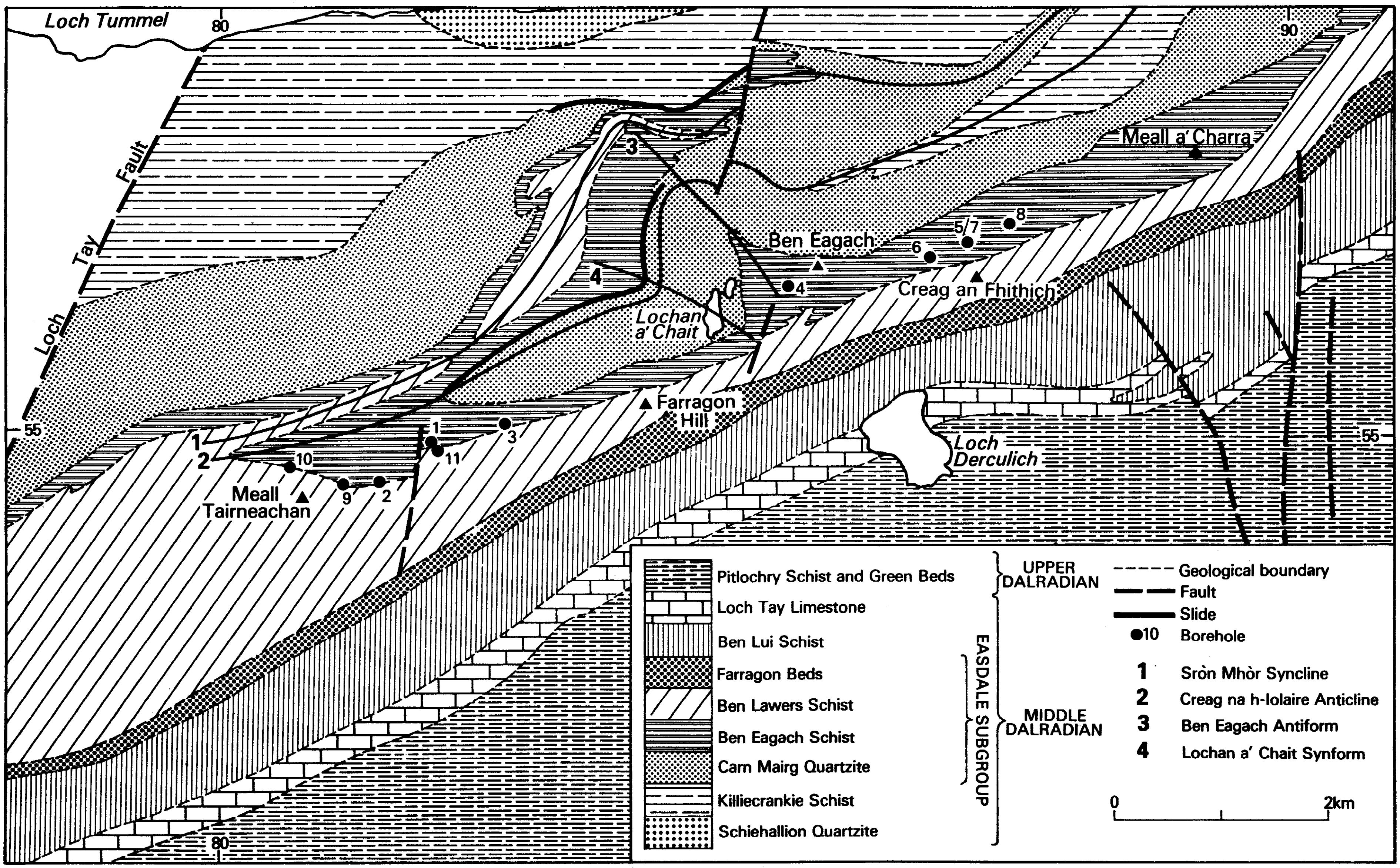

Fig. 2. Geology and location of boreholes

In marked contrast to the uniform massive baryte the quartz-celsian rock is present in a wide variety of forms. These range from a coarse grained rock lacking structure, through coarse to medium grained banded and schistose varieties, to a fine grained cherty rock with parallel sulphide-rich trails. The celsian forms between 5 and 80% of the rock, the remainder being varying quantities of quartz and dolomite with small amounts of muscovite, pyrite, rutile, sphalerite, galena and chalcopyrite. Zircon, epidote and fuchsite have also been recorded. Bands of quartzite occur close to the mineralised zone and can usually be distinguished from quartz-celsian rock by the presence of clastic grains.

Carbonate rock is less abundant than other lithologies in the mineralised zone but is nevertheless important as it forms the principal host rock of the zinc-lead mineralisation. On the western flank of Ben Eagach at the site of borehole 4 a white calcite rock is present containing abundant sub-parallel bands of massive sphalerite and galena, and at the site of borehole 3 a coarse-grained and heterogeneous calcite rock with a fragmental texture is found.

To the east of Ben Eagach quartz-muscovite-schist and dark phyllite are intimately associated with the baryte and quartz-celsian rocks and although not obviously mineralised they have been shown by X-ray fluorescence analysis to contain up to 5% barium. Both rock types are predominantly composed of muscovite and this is believed to be the principal barium-bearing mineral although small amounts of celsian and/or baryte may also be present.

An epidiorite outcrops within the Ben Eagach Schist in the west of the surveyed area, between boreholes 2 and 9. It is readily distinguishable from the dark phyllite by its greenish colour and the presence of prominent 'rhombs' of calcite which are particularly evident on the weathered surfaces. It occurs as a distinct unit which is structurally concordant with the Ben Eagach Schist in the upper part of the formation close to the Ben Eagach/Ben Lawers contact but below the main mineralised band.

Structure

Discontinuous outcrops of the mineralised horizon have been traced for a distance of 7 km along the southern limb of the Creag na h-Iolaire Anticline (Sturt, 1961) and in the Meall Tairneachan area there are traces of mineralisation in the rocks on the northern limb. Both limbs dip towards the south at angles varying from about 50° to vertical, the variation being due to later, superimposed, intermediate scale folds with horizontal axes. The effects of these secondary structures on the mineralised horizon are well seen in exposures between boreholes 9 and 2 where there are open folds with amplitudes of several tens of metres and at borehole 2 the baryte rock is nearly horizontal. The fairly consistent strike but variable southerly dips continue eastwards towards the Ben Eagach area where there is considerable structural complexity which is probably related to the Ben Eagach Antiform. East of Ben Eagach the ENE strike is resumed but the dips are at high angles to the north.

Two small faults on the SW side of Ben Eagach have similar trends and movement senses to the Loch Tay Fault though the magnitude of their displacements (c300 m) is considerably smaller. The VLF-EM survey accurately located a further displacement of similar sense and magnitude affecting the mineralised zone between borehole 2 and boreholes 1 and 11 (see Fig. 2). Unlike the other faults, however, the trend is more northerly and its southerly extension coincides with a well defined gap in the ridge.

Geological mapping, together with geophysical and geochemical surveys provides strong evidence that the mineralised outcrops, though predominantly at the same lithostratigraphic level, are not continuous. This can be seen in the relatively well exposed ground between the site of borehole 3 and the eastern flank of Farragon Hill (see Fig. 2) and again around Creag an Fhithich where the zone also shows great variations in thickness. In the latter area individual baryte bands vary in thickness from 1 m to 6 m over quite short distances on the surface and there is considerable difficulty in correlating surface exposures with the borehole intercepts. It is not immediately apparent as to whether these are original depositional features (i.e. lateral facies changes) or whether they result from subsequent folding, boudinage, and/or faulting. Only one significant baryte band was identified in the mineralised zone at any one locality within the western half of the survey area. However, the varying position of the band relative to the Ben Lawers Schist boundary and subordinate baryte and celsian bands on either side of the fault between boreholes 1 and 2 may indicate the presence of more than one horizon. Despite this the thickness is quite constant relative to bands in the eastern part of the area, being approximately 3 to 4 m and reaching a maximum of 15.5 m locally (Table II, borehole 1).

GEOPHYSICAL SURVEYS

A trial survey to ascertain whether the mineralised zone could be delimited using geophysics was undertaken in 1977. The survey was carried out over the mineralised outcrop in the vicinity of borehole 5 where the area had been mapped in detail and found to contain a wide variety of steeply-dipping mineralised and unmineralised rocks including massive baryte rock, quartz-celsian rock, muscovite-schist, calcareous mica-schist and dark phyllite.

The results (Marsden, 1977) proved that the mineralised zone could be defined quite accurately using the very low frequency electromagnetic method (VLF-EM). In the area of these surveys the zone forms an electrically resistive band wholly within the conductive black schists and gives rise to a weak negative crossover or inflexion in the VLF in-phase component. This can be seen most clearly by applying to the data the filtering techniques described by Fraser (1969). The method has the added advantages of being cheap and rapid.

Clearly the VLF-EM method is unable to distinguish between massive baryte rock and unmineralised but electrically resistive horizons, such as quartzite. By the same token, the line cannot be drawn between the mineralised zone and the calcareous Ben Lawers Schist where they occur in close proximity (see below).

However, the results were sufficiently encouraging for coverage to be extended over most of the Ben Eagach Schist shown in Fig. 2 (between Meall a'Choire [NN 891 576] and Coire an t-Suidhe [NN 799 547]), a strike length of 8 km. Readings were taken at 10 m intervals along lines 30 m apart, on an azimuth of 159°, approximately at right-angles to the strike direction of the Ben Eagach Schist.

The extension of the trial survey near borehole 5 outlined an electrically resistive zone 1.5 km long and 50 m wide splitting eastwards and appearing to close up with the Ben Lawers Schist to the west. Presumably where the zone is almost totally enclosed in Ben Eagach Schist and relatively remote from the Ben Lawers Schist, the boundaries could easily be recognised from the geophysical data. The geophysically determined lines also agreed closely with the geological boundaries near borehole 5 but drilling results showed that the linear VLF-EM anomaly is due in part at least to a calcareous mica schist in the west (borehole 6) and to quartzite in the east (borehole 8).

A number of similar features also occur parallel and to the north of the main anomaly in areas of poor exposure. There are indications that quartzite ribs within the black schists may be responsible, but because one at least of these geophysical anomalies coincides with a barium anomaly in a soil sample they require some further attention.

The area around Ben Eagach itself is structurally complex and the VLF-EM maps reflect this. Attempts to interpret this area are incomplete.

From Lochan a'Chait across Farragon Hill to Creag na h-Iolaire, the northern and southern boundaries of the Ben Eagach Schist can be clearly distinguished on the VLF-EM maps. Where massive baryte rock lies nearly adjacent to the Ben Lawers Schist to the south, as between boreholes 3 and 9, the two are indistinguishable by VLF-EM methods. The nose of a small fold was located in the poorly exposed area to the west of Farragon Hill.

Similarly, in the large fold nose extending from Creag na h-Iolaire to Coire an t-Suidhe the mineralised zone abuts onto and is geophysically indistinguishable from the calcareous schists to the south. Both northern and southern boundaries of the Ben Eagach Schist are clearly seen along almost their whole extent from the VLF-EM maps, even where exposure is very poor. A fault can be identified running NNE-SSW just west of borehole 1, approximately along Frenich Burn. A very strong anomaly with a strike length of about 2 km occurs in the Ben Eagach Schist on the northern limb of the Creag na h-Iolaire Anticline about 50 m south of the boundary with the Ben Lawers Schist. Exposure over this geophysical anomaly is very poor but quartzite enriched in sphalerite is known to occur locally and drilling will be necessary to determine its extent.

The VLF-EM method proved to be a useful aid to geological mapping. It allows precise delimitation of the Ben Lawers-Ben Eagach Schist boundary to be made even across areas of deep overburden, and several VLF-EM anomalies were further examined by power auger sampling and drilling.

GEOCHEMICAL SURVEYS

Drainage survey

A regional geochemical drainage survey was carried out in 1975 at a sample density of about 1 sample per 1.5 km^2 over the area between Ben Lawers and Blair Atholl. The main target of the exploration was the Middle Dalradian 'Pyrite Zone' (Smith and others, 1977). Samples of -100 mesh stream sediment and -8 + 100 mesh heavy mineral concentrate were collected, the former analysed for Cu, Pb, Zn, Ag, U, Be, B, V, Cr, Mn, Fe, Co, Ni, Y, Zr, Nb, Mo, Sn and Ba and the latter for Ce, Ba, Sb, Sn, Pb, Zn, Cu, Ca, Ni, Fe, Mn and Ti.

Cumulative frequency diagrams were used to identify elements with strongly anomalous populations and to give class intervals for plotting greyscale maps in the same manner as Lepeltier (1969). These methods, combined with factor analysis, identified a group of samples with highly anomalous metal values north of Aberfeldy (see Figs. 3-4). The association of Pb, Zn, Ba and Mn was most marked in the headwaters of Frenich Burn, which drains the ridge east of Meall Tairneachan, in the two streams draining north from Creag an Fhithich, and in one stream flowing south from Ben Eagach to Loch Derculich.

This association is best illustrated by the distribution of barium in panned concentrate samples (Fig. 3) and zinc in stream sediments (Fig. 4). A dispersion train of both elements up to 3 km in length can be identified in the streams flowing north from the main topographic ridge in the direction of the main fluvial transport. Dispersion to the south of the watershed is due to glacial transport of mineralised material over the ridge. The one strongly anomalous stream flowing into Loch Derculich drains the only area of mineralisation situated to the south of the main ridge.

Subsequent detailed drainage sampling upstream from the anomalous sites shows an increase in barium to over 10% in panned concentrates, related to the presence of baryte, while anomalous levels are detectable up to 3 km downstream. Zinc and lead in stream sediments show similar patterns, zinc reaching a maximum level of 2000 ppm. The lead content of the panned concentrates is the more precise indication of mineral distribution, dropping to near background levels within a few hundred metres of the source.

Metal values reach a maximum immediately downstream of the outcrop of the mineralised zone in the Ben Eagach Schist. In most districts, there is a gentle decrease upstream of this horizon without a sudden cut-off point because of the presence of mineralised blocks transported uphill and southwards by ice movement.

Overburden sampling

The results of the earlier surveys indicated that the mineralisation extended for 7 km from Meall Tairneachan to Creag an Fhithich and a hand auger survey was planned in order to delineate the lateral extent and thickness of the mineralised horizon. Hand auger sampling (reaching a maximum depth of 1.3 m)

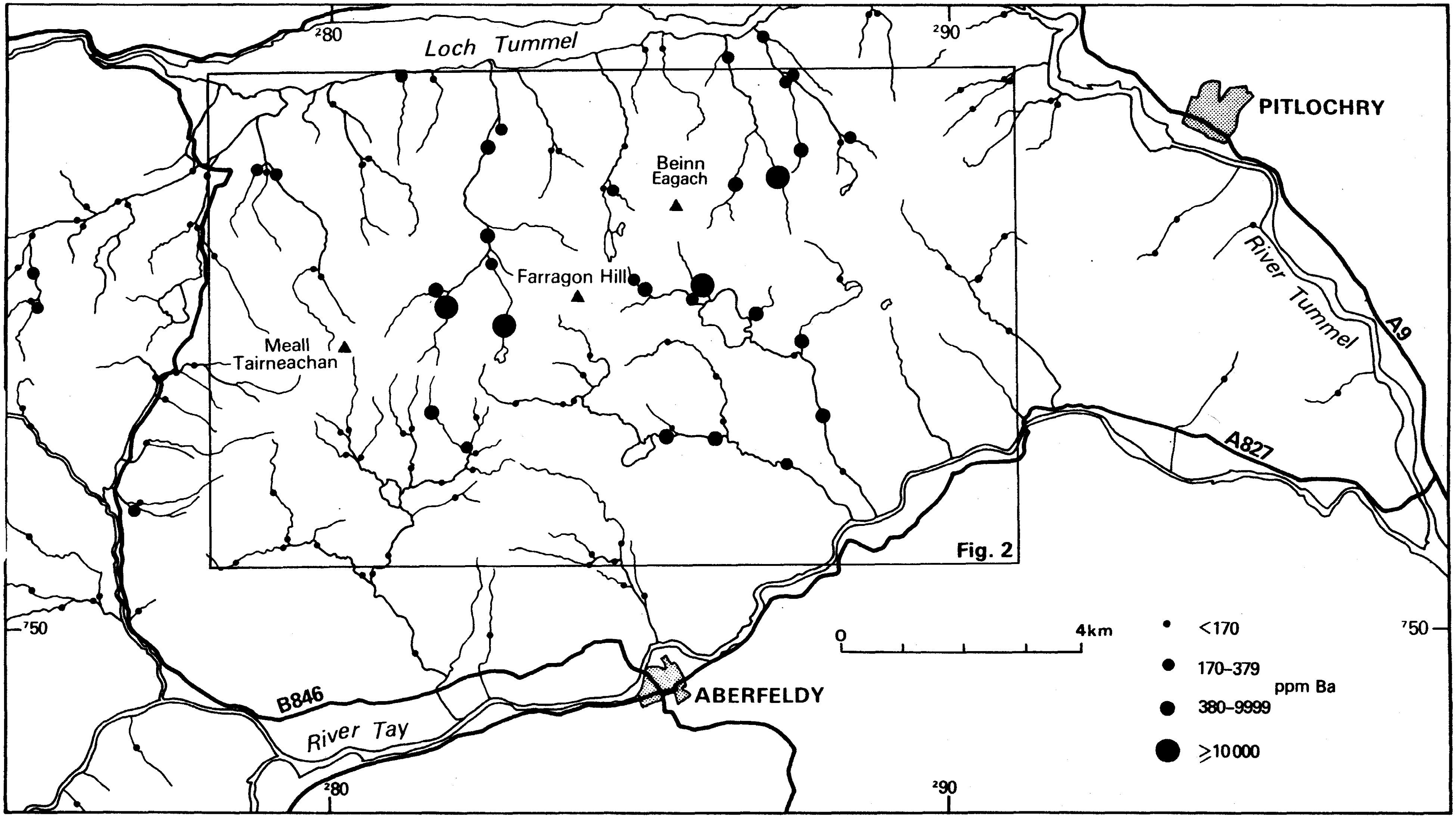

Fig.3 Barium in regional panned concentrate samples

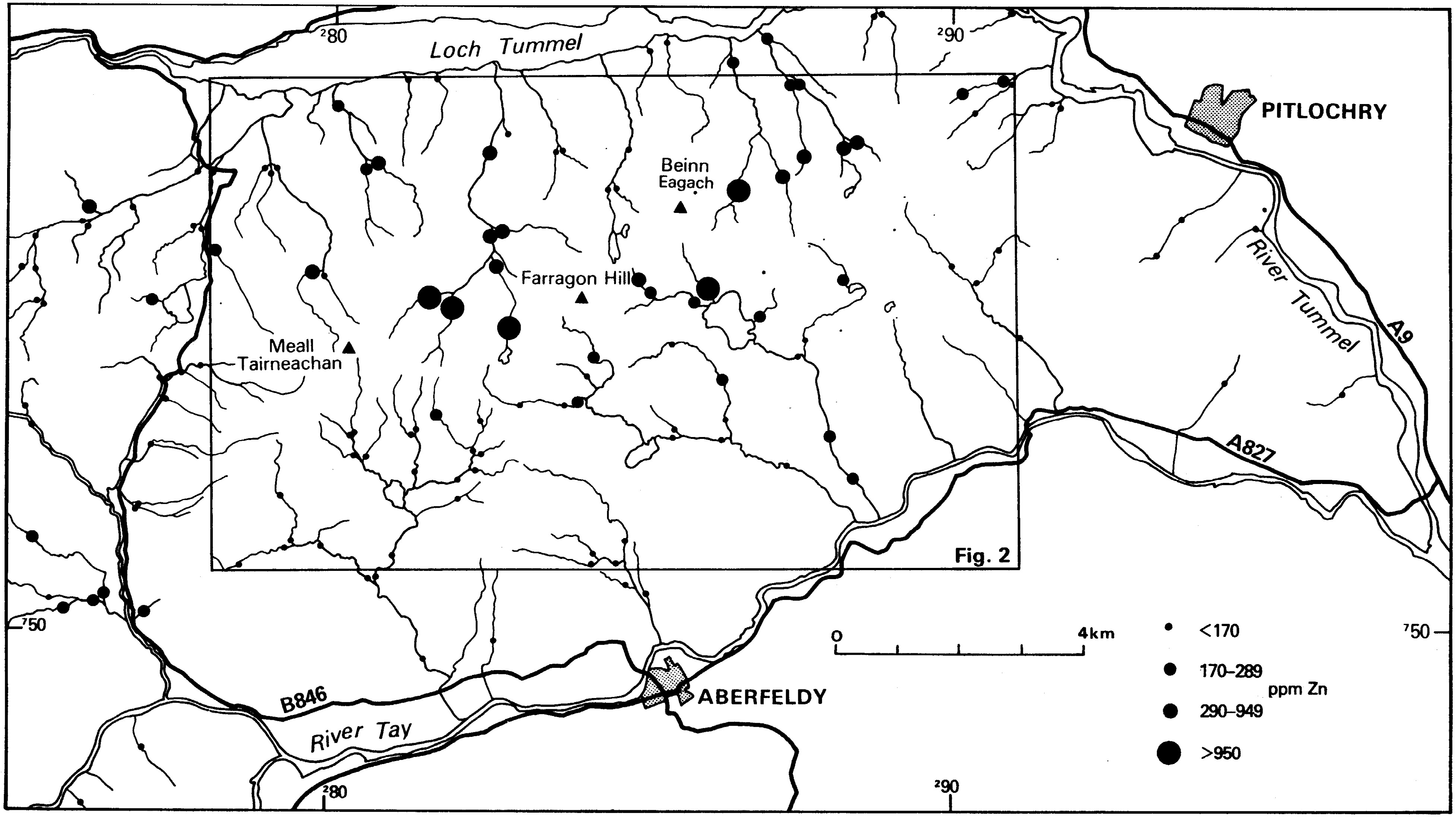

Fig.4 Zinc in regional stream sediment samples

could not be very successfully employed in the valleys because of thick drift and peat cover and was therefore restricted to six areas covering the main ridges. The areas were chosen to extend north from the Ben Lawers Schist outcrop and a grid spacing of 100 x 10 m used. Samples were collected from the 'C' horizon wherever possible but in some areas the depth of peat cover exceeded 1.3 m limiting sampling to the organic rich 'A' horizon. They were dried, sieved through 80 mesh and analysed for Cu, Pb, Zn, Ag, Mn, Fe, Mo and Ba.

The mineralised horizon was shown to extend from Meall Tairneachan to at least as far as Creag an Fhithich, but strongly anomalous Ba, Pb, Zn and Ag values were absent in the central section around Farragon Hill, thus confirming the gap in the drainage anomalies. Three areas were outlined which showed promise for economic Ba-Pb-Zn mineralisation; one extending from the north flank of Meall Tairneachan to the site of borehole 3, the second just south-west of Ben Eagach, and the third north of Creag an Fhithich. Peak values of 50% Ba, 2.2% Pb, 1.5% Zn and 55 ppm Ag were reached in individual soil samples.

Since the hand auger sampling covered only limited areas and later geophysical and geological work was not specific about the nature of the mineralised horizon in poorly exposed ground, a programme of power auger sampling was performed in order to determine the position of the baryte and sulphide-bearing rock prior to drilling. Laboratory analysis of the 200 samples obtained in this way is not yet complete, but the distribution of suboutcropping barium mineralisation was defined prior to drilling at the site of borehole 8 by semi-quantitative X-ray fluorescence analysis of heavy mineral concentrates derived from basal till.

MINERALOGY

Mineralogical study of selected pieces of drill-core and outcrop specimens principally involved microscopic examination of polished thin sections under transmitted and reflected light. Additional tests included X-ray diffractometry of bulk samples, carbonate staining with Alizarin-Red solution, carbonate testing with dilute (20%) HCl solution and determination of specific gravity of core specimens using a simple spring balance. Electron microprobe techniques provided confirmation of the identities of barium feldspars, barian muscovite and fuchsite.

The baryte rocks are massive, coarse, mosaic-textured rocks consisting largely of anhedral baryte crystals with small amounts of quartz and pyrite as dispersed, smaller grains. Other dispersed minor constituents commonly include muscovite, dolomite and sphalerite, and less common ones include fuchsite (chromian mica), chlorite, magnetite and galena.

The celsian-rich rocks are of varied texture. Some are fine to medium grained, massive, granular rocks in which celsian, quartz, dolomite and pyrite are disseminated among one another. Others are coarse rocks in which branching, bladed porphyroblasts of celsian occur in a pyritiferous, dolomitic quartz matrix. In rare cases anhedral, coarse celsians give the rock a massive texture similar to the baryte rocks. In all these types the celsian is accompanied by minute, euhedral crystals of rutile. Other minerals observed in these rocks include pyrrhotine, sphalerite, galena, muscovite, biotite and fuchsite.

Dolomite-quartz rocks frequently contain minor amounts of baryte, celsian, rutile, biotite, chlorite, pyrite, pyrrhotine, sphalerite, galena and chalcopyrite. The schists lack more than accessory amounts of baryte or celsian, but consistently carry pyrite, pyrrhotine, sphalerite and rare galena. Furthermore, they tend to have low but persistent levels of barium enrichment, which appears to be due to the presence of barium within the lattice of the muscovite in these rocks. Graphitic schist from borehole 8 (135 m) with 4.5% Ba (whole-rock) proved to contain a major amount of muscovite with some 8.12% BaO. Similar rock from borehole 7 (36.7 m) contains barian muscovite (3.99% BaO) and a quartzose schist from borehole 7 (40.5 m) contains barian muscovite (5.93% BaO) in equilibrium with accessory hyalophane (13.92% BaO). Some thin sections of barium-enriched schists from boreholes 7 and 9 carry minute grains of baryte and others contain probable celsian.

Calcareous epidiorites from borehole 9 are chlorite-rich rocks containing variable amounts of muscovite and biotite. Minor constituents include minute rutile grains, traces of pyrrhotine, chalcopyrite and ilmenite, and thinly dispersed pale-green 'spots' of illite.

Orientated fabrics are rare in baryte rocks but tend to be strongly expressed in the coarser celsian-rich rocks by the bladed crystals of the barium feldspar. In contrast these rocks are ubiquitously banded. The banding reflects the tendency for contrasted baryte-rich and celsian-rich rocks to succeed one another abruptly. Coexistence of celsian and baryte within individual thin sections of the core is uncommon and cases of celsian rock grading into baryte rock unknown. The impression gained is that of a bedded sequence and this is emphasised by other smaller scale banding in the rocks. In the graphitic schists thin bands of massive, dark limestone or dolomite are common. Muscovite-schist tends to carry quartzitic and dolomitic bands. In the barium-rich lithologies banding is expressed by the abundant layers rich in sulphide grains. Such layers tend to be richer in quartz than the adjacent rock. The magnetite observed in some baryte rocks is similarly prone to being segregated into thin layers. Such layers lie parallel to one another. They may be impersistent "streaks" or have the appearance of continuous bands. There is no evidence to suggest that this small-scale banding does not parallel the larger scale "bedding". A white calcite-rock in borehole 4 contains abundant sulphide-rich layers (pyrite and sphalerite) which impart a strongly striped appearance. In flexures of the banding in this rock the sulphide-rich layers tend to be parallel to each other.

Another texture well displayed by material from borehole 4 is a fragmental or brecciated texture in which sub-angular fragments of sulphide-poor quartz-rock, dolomite and celsian are set in a sulphide (pyrite and sphalerite)-rich quartzose matrix. This texture appears to be pre-tectonic in origin.

DRILLING RESULTS

Five shallow boreholes (BH1-5) and a further six holes (BH6-11) varying from 19 m to 200 m in rod-length were drilled to investigate the subsurface extent of the barium-zinc mineralisation (Table I). Boreholes 1, 3, 4, 5, 6, 7, 9 and 11 were inclined with the intention of testing the down dip extension of out-cropping massive baryte rock. Boreholes 7 and 11 were sited to intersect the same sections as boreholes 5 and 1 respectively but at greater depth. Boreholes 8 and 10 were also inclined holes but were sited to investigate geophysical and geochemical soil anomalies associated with sulphide-bearing quartz-celsian rock debris (borehole 10) and baryte in heavy mineral concentrates from basal till (borehole 8). Borehole 2 was drilled vertically into sub-horizontal massive baryte rock. Abbreviated borehole logs are presented in the Appendix.

The azimuths adopted for most of the boreholes were dictated by the attitude of the mainly steeply-dipping schists. Hence boreholes 6-8 were collared in Ben Eagach Schist to the north of the mineralised zone and terminated in Ben Lawers Schist. On the other hand, boreholes 9 and 11 penetrated the Ben Lawers-Ben Eagach Schist boundary before entering the mineralised zone. Borehole 10 was sited in poorly exposed ground and cored entirely in Ben Eagach Schist. Borehole 10A was therefore stepped back 40 m SSE from the collar of borehole 10 to intersect the Ben Lawers-Ben Eagach Schist boundary.

Boreholes 1-5 were drilled with the IGS Winkie drill; boreholes 6-8 were contract holes drilled by Drillsure Ltd. with an Atlas Copco Diamec 750 and the remaining four holes were drilled with a JKS 300 rig belonging to IGS. Core sizes used were as follows:

BH 1-5	TAX
BH 6, 7	NQ
BH 8	NQ to 69 m, TBW below
BH 9	BQ
BH 10	BQ to 59 m AQ below
BH 10A	BQ
BH 11	BQ to 59 m, AQ below

TABLE I

Locational and other features of boreholes near Aberfeldy

Borehole No.	Nat. Grid. Ref. (NN)	Map Sheet (1:10,000 OS)	General location	Collar elevation (m)	Azimuth (inclined hole, degrees)	Inclination*		Rod-length (m)
1	8195 5490	85 SW	E bank of Frenich Burn	584	342	45		30.50
2	8148 5433	85 SW	150 m E of Creagan Channaich	650	vertical	-		19.14
3	8267 5506	85 NW	600 m NNW of Lochan Lairig Laoigh	620	142	45		35.45
4	8530 5641	85 NE	320 m SW of Ben Eagach	650	152	40		25.39
5	8696 5678	85 NE	380 m NNW of Creag an Fhithich	560	172	43		33.81
6	8619 5645	85 NE	960 m W of Creag an Fhithich	546	159	45	35	176.20
7	8697 5679	85 NE	400 m NNW of Creag an Fhithich	555	155	45	52	170.75
8	8736 5697	85 NE	West bank of Allt Coireih a Chinn	491	160	45	52	200.83
9	8119 5454	85 SW	150 m of Creag an Channaich	737	013	55		100.48
10	8069 5466	85 SW	290 m NNW of Meall Tairneachan	729	015	55	48	136.25
(10A)	8068 5463	85 SW	260 m NNW of Meall Tairneachan	739	015	50		39.62
11	8198 5481	85 SW	E bank of Frenich Burn	595	346	55	35	174.90

*First Column: inclination at surface
Second Column: inclination at base of hole

Mineralised intersections

Seven of the twelve boreholes intersected bands of massive baryte (Table II). The estimated true thickness of the intercepts ranged from 15.5 m (borehole 1) to 2.0 m (borehole 4) with an average of about 5 m. Bands of baryte less than 2 m in thickness are also present in the cores from borehole 7 (Appendix). Compared with surface measurements only borehole 9 showed an increase in baryte thickness with depth. Boreholes 1 and 4 showed little appreciable reduction in thickness of mineralisation. Boreholes 7 and 11 (drilled below boreholes 5 and 1 respectively) produced mineralised intercepts of much reduced thickness relative to those encountered at the surface and in the shallower boreholes although, if the considerable thickness of quartz-celsian rock in borehole 7 is also included, then there is little reduction in total thickness over a vertical interval of approximately 87 m. Similarly on the steep slope between boreholes 9 and 2 there is no apparent thinning of the baryte band over 100 m of vertical interval.

In boreholes 3, 4 and 9 the massive baryte comprises a single band; in boreholes 1, 2 and 11 there are two bands; three were recorded in boreholes 7 and 4; and four in borehole 5. Calculated $BaSO_4$ contents for boreholes 1-5 are in the range 77-90%, the main impurities being quartz and dolomite. Pyrite and magnetite are common but only occur together to a limited extent. Sphalerite is usually present as a minor constituent.

Fine grained, frequently cherty-looking quartz-celsian rock containing variable amounts of pyrite, calcite and dolomite invariably accompanies the massive baryte. Muscovite-schist is also a major associated rock type in borehole 5 and 7, along with dolomitic limestone and biotite schist.

Sulphides include pyrite, pyrrhotine, sphalerite and galena and are extremely common outside the massive baryte, principally in carbonate rock and quartz rock. In borehole 4, for example, peak assays of 20% Zn and 6.6% Pb were recorded in 1.04 m of brecciated calcite-rock (part of intersection 4(b), see Table II).

TABLE II

Grade and thickness of mineralised intersections in the Ben Eagach Schist near Aberfeldy

Borehole no. (see Table I)		*Lithology	Ore minerals	Intersection, m	True width, m	Assay (%) Ba	Pb	Zn
1		Massive baryte	Baryte	23.60	15.5	52	0.1	0.3
2	(a)	Massive baryte	Baryte	5.75	2.6	50	< 0.1	<0.1
	(b)	Massive baryte	Baryte	5.65	2.5	52	< 0.1	<0.1
3	(a)	Massive baryte	Baryte	7.37	6.4	46	0.1	0.3
	(b)	Calcareous quartz-celsian rock	Sphalerite, galena, baryte	1.16	1.0	17	1.1	4.0
4	(a)	Massive baryte	Baryte	2.85	2.0	54	0.3	0.7
	(b)	Brecciated quartz rock, calcite rock and quartz-celsian rock	Sphalerite, galena	6.09	4.3	8	3.6	8.5
5		Massive baryte	Baryte	5.67	3.6	48	0.1	0.2
9		Massive baryte	Baryte	3.48	3.4	to be determined		
11		Massive baryte	Baryte	2.51	2.3	to be determined		

*See borehole logs in the Appendix for more detailed description

Systematic examination of the drill core using the Mineral Analyser has shown that cryptic barium mineralisation is present in the Ben Eagach Schist and to a lesser extent in the Ben Lawers Schist. This was exemplified in borehole 8 where difference count rates equivalent to 3-5% Ba were obtained from graphitic muscovite-schist.

The logs of boreholes 6-11 and preliminary analytical results on the cores demonstrate that fine grained sphalerite is also widespread in the mineralised zone within the Ben Eagach Schist.

CONCLUSIONS

A stratabound zone of barium and base metal enrichment, containing bands and lenses of massive baryte has been identified by a combination of geochemical, geophysical and geological techniques over a strike-length of some 7 km in the Dalradian Ben Eagach Schist near Aberfeldy. In the east between boreholes 6 and 8, the baryte is in relatively small lenses with a total thickness decreasing from 11.3 m at surface to 6.0 m at a depth of around 14 m and 1.5 m at around 28 m depth. The massive baryte has an estimated lateral extent of 350 m. It appears to die out to the east where only minor amounts of disseminated rather than massive baryte occur in borehole 8, and to be represented in the west by mineralised quartz-celsian rock. On Ben Eagach the single band of massive baryte is 2.5 m thick at the surface and 2.0 m at a depth of 11m in borehole 4. Lack of exposure makes an estimate of strike extent difficult; 350 m is possible but it could be much less. In the western part of the mineralised zone (Fig. 2, boreholes 3-9) only one major baryte band was intersected at any one locality, although several minor bands are present. It is possible that outcrops east and west of the fault between boreholes 1 and 2 belong to more than one horizon, but thicknesses are relatively constant, particularly with respect to bands in the eastern half of the zone. Although exposure is poor between the main outcrops, coincident geochemical and geophysical anomalies suggest that massive baryte may extend, at least intermittently, over a strike length of 1.8 km. The true thickness of the main western baryte band, where observable at surface or in boreholes, varies from 2.3 m to 15.5 m (Table II) and it is exposed over a minimum vertical interval of about 100 m. Because of the limited outcrop and borehole data it is not possible to estimate the possible reserves of baryte represented by the main western band.

The zinc, lead and silver contents of some units in the mineralised zone are fairly high, but excepting a 4 m intersection in borehole 4 containing 8% Zn and 4% Pb, the units are thin and impersistent, indicating that they are of limited economic potential. It is nevertheless possible that small tonnages of galena and sphalerite might be recoverable as by-products of baryte extraction.

The unusual composition of the rocks in the mineralised zone in the Ben Eagach Schist is considered to be an original feature even though the fabric is mainly metamorphic. The various lithological types are interbedded, generally on a scale of several metres, with sharp contacts between the units, and mixed or intermediate varieties are absent. There is no obvious systematic zoning either parallel to or normal to the strike, although it is possible that rhythmic cycles of sulphide-rich carbonate rock, baryte rock and quartz-celsian rock are present. The presence of celsian, magnetite, barian muscovite and rare fuchsite is also unusual. Celsian is generally associated only with manganese ore deposits such as Franklin Furnace, USA (Frondel and Baum, 1974) and Benallt, Wales (Spencer, 1942) but there is one record from the major lead-zinc deposit of Broken Hill, New South Wales (Mawson and Segnit, 1946). A detailed description of the paragenesis of the celsian will be given in the final report.

In view of the marked stratabound nature of the rocks in the mineralised zone it is concluded that they are of syn-sedimentary origin. Their unusual composition and the apparent lack of clastic material suggest an origin by direct precipitation with probable diagenetic modification. A similar association of bedded baryte, chert and black shale and the absence of volcanic rocks is seen at Meggen (Zimmerman, 1970) and Rammelsberg (Anger et al., 1966) in West Germany. The sedimentary baryte deposits at Barberton Mountain Land, South Africa (Heinrichs and Reimer, 1977) and Northumberland Canyon, USA (Shawe, Poole and Brobst, 1969) also have broad similarities with the Ben Eagach mineralised zone. However, the zinc, lead and silver content of the Ben Eagach zone suggests a hydrothermal-exhalative origin comparable with the 'McArthur type' of lead-zinc-silver deposits described by Lambert (1977) as typically occurring within thick sedimentary sequences in intracratonic basins. Here, the host rock is usually a black iron sulphide-bearing shale containing cryptic geochemical enrichments of barium and zinc along strike from the ore. Alteration haloes and associated igneous activity may occur distally from the ore deposits which are found in local, perhaps fault-controlled, basins. These deposits are thought to be formed from hydrothermal fluids introduced via fault zones on to the sea floor in a stagnant euxinic environment.

The results obtained at Aberfeldy provide the basis for further work on the distribution of mineralisation within the Ben Eagach Schist and associated Dalradian lithologies of the Easdale Subgroup. This stratigraphic horizon can now be regarded as one of considerable promise for the location of stratabound baryte and base metal mineralisation in the Central Highlands.

A full economic evaluation of the mineralised zone in the Ben Eagach Schist cannot be made from the data available, nor was it the objective of the investigation. Based on the targets which have been broadly delineated, such evaluation requires further drilling of the main baryte band recognised in the western part of the zone to prove continuity and thickness along strike and in depth, and to locate new lenses of massive baryte. It is perhaps pertinent to an assessment of potential that at Rammelsberg the ore deposit consists of a series of lenses and blind orebodies discovered only by drilling or underground development.

Finally, it is recommended on the basis of this preliminary study that further exploration in the Dalradian of the Scottish Highlands should concentrate on the Ben Eagach Schist Formation and its lateral equivalents. The presence of cryptic barium mineralisation and disseminated sphalerite, detectable from geochemical analysis of drainage samples and by lithogeochemical sampling and analysis, utilising portable X-ray fluorescence analysers may prove to be the best exploration guide for mineralisation of the type identified.

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APPENDIX I: ABBREVIATED BOREHOLE LOGS WITH CHEMICAL ANALYSES WHERE AVAILABLE FOR BOREHOLES 1-11

Inclined depth (m)	Inter-section (m)	Geological record	Assay (%) Ba	Pb	Zn
		BOREHOLE 1			
0.00					
2.50	2.50	Superficial deposits			
		BEN EAGACH SCHIST			
4.70	2.20	Dolomite rock with calcite, quartz and celsian, and with pyritic laminae inclined 35° to the core axis	19	0.035	0.085
19.14	14.44	Baryte rock with quartz, dolomite micas, celsian, magnetite, pyrite, sphalerite and galena; banded structure inclined 35° to core axis	52	0.17	0.43
19.29	0.15	Biotite-schist with pyrite)			
28.15	8.86)	Baryte rock with quartz, dolomite, micas, celsian, pyrite, sphalerite)	52	0.09	0.11
28.75	0.60)	and galena; banded structure)			
29.00	0.25	Dolomite with quartz, celsian and pyrite)			
30.50	1.50	Soft, calcareous, graphitic schist with minor pyrite, sphalerite and galena)	21	0.11	0.35
30.50		End of borehole			
		BOREHOLE 2			
0.00		BEN EAGACH SCHIST			
5.75	5.75	Baryte rock with quartz, pyrite, dolomite, micas, magnetite, sphalerite and galena; banded structure at 40° to core axis	50	0.07	0.08
7.68	1.93	Gossanised brecciated quartzite leading into a bed of massive quartz followed by a bed of quartz-celsian-pyrite rock	18	0.03	0.02
13.33	5.65	Baryte rock with quartz, dolomite, micas, magnetite, pyrite, pyrrhotine, sphalerite and galena; banding at 15° to core axis	52	0.02	0.02

Inclined depth (m)	Inter-section (m)	Geological record	Assay (%) Ba	Pb	Zn
14.68	1.35	Quartz-rich rocks calcareous then dolomitic containing celsian, pyrite, sphalerite and galena	12	0.33	4.7
15.11	0.43	Pyritic quartz-muscovite-schist with structure at 50° to core axis	7	0.03	0.17
19.14	4.02	Calcareous graphitic quartz-muscovite-schist with accessory pyrite, sphalerite and galena	0.68	0.11	0.44
19.14		End of borehole			
		BOREHOLE 3			
0.00					
3.00	3.00	Superficial deposits			
		BEN EAGACH SCHIST			
19.46	16.46	Quartz-muscovite schist, mostly graphitic and dolomitic; structure inclined at 65° to core axis; minor pyrite, pyrrhotine and sphalerite	0.03	0.09	0.31
25.07	5.61	Dolomite rock with celsian, quartz, pyrite, pyrrhotine, sphalerite and galena	2.8	0.73	2.1
32.45	7.37	Baryte rock with quartz, calcite, muscovite, magnetite, pyrite, sphalerite and galena; banding at 60° to core axis	46	0.08	0.26
33.61	1.16	Calcareous quartz-celsian rock with baryte, muscovite, pyrite, sphalerite and galena	17	1.1	4.0
35.45	1.84	Muscovite-schist with minor pyrite, pyrrhotine and sphalerite	1.4	0.20	0.85
35.45		End of borehole			

Inclined depth (m)	Inter-section (m)	Geological record	Assay (%) Ba	Pb	Zn
		BOREHOLE 4			
0.00					
3.30	3.30	Superficial deposits			
		BEN EAGACH SCHIST			
5.77	2.47	Weathered schist (not sampled)			
13.00	7.23	Graphitic mica-schist with calcite and dolomite; structure inclined at 45° to the core axis; minor pyrite	1.1	0.002	0.21
13.84	0.84)	Quartz rock with dolomite and pyrite, initially fissile with muscovite becoming massive with baryte,	(1.5	0.02	0.17
14.50	0.66)	pyrite, sphalerite and galena	(13	0.84	2.5
17.35	2.85	Baryte rock with quartz, pyrite, sphalerite and galena	54	0.27	0.68
18.00	0.65	Brecciated quartz rock with dolomitic sulphide-rich matrix	7.6	3.6	10.5
22.08	4.08	Banded, folded calcite rock with quartz, baryte, pyrite, sphalerite and galena; the central part is brecciated, the fragments being set in a sulphide-rich matrix	10.3	3.4	8.7
23.44	1.36)	Quartz-celsian rocks with minor	(0.95	4.2	7.1
25.39	1.95)	sphalerite and baryte	(20	0.02	0.08
25.39		End of borehole			

Inclined depth (m)	Inter-section (m)	Geological record	Assay (%) Ba	Pb	Zn
		BOREHOLE 5			
0.00					
2.30	2.30	Superficial deposits			
		BEN EAGACH SCHIST			
4.08	1.78	Banded quartz rock with dolomite, baryte, celsian, pyrite, sphalerite and galena	22	0.13	0.16
5.30	1.22	Baryte rock with pyrite and sphalerite	57	0.13	0.095
6.01	0.71	Quartz rock	18	0.08	0.10
6.93	0.92	Baryte rock with quartz, pyrite, sphalerite and galena	53	0.14	0.12
17.45	10.52	Quartz rock with dolomite, celsian, rutile, pyrite, sphalerite and galena; banding at 60° to the core axis	9.8	0.06	0.07
19.00	1.55	Baryte rock with quartz, celsian and pyrite	49	0.11	0.06
21.40	2.40	Quartz rock with some baryte; much limonite	24	0.31	0.03
27.07	5.67	Baryte rock with quartz; pyrite, sphalerite and galena; celsian-rich bands and bands of biotite-schist are present; banding at 40° to the core axis	48	0.08	0.17
33.81	6.74	Quartz rock with dolomite, muscovite, celsian, pyrite and sphalerite	8.1	0.06	0.27
33.81		End of borehole			

Inclined depth (m)	Inter-section (m)	Geological record	Inferred Ba %
		BOREHOLE 6	
0.00			
2.15	2.15	Superficial deposits	
		BEN EAGACH SCHIST	
101.10	98.95	Interbanded chlorite-muscovite-quartz-schist and biotite-chlorite-muscovite-quartz-schist occasionally garnetiferous with local quartz-muscovite-schist and micaceous quartzite units; characteristically dolomitic with dominant foliation inclined 85-90° to core axis, locally variable due to intense folding; minor pyrite and rarer pyrrhotine sporadically distributed throughout	1.5
126.34	25.24	Graphitic muscovite-schist, sometimes chloritic, and grey dolomitic schist with interbanded chlorite-muscovite-quartz-schist units and thin limestone bands; foliation inclined 85-90° to core axis outwith the intensely folded areas; pyrite common	-
127.00	0.66	Calcareous quartzite, dark grey biotitic quartzite with graphitic partings	0.5
132.16	5.16	Quartzite, pale grey with chlorite partings and dolomite veins; minor interbanded chlorite-sericite-quartz-schist units; minor pyrite in thin trails along chloritic partings	1
		BEN LAWERS SCHIST	
161.61	29.45	Dominantly striped dolomitic sericite-biotite-chlorite-quartz-schist with thin interbanded graphitic schists above 147.00 m; amphibole with characteristic garbenschiefer texture prominent below approximately 149.00 m; foliation inclined 70-80° to core axis; very minor pyrite and trace of pyrrhotine	-
166.51	4.90	Epidiorite, dark green calcareous hornblende schist with traces of pyrite	-
175.03	8.52	Chlorite-sericite-hornblende-quartz-schist, finely laminated and calcareous with foliation inclined 30-60° to core axis; rare pyrite	-
176.20	1.17	Epidiorite, finely laminated with quartz-calcite segregations	-
176.20		End of borehole	

Inclined depth (m)	Inter-section (m)	Geological record	Assay (%) Ba	Pb	Zn
		BOREHOLE 7			
0.00					
3.14	3.14	Superficial deposits			
		BEN EAGACH SCHIST: mica-schist member			
5.00 6.45	1.86) 1.45)	Calcareous quartz-muscovite-schist with dolomitic bands at 65° to the core axis	0.57	0.013	0.24
27.03	20.58	Dolomitic biotite-muscovite-schist exhibiting crenulated foliation at 35°-50° to the core axis; minor amounts of sulphides, hornblende and possible baryte are present	0.94	0.007	0.081
34.09	7.06	Banded quartz-celsian rock with baryte bands 0.58 m and 0.70 m in thickness; pyrite, sphalerite and galena occur in both lithologies	16	0.085	0.26
38.52	4.43	Muscovite-schist with minor baryte, sulphides and possible celsian	3.1	0.004	0.054
44.73	6.21	Banded quartz-celsian rock with a 0.69 m baryte band and minor sulphides which increase towards base	13	0.33	0.44
57.49	12.76	Muscovite-schist, very leached, containing some celsian and sulphides; the foliation angle to the core axis varies from 35° to 60°	1.8	0.030	0.26
63.22	5.73	Quartzite with celsian, pyrite and minor sphalerite	6.6	0.058	0.27
75.36	12.14	Muscovite-schist containing celsian minor chlorite and biotite, pyrite and accessory sphalerite and galena; foliation at 80° to the core axis	1.6	0.010	0.079
88.16	12.80	Banded quartz-celsian rock in which both dolomite and calcite are present together with relatively common sphalerite	8.8	0.11	0.41
		BEN EAGACH SCHIST: graphitic schist member			
113.84	25.68	Graphitic muscovite-schist with carbonates, minor biotite and probable hyalophane porphyroblasts; both pyrite and pyrrhotine are present in disseminations and pyrite also occurs in calcite-chlorite veinlets	0.43	0.004	0.022

Inclined depth (m)	Intersection (m)	Geological record	Assay (%) Ba	Pb	Zn
123.30	9.46	Thinly-bedded quartzites and interbedded graphitic muscovite-schist	0.22	0.001	0.011
124.18	0.88	Lamprophyric rock exhibiting chilled margins	0.26	0.001	0.008
131.71	7.53	Muscovite-schlorite-schist with minor biotite followed by graphitic muscovite-schist; foliation at 90° to the core axis	0.28	0.001	0.010
		BEN LAWERS SCHIST			
148.90	17.19	Biotite-muscovite-schist, calcareous, containing almandine, followed by the same lithology in which hornblende is present but almandine absent; some bands are slightly graphitic; foliation at 90° to the core axis	0.11	0.002	0.010
151.82	2.92	Hornblende-amphibolite, calcareous, with biotite and minor plagioclase; foliation highly contorted	0.040	0.006	0.019
170.75	18.93	Biotite-muscovite-schist, calcareous with hornblende porphyroblasts; foliation at 60°-80° to the core axis	0.070	0.004	0.013
170.75		End of borehole			

Inclined depth (m)	Inter-section (m)	Geological record	Inferred Ba %
		BOREHOLE 8	
0.00			
4.46	4.46	Superficial deposits	
		BEN EAGACH SCHIST	
46.27	41.81	Graphitic muscovite-schist with interbanded muscovite-biotite-quartz-schist units, dolomitic throughout; strong foliation 60-70° to core axis, with minor folding; pyrite common throughout and pyrrhotine occurs below 39.00 m	1
73.53	31.72	Micaceous quartzite, dolomitic with muscovite-schist and graphitic schist units; foliation 80-90° to core axis; pyrite and pyrrhotine occur in variable amounts	0.5
102.80	29.27	Graphitic muscovite-schist as above with foliation 75-90° to core axis; variably dolomitic throughout with pyrite, pyrrhotine and rare sphalerite	1.5
105.75	2.94	Quartz rock, chloritic and micaceous with celsian and abundant pyrite, pyrrhotine and sphalerite; trace of galena	10
118.42	12.68	Muscovite-schist locally chloritic with strong foliation inclined 65-90° to core axis; characteristically dolomitic with common pyrite and pyrrhotine	1.5
155.03	36.61	Graphitic muscovite-schist unit with foliation 70-85° to core axis; pyrite and pyrrhotine occur throughout; lamprophyre at 136.73-137.49	5
		BEN LAWERS SCHIST	
200.83	45.80	Calcareous mica-quartz-schist with interbanded calcareous quartzites; amphibole with characteristic garbenschiefer texture below 166.00 m; minor pyrite	-
200.83		End of borehole	

Inclined depth (m)	Inter-section (m)	Geological record	Inferred Ba %
		BOREHOLE 9	
0.00			
3.50	3.50	Superficial deposits	
		BEN LAWERS SCHIST	
17.69	14.19	Calcareous biotite-sericite-quartz-schist with foliation inclined 40-60° to core axis and local folding; dolomitic with dolomitic quartzite below 16.50 m; minor pyrite and pyrrhotine occur with trace of chalcopyrite	1
		BEN EAGACH SCHIST	
20.03	2.34	Graphitic quartz-muscovite-schist sparingly dolomitic with strong foliation inclined 60-75° to core axis; pyrite common	3.5
22.50	2.47	Banded quartz-celsian rock sparsely micaceous with pyrite and minor baryte	17
25.98	3.48	Baryte rock with limonitic staining and minor pyrite	35
29.14	3.16	Banded cherty quartzite with banding inclined 75° to core axis, locally limonitic; pyrite common with accessory sphalerite	11
37.31	8.17	Graphitic muscovite-quartz schist with interbanded muscovite-schist units, foliation inclined 45-75° to core axis with local folding; characteristically dolomitic with common pyrite, pyrrhotine and sphalerite; trace of chalcopyrite	1.5
45.23	7.92	Epidiorite, locally biotitic; dolomitic below 43.24 m with interbanded dolomitic quartz-schist unit; pyrrhotine and pyrite noted	0.5
48.49	3.26	Carbonaceous muscovite-quartz-dolomite-schist with irregular foliation inclined 60-70° to core axis; common pyrrhotine, pyrite and sphalerite; trace of chalcopyrite	1
53.45	4.96	Calcareous epidiorite with trace of pyrrhotine	-
56.95	3.50	Muscovite-schist, dolomitic and carbonaceous in parts; foliation inclined 75-90° to core axis; sphalerite and pyrite abundant with lesser amounts of pyrrhotine and trace of chalcopyrite	0.5

Inclined depth (m)	Inter-section (m)	Geological record	Inferred Ba %
67.60	10.65	Graphitic muscovite-quartz schist, dolomitic in parts, with foliation inclined 80° to core axis; pyrrhotine, pyrite and sphalerite relatively common	1
71.62	4.02	Dolomitic muscovite-quartz schist with graphite throughout; foliation inclined 60° to core axis; pyrrhotine and pyrite common	1.5
78.37	6.75	Cherty quartz rock locally dolomitic with celsian, pyrite and pyrrhotine; minor sphalerite and galena	8
90.53	12.16	Muscovite-schist, moderately graphitic with pyrrhotine, minor pyrite and sphalerite	1
100.48	9.95	Graphitic muscovite-schist with pyrite and pyrrhotine	-
100.48		End of borehole	

Inclined depth (m)	Inter-section (m)	Geological record	Inferred Ba %
		BOREHOLE 10	
0.00			
3.05	3.05	Superficial deposits	
		BEN EAGACH SCHIST	
5.75	2.70	Muscovite-schist with graphitic partings; foliation 45° to core axis	2
13.20	7.45	Graphitic muscovite-schist with interbanded muscovite-quartz schist units, foliation inclined 60-90° to core axis; pyrite and pyrrhotine common throughout; traces of galena and (?) sphalerite	4.5
26.68	13.48	Interbanded calcareous biotite-schist and muscovite-chlorite-quartz-schist with good foliation inclined 60-80° to core axis; pyrite and pyrrhotine content increases below 19.00 m	-
27.04	0.36	Celsian rock with irregular foliation and minor pyrrhotine and pyrite	21
27.36	0.32	Muscovite-chlorite-quartz schist with strong foliation inclined 80° to core axis; minor pyrrhotine and pyrite	10
43.62	16.26	Graphitic muscovite-schist with interbanded mica-quartz schist units, foliation inclined 80-90° to the core axis; pyrite, rare pyrrhotine and (?) sphalerite present	1
69.31	25.69	Micaceous quartzite with interbanded graphitic schist units and thin limestone bands, foliation inclined 70-90° to core axis; variable amounts of pyrrhotine and pyrite with occasional sphalerite and chalcopyrite	-
77.79	8.48	Graphitic garnet-mica-schist with interbanded garnet-mica-quartzite, characteristically dolomitic throughout; pyrrhotine common with minor amounts of pyrite and sphalerite	-
134.85	57.06	Dolomitic quartzite and interbanded dolomitic graphitic muscovite-schist units, foliation inclined 70-80° to core axis; pyrrhotine occurs with subordinate pyrite and sphalerite and rare galena and chalcopyrite	-
136.25	1.40	Limestone with interbanded graphitic units and partings, foliation varies 0-90° due to folding; pyrrhotine with minor sphalerite and pyrite and trace of chalcopyrite present	-
136.25		End of borehole	

Inclined depth (m)	Inter-section (m)	Geological record	Inferred Ba %
		BOREHOLE 10A	
0.00			
1.15	1.15	Superficial deposits	
		BEN LAWERS SCHIST	
13.63	12.48	Quartz-muscovite-chlorite-dolomite-schist without visible mineralisation; foliation inclined 45-70° to core axis	-
31.49	19.01	Calcareous and dolomitic quartz-muscovite-schist with minor biotite; sulphide restricted to isolated specks of chalcopyrite in quartz lens	-
38.50	7.01	Sparingly dolomitic muscovite-schist with a little chlorite and some carbonaceous material containing accessory pyrite	1
		BEN EAGACH SCHIST	
39.65	1.15	Graphitic muscovite-schist with minor pyrite	3
39.65		End of borehole	

Inclined depth (m)	Inter-section (m)	Geological record	Inferred Ba %
		BOREHOLE 11	
0.00			
2.14	2.14	Superficial deposits	
		BEN LAWERS SCHIST	
22.81	20.67	Calcareous-chlorite-sericite-schist with hornblende and garnet porphyroblasts and interbanded limestone and calcareous quartzite units; bedding foliation inclined 15-70° to core axis; pyrrhotine, traces of pyrite and rare chalcopyrite present; fault zone 21.56-21.85 m	-
		BEN EAGACH SCHIST	
38.45	15.64	Interbanded sparsely micaceous celsian-quartz rock and pale and dark banded dolomitic and calcareous calcite rocks;banding inclined 70-80° to core axis; pyrite and pyrrhotine noted	11
39.38	0.93	Graphitic muscovite-schist with calcareous bands and patchy pyrite	3.5
41.30	1.92	Fine-grained quartzite with micaceous partings inclined at 60° to core axis; stratiform and vein pyrite	-
57.70	16.40	Graphitic muscovite-schist and muscovite-quartz-schist with calcareous and quartzose bands passing at 50.64 m into calcareous biotite-chlorite-sericite schist; foliation inclined 50-70° to core axis; rare pyrite and pyrrhotine noted	3
68.37	8.37	Crumpled calcareous muscovite-biotite-quartz-schist, dolomitic and chloritic below 68.37 m with finely disseminated pyrrhotine and traces of pyrite	1.5
69.70	1.33	Quartz-muscovite-schist with foliation inclined 70° to core axis; pyrrhotine disseminated throughout	4
90.38	20.68	Striped calcareous biotite-quartz-schist to 75.45 m followed by laminated dolomite-quartz-sericite-biotite-schist with bands of dolomitic and calcareous quartzite; lamination inclined at 70° to core axis; finely divided pyrrhotine noted	0.5

Inclined depth (m)	Inter-section (m)	Geological record	Inferred Ba %
111.33	20.95	Poorly striped dolomitic chlorite-biotite-sericite-quartz-schist interbanded with dolomitic and non-dolomitic quartzite and chlorite-sericite-biotite-schist; rare pyrrhotine and traces of pyrite	0.5
123.21	11.88	Fine-grained quartzite with micaceous, graphitic and dolomitic partings and rare bands of graphitic muscovite-schist and dolomitic limestone; abundant pyrite, pyrrhotine and sphalerite	2
126.37	3.16	Dark grey quartz-celsian rock with small pods and streaks of quartz and rarer chlorite; stratiform pyrite with subordinate pyrrhotine and sphalerite noted	12
129.90	3.53	Interbanded graphitic quartz-muscovite-schist, muscovite-schist, graphitic micaceous quartzite and dolomitic limestone	1
131.12	1.22	Interbanded quartz-celsian rock and massive baryte; ubiquitous pyrite trails with variable sphalerite content and traces of galena	22
132.60	1.48	Graphitic muscovite-quartz-schist with interbanded quartzite and muscovite-schist; pyrite with subordinate sphalerite disseminated throughout	3
136.36	3.76	Cherty celsian quartzite with calcareous, quartzose and rare dolomitic bands; pyrite disseminated throughout with minor sphalerite trails, magnetite and galena	8
140.00	3.64	Interbanded graphitic dolomite-muscovite-schist and sericite-dolomite-quartz-chlorite-schist with minor dolomitic limestone and quartzite; foliation inclined 20-60° to core axis; pyrite irregularly distributed in trails and veinlets	4.5
142.87	2.87	Pale green and brown cherty quartz-celsian rock with abundant pyrite, lesser amounts of sphalerite and rare galena	12
144.92	2.05	Massive baryte with abundant pyrite, massive in parts with subordinate interstitial sphalerite; sulphide trails inclined at 65-88° to core axis	15.5
174.90	29.98	Sparsely dolomitic graphitic muscovite-quartz-biotite-schist, sometimes biotitic, with bands of dolomitic limestone, micaceous quartzite and non-graphitic schist; foliation inclined at 70-80° to core axis; disseminated pyrite and sphalerite with subordinate pyrrhotine noted	-
174.90		End of borehole	