Natural Environment Research Council

Institute of Geological Sciences

Mineral Reconnaissance Programme Report

A report prepared for the Department of Industry

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SUMMARY

A small stratiform occurrence of massive sulphide, apparently over 2 m thick, has long been known to occur in the Dalradian schists at McPhun's Cairn beside Loch Fyne, Argyllshire. At outcrop it contains 3.5 per cent Zn, 3.0 per cent Pb, 6 ppm Ag and 0.75 ppm Au.

Geological, geophysical (IP, magnetic, resistivity) and geochemical (soil, stream sediment, panned concentrate) surveys did not locate any direct inland extension of the mineralisation, indicating only the presence of sporadic weak mineralisation. Regional structural analysis and examination of the mineralisation as exposed, by excavation, suggests that local concentration of sulphides has occurred at the nose of a steeply plunging small fold system. No relationship to an adjacent horizon of widespread dominantly barren stratiform sulphide (Smith and others, 1977) appears to be possible.

Shallow drilling of the landward geophysical and geochemical anomalies has located only sparsely disseminated sulphide in the schists. A borehole to investigate the outcrop occurrence proved the extension of mineralisation down the fold axis and indicated that the form is analogous to that of some Scandinavian stratiform massive sulphides.

The occurrence at McPhun's Cairn has no economic potential but the possibility of a larger body of similar type occurring in the area is considered reasonable. Geochemical anomalies located in the wider survey may represent indications of other significant occurrences.

Investigation of stratiform sulphide mineralisation at McPhun's Cairn, Argyllshire

C.G. Smith and others

BACKGROUND

In the Ben Lawers Schist of central Perthshire a zone of disseminated pyrite with accessory chalcopyrite is known to have considerable lateral extent (Smith and others, 1977). To the south-west, in the Loch Fyne/Cowal area, the Ben Lawers Schist is known as the Ardrishaig Phyllite and at Creggan's Point (Fig. 1) on the eastern shore of Loch Fyne pyritiferous beds occur at a similar lithostratigraphic horizon as in Perthshire. Elsewhere in the Loch Fyne area the Ardrishaig Phyllite contains showings of stratabound mineralisation where pyrite and/or pyrrhotite is accompanied by base-metal sulphides. At Craignure and Coille-bhraghad (Fig. 1) on the western side of Loch Fyne deposits were mined for copper and nickel during a short period in the 19th century, and were reinvestigated by various mining companies in the early 1970's under the MEIGA scheme. The results of these investigations have not been made public.

At a locality known as McPhun's Cairn* (Fig. 1) 1 km NNE of Creggan's Point on the south-east shore of Loch Fyne a small beach exposure (NGR NN 089 032) of massive sulphides, 7 m long and 6.5 m wide, is separated from the surrounding rocks by superficial deposits and vegetation. This outcrop has been known for many years to contain base-metal sulphides in proportions which would be of economic value, were the deposit a large one, but, as it was considered to be limited by faulting away from the foreshore (Hill and others, 1905) and was of unknown extent towards the Loch, it was evidently not considered attractive enough by mining companies to be investigated by drilling or more detailed methods.

A reappraisal of its potential, however, raised a number of possibilities, especially interesting as the orebody was apparently similar to ones currently worked in Scandinavia, although even the most optimistic estimates indicated that it could not approach these in size. Encouraging features were:

a. Faulting alone would displace the orebody but not remove it. Modern techniques might locate a displaced continuation away from the foreshore.

b. The orebody might be on the same horizon as the sulphide zone at Creggan's Point, brought to land by a large fold under the water of Loch Fyne. In this case a 'saddle reef' of sizeable proportions might lie under Loch Fyne.

c. The full extent of the body on the foreshore had not been proved.

d. Confirmation of the nature of the body as a "Scandinavian type" would directly encourage further search in similar conditions in Scotland. A preliminary reconnaissance was carried out in 1970 and analysis of a sample of ore assayed 7% zinc and 2% lead.

*64m north-north-east of the former site of McPhun's Cairn which has been destroyed by road widening.

sample of ore assayed 7 per cent zinc and 2 per cent lead.

OBJECTIVES

The aims of the reinvestigation were:

a. To define the extent of the body on the foreshore and search for a possible fault displaced occurrence uphill.

b. To establish the relationship between this occurrence and the pyritiferous horizon at Creggan's Point.

METHODS

A detailed (1:1000) geological map (Fig. 3) of McPhun's Cairn and its environs was produced, whilst a more rapid appraisal of geological structures on the shore between Creggan's Point and Aird Cottage (Fig. 1) was undertaken in connection with objective b. Induced polarisation and magnetic measurements (Fig. 2) were made over the beach and hinterland; the magnetic measurements being extended out into Loch Fyne. Soil samples (Fig. 2) were collected close to the mineralised exposure and along some of the geophysical traverse lines further inland, while drainage samples were collected from streams as far north as Aird Cottage.

Shallow follow-up drilling (Fig. 3) investigated geophysical and geochemical anomalies and the possible down-dip continuation of the beach occurrence. The area about the outcrop was trenched (Fig. 4), and the offshore continuation of an associated magnetic anomaly was investigated by a short diving programme.

RESULTS AND CONCLUSIONS

The mineralisation at McPhun's Cairn consists of folded narrow bands of essentially stratiform sulphides, which appear to have been concentrated in the nose of a small north-easterly closing anticline. Some down-dip extension was proved by drilling (Appendix IV, BH3) and the general form of the orebody indicates that it may be an elongated, roughly pencil-shaped mass lying parallel to the north-westerly-plunging fold axis (that is, parallel to the lineation). Since there is no evidence in the area of any major fold closures (Appendix II), this fold is likely to be a minor structure on the south-east limb of the Ardrishaig Anticline (Fig. 1) which would preclude any connection with the pyritiferous horizons at Creggan's Point. The evidence indicates fairly strong lithological and structural controls, and it seems likely that there may be other similar occurrences of mineralisation along the same horizon within the Ardrishaig Phyllites. A possible lateral extension of the thin sulphide bands toward the south-west into Loch Fyne was indicated by a limited offshore magnetometer survey, but a small diving programme (Appendix V) was unable to confirm this, due to lack of exposure.

As a further consequence of the structural interpretation (Appendix I), there is not likely to be any extension of the deposit immediately to the north-east of McPhun's Cairn. This was confirmed by the absence of any geophysical or geochemical anomalies. However, since curved fold axes have been recorded in the area (Appendix I), it is possible that the mineralised horizon may reappear somewhere along strike at a distance inland from the shore, possibly in the area of the lead-zinc soil anomaly at 250E/50N (Appendix III). Significant IP and magnetic responses were obtained from the mineralised outcrop on the shore, and, just to the south, an east-west zone of high chargeability and low resistivity extends across the area surveyed. From the down-hole IP response (for example, BH1) it would appear that the latter are due principally to widespread, but small, finely disseminated sulphide concentrations in bands, ranging from a few mm to over 20 cm in thickness, occurring near the surface. Likewise, most, if not all, of the larger magnetic anomalies, east of the road, probably reflect small concentrations of pyrhotite in the phyllites.

Though none of the analysed stream sediments contain anomalous metal concentrations, some heavy mineral sample values exceeded the regional threshold (for example, 1443 ppm Pb, 410 ppm Zn and 224 ppm Cu) and may imply a northerly extension of the mineralised body.

Field evidence and, more specifically, borehole evidence tends to indicate that the pyrite and pyrrhotite-bearing areas are closely related (Appendix I) forming thin bands within the Ardrishaig Phyllite Formation. From both the surface excavations (Fig. 4) and BH 3 it is clear that the available ore-grade material is of very limited development and is of no economic significance. However, the possibility of other similar concentrations of economic proportions cannot be entirely ruled out, particularly if the mineralisation has the lateral persistence of the adjacent (Creggan's Point) pyritous schist. It is also significant that the Lower Cambrian rocks of the McPhun's Cairn area are lithologically similar to Ordovician rocks in the Roros district, Norwegian Caledonides, which contain stratabound sulphide deposits of economic proportions (Rue and Bakke, 1975).

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APPENDIX I: GEOLOGICAL SURVEYS

The area described lies within one-inch Geological Sheet 37 (Scotland) and has been the subject of a Memoir (Hill and others, 1905). There has been no subsequent detailed study by IGS, although the major structures have been described by Bailey (1922) and Roberts (1974).

PHYSICAL FEATURES

Between Aird Cottage and Creggans Point (Figs 1 and 3) the eastern side of Loch Fyne comprises a narrow beach zone 30 to 80 m wide, surmounted by a slightly convex smooth wooded hillslope. The beach zone consists of the present shore and a (low) raised beach platform, on which runs the main Arrochar to Dunoon road (A815). The present beach provides adequate exposure of bedrock and an almost continuous north-south section is present along the scarp separating the present and raised beaches. At the rear of the raised beach there is a well defined break of slope, above which the hill profile maintains a fairly even gradient of 15 to 20° within the area surveyed.

Augering has shown the overburden to be seldom more than 2 m in thickness. In spite of the steep topography, the combination of clayey overburden, impervious bedrock and high precipitation leads to waterlogging, particularly in depressions or areas of impeded drainage, producing boggy ground. Some subsurface percolation of water is indicated by borehole BH 1, tapping a spring and by a number of seep areas. During periods of high precipitation there is a certain amount of sheetwash, though most of the surface drainage is carried by runnels which expose bedrock where the overburden is thin. The larger streams provide almost continuous exposure along their length and in places have cut narrow gorges into the soft phyllite. Where quartzite is the dominant lithology the stream course is locally controlled by minor folds.

BEDROCK

The bedrock in the Loch Fyne area consists principally of Middle Dalradian (Lower Cambrian) metasedimentary rocks and intrusions of Caledonian age. The metamorphic rocks are cut by narrow basic dykes of Tertiary age. As the Tertiary dykes have no relevance to the mineralisation they are not described below. The Caledonian intrusions are not present in the area described and, although they may prove to be of significance to the general question of Dalradian stratabound mineralisation, they are not discussed in this report.

The metasedimentary rocks belong to the Ardrishaig Phyllite Formation. These comprise argillaceous, calcareous and siliceous rocks which underwent greenschist facies metamorphism during the Caledonian orogeny. Within the mapped area argillaceous rocks are dominant, though there is both a lateral and cross-strike increase in the volume of siliceous material to the south-west and south-east respectively. The argillaceous rocks are micaceous phyllites and low grade schists, characterised by an appreciable calcium carbonate content. They are generally pale greenish grey in colour, often with a silvery lustre, but are dominantly light grey when associated with siliceous rocks. These rocks generally have a soft, flaky texture, but become platy with increasing quartz content. The micaceous material is mostly sericite or muscovite but lesser amounts of chlorite are also present. The white mica commonly forms coarse plates and sheaves, which are seen as thin poorly-defined compositional laminations in the borehole cores. Mottling due to diffuse blebs of segregated carbonate is also a common feature, well displayed in some of the cored material (Appendix IV). Segregations of quartz, often accompanied by carbonate and/or variable amounts of iron-sulphide, are common and concordant to the schistosity. Quartz, in places accompanied by carbonate, is also seen to infill tensional fissures and other open spaces in the formation.

Flaggy quartzite intercalations, sometimes present in the schist, progressively increase in number and thickness as dominantly siliceous areas are approached. The siliceous units consist of fine-grained quartzites, micaceous quartzites, calc-quartzite and quartz-schists. Individual quartzite bands range up to 1 m in thickness, but are generally less than 15 cm. Quartz-schists are common, particularly where there is a continuous passage between argillaceous and siliceous rocks. Some grits occur (Appendix IV, BH 1), but they are thin, rarely coarse-grained and merely represent a local coarsening of the quartzitic horizons. In the more calcareous units, the irregular diffusion of the calcareous material is reflected by their colour variation from white, pale grey or buff to bluish green. This is especially evident close to schistose material or in isolated thin quartzitic ribs in the phyllite.

STRUCTURE

The quartzitic ribs in the Ardrishaig Phyllite show intense tight to isoclinal folding. Many of the fold limbs are extremely attenuated and the closures then have a lenticular, mullion-like form. A penetrative slaty cleavage, which is developed in the enclosing phyllite, is axial planar to the folds. In many exposures the bedding and cleavage are approximately parallel, forming a foliation which dips towards the north-west (Figs 3 and 5a). A mineral lineation (the stretching-direction of Roberts and Sanderson, 1974) plunges down the dip of the foliation towards the north-west.

North of McPhun's Cairn the folds have a fairly constant west-north-westerly plunge but to the south it is much more variable. The nature of this variation is revealed by an exposure approximately half way between McPhun's Cairn and Laurel Bank [NN 088 025]. Here minor folds have curvilinear axes lying within a constantly-orientated axial plane. A curve through 60° has been observed and much greater total curvature is inferred from fold axis measurements (Figs 5a and 5c). The fact that the cleavage remains undistorted is taken to indicate that the curvature is an original feature and not the result of refolding. When allowance is made for variation of the plunge direction the sense of overturning is found to be consistent with the section being situated on the overturned south-east limb of the Ardrishaig Anticline (Fig. 5b). The change from S to Z (Figs 5a and 5c) is due to the plunge varying through the horizontal and not to a change in the sense of overturning. A few anomalous samples were noted approximately 100 m north of Colliechaol, but these appear to be situated on the short limbs of larger strongly-asymmetrical folds with the normal sense of overturning (Fig 5d).

In contrast to the fold axes the mineral lineation is remarkably constant in orientation (Fig. 5a). It is developed on the cleavage surfaces in the phyllite and also on the bedding planes of the quartzite ribs, where it is marked by strongly-elongated brownish spots. It is not normally visible in the hinge region of the folds where, instead, there is an axial lineation formed by the intersection of the cleavage and the bedding.

Microcrinkling and small-scale monoclinal folding of the cleavage are common. These structures are clearly later than the main deformation and were not studied in detail.

No major faults were recorded in the area. There is a double system of dislocations which are best seen on the shore and in the gorge of Allt Sean Roib (Fig. 3). One set trends north-north-easterly, dips deeply to the west and appears little more than master joints, while another later set trends north-west to north-north-westerly, dips steeply to the south-west and generally has a small sinistral displacement. Some of the later set are occupied by Tertiary dykes.

The mineralised outcrop is essentially concordant with the foliation in the enclosing rocks, but does not occur in the low cliff behind the high water mark (Fig. 3). To explain this sudden easterly termination Hill and others (1905) suggested that the gap in the shore exposures contained a north-westerly trending fault. However, removal of shingle from around the orebody on the beach revealed that the main outcrop constituted a relatively thin horizon which had been appreciably thickened at that point by the stacking of north-westerly plunging isoclinal minor folds (Fig. 4). Within the outcrop there is a change in the sense of overturning of the folds suggesting that the body is in the core of a small north-westerly plunging fold. Hence its absence east of the shore is more likely to be the result of folding than of faulting.

The constant sense of overturning of minor folds indicates that the whole of the section is situated on the inverted south-east limb of a major antiform and that no major fold closure associated with the minor structures is present in the area studied.

It might be suggested that duplication of a single sulphide horizon could have occurred during a period of folding which pre-dated the formation of the cleavage. However, this would necessitate all minor structures being destroyed by later movements; it is most unlikely, because the style of folding and the relative continuity of the quartzite ribs show that the amounts of deformation would have been insufficient to completely obliterate earlier fold structures.

It is also possible that the sulphide horizon is repeated by strike faulting, but the fact that the section is fairly continuous and that no major crush zone was noted make this unlikely.

The structural evidence points to the conclusion that the sulphide-bearing phyllite at McPhun's Cairn is not the same horizon as that seen at Creggans. There is therefore no indication that a large-scale 'saddle reef' in the nose of a major fold exists under Loch Fyne. There remains, of course, the possibility of minor fold-thickened bodies comparable to, or greater than, that at McPhun's Cairn.

MINERALISATION

McPhun's Cairn

The mineralised outcrop near the former site of McPhun's Cairn is exposed on the beach 950 m north-north-east of Creggans Point. After trenching the mineralisation was seen to have a minimum cross-strike width of 6.5 m and to extend along the strike for at least 7 m (Fig. 4).

The host rock is chiefly siliceous schist with quartzitic bands up to 20 cm thick. Although the quartz has largely recrystallised, micaceous partings within the quartzites indicate an early schistosity. The mineralisation is concordant with the lithological boundaries and reaches its maximum development in the quartzite bands. Where recrystallisation has not completely obliterated the earlier structures the thin sulphide-rich bands are seen to parallel the early schistosity. In places, the mineralisation is clearly seen to wrap around quartz segregation pods, which also have their longer axes aligned parallel to the schistosity. Where the quartz appears to have been remobilised the segregation pods seldom have well defined margins, but frequently have coarsely crystalline sulphide impregnating their outer zones. Only the cores of these segregations are essentially sulphide-free.

Pyrite is the dominant sulphide, forming up to 70 per cent of the rock, with subordinate sphalerite, seldom exceeding 10 per cent, and quartz constituting about 20 per cent. Minor galena and pyrrhotite occur as discrete grains in roughly equal proportions and, together, constitute several per cent of the rock. The textures vary from fine to coarse grained and are characterised by sub- to euhedral pyrite grains, cemented with interstitial base-metal sulphides and gangue. The pyrite is relatively coarse grained, often cataclastic, with grains commonly up to 2 mm in diameter, but scattered individuals may measure 1 to 2 cm where associated with segregated quartz. The galena and sphalerite may be readily identified in hand specimen and can be seen to occur along ill-defined seams in the dense pyrite-rich material. Corrosion and replacement of pyrite by sphalerite and galena has been minimal; it merely occupies the interstices between cubes and broken grains, and infills holes in the cubes. A certain amount of recrystallisation has taken place, with galena and sphalerite exhibiting shapes in accordance with their respective interfacial energies.

A grab sample collected in 1970 from the outcrop yielded the following metal concentrations; Cu: 410 ppm; Pb: 20 900 ppm; Zn: 74 800 ppm; Ni: 55 ppm. 700 ppm arsenic was recorded and it is probably present in the pyrite, as no arsenic phase was seen. The ore is also known (Hill and others, 1905) to contain 75 ppm gold and 6 ppm silver.

A vertical borehole drilled on the beach (Fig. 3, BH 3) to test the down-dip extension and thickness of the mineralised outcrop intersected a mineralised zone between 4.57 and 7.6 m below surface (Fig. 7). This was confirmed by down-hole IP logging, but because the measurements are made at discrete intervals, not continuously, and the core recovery was exceedingly poor (8.5 per cent), it is not possible to assess its true thickness. Only 25 cm of core was recovered in this interval, of which 7 cm was composed of 80 to 90 per cent massive aggregated sulphide. Much of the remaining material consists of folded narrow bands of mineralised calc-muscovite-schist with a sulphide content of 8 to 40 per cent. Mineralogical examination has confirmed that this is a pyrrhotitic ore, forming a massive granular fabric of slightly interlocking anhedral crystals. Unlike the surface outcrop, the grains of this ore tend to show a degree of elongation which imparts a schistose lamination on the rock. Additional sulphide minerals occurring in minor amounts included chalcopyrite (around 1.5 per cent), galena (around 1 per cent) and sphalerite (2 per cent). However, it should be noted that the metal values are typically erratic, and from macroscopic examination of this ore, as a whole, it is evident that chalcopyrite is by far the most common base-metal sulphide in the borehole and commonly occurs as rich 'splashes' within the pyrrhotite and adjacent to the quartz gangue. In contrast to the pyritic ore, the sulphides appear to have grown largely by replacement of the pyrrhotite. No nickel bearing sulphides were identified, which distinguish this ore type from the Cu-Ni ores of Coille Bhraghad and Craignure on the west side of Loch Fyne.

Thus there are two distinctive sulphide assemblages present. The surface outcrop constitutes a pyritic ore, with sphalerite and subordinate amounts of pyrrhotite and galena. The down-hole mineralised intersection is essentially a pyrrhotitic ore, with chalcopyrite and sphalerite occurring in erratically varying proportions to each other. Galena is generally rare and pyrite wholly or nearly absent.

Pyritic and pyrrhotitic ore types are present in many of the worlds Palaeozoic fold mountain belts including the Norwegian Caledonides (Stanton, 1972; Vokes, 1962). In its Caledonian setting the McPhun's Cairn occurrence, though on a much reduced scale, strongly resembles the stratabound sulphide mineralisation of the Roros district Norway (Rui and Bakke, 1975), where there is also a similar close association of pyritic and pyrrhotitic ore types.

MINOR SULPHIDE HORIZON

A somewhat smaller sulphidic horizon inland, detected initially by IP and geochemical anomalies and subsequently proved by boring (Fig. 3, BH 1 and 1A), gives a better indication of the close relationship of pyritic and pyrrhotitic ore material. It is approximately 1 cm thick (Fig. 8) and consists of varying proportions of pyrite, pyrrhotite, galena, sphalerite and chalcopyrite in a quartz and/or carbonate gangue.

Evidence of distinct banding or zoning is apparent in BH 1A (Fig. 8), where small-scale mobilisation of some of the constituent sulphides together with varying proportions of quartz and carbonate is well displayed. Chalcopyrite, pyrrhotite and to a lesser extent sphalerite seem to have been particularly mobile. A comparable section through the same horizon with rather less mobilisation is proved by BH 1 (Fig. 8). There the horizon comprises a 1 cm band of aggregated sulphide containing mostly pyrite, pyrrhotite and sphalerite, with only a little galena. The sulphide assemblage is equivalent to the thin band above the micaceous parting in BH 1A and is a similar ore type to the McPhun's surface outcrop. It is evident (Fig. 8) that chalcopyrite mostly occurs outwith the mineralised band. In a 4 cm zone below 2.96 m it often accompanies quartz and pyrrhotite in tiny irregular fractures, providing further evidence of late stage mobilisation. The essential features to be noted are that the band is dominantly pyritic and that the interstitial sulphides have moved relative to the pyrite. Pyrrhotite dominates below the mineralised band while galena is clearly concentrated along the upper contact.

Reorganisation of the mineral assemblage has taken place during or subsequent to Caledonian regional metamorphism. The mineralised band also appears to have been brecciated; semi-concordant schist inclusions and quartz blebs are enclosed in the sulphidic matrix. Brecciation is also a common feature of Norwegian pyrrhotitic ores (Vokes, 1962; Rui and Bakke, 1975). In the pyrrhotitic ore from BH 3 there is no clear evidence of brecciation but there are abundant inclusions of clear quartz, typical of Roros pyrrhotitic ores.

From the logs of BH 1 and BH 3 (Appendix IV) it would appear that the schist is more muscovite adjacent to the ore-bearing horizons with the development of thin bands of white mica. However, it should be noted that coarse muscovite is occasionally seen elsewhere and is not necessarily associated with mineralisation. Internal zones of abundant muscovite occur in the Killingdal mine (Rui, 1973), though the sulphide deposits of Roros are more usually surrounded by halos of chlorite-rich schists.

OCCURRENCE OF SULPHIDES OUTWITH THE MINERALISED HORIZONS

Within the Ardrishaig Phyllite formation, outwith the mineralised horizons, iron-sulphide is a common accessory constituent of both argillaceous and siliceous lithologies. Finely disseminated pyrrhotite is the most abundant sulphide and occurs throughout much of the sequence, particularly in the micaceous phyllite. It is seen as specks and patchy smears of folia, but is noticeably concentrated in lenticles of finely granular quartz, carbonate and epidote. With increasing concentration, the form of the pyrrhotite ranges from a few sporadic specks and patches, through discontinuous seams and threaded areas, to distinct laminae of solid pyrrhotite. The parallelism of the micas has tended to inhibit the cross-foliation sulphide migration. In thin section it is evident that pyrrhotite and calcite were the most mobile constituents during tectonism. Small-scale mobilisation and replacement has taken place in the granular layers, and rounded relicts of original quartz may be seen in bands flooded with pyrrhotite and calcite. Within the micaceous phyllites, the development of pyrrhotite is particularly conspicuous in the quartz - carbonate segregations (Appendix I). It generally occurs at the margins of the segregations or at the contact of quartz and carbonate within them, and takes the form of thin seams or sizeable clots.

Pyrrhotite is only sparsely distributed in the quartzite bands. The thin greenish calc-quartzite horizons (Appendix I) usually contain more sulphide than the massive, compact, white quartzites. Even so, the sulphide is mostly confined to the micaceous partings within the quartzite. Thus the thinly banded micaceous quartzites are often relatively enriched in pyrrhotite. Where these rocks are highly contorted, recrystallised and segregated pyrrhotite occurs in prominent streaks.

Pyrite is distinctly subordinate to pyrrhotite, with which it is usually associated. Its granular texture is better preserved, particularly within the thin aggregated polymetallic sulphide layers and where it is sparsely disseminated in the siliceous matrix of some quartzite bands. The occurrence of pyrite is particularly evident along some joints and brittle fractures in the gorge sections of Allt Sean Roib (Fig. 2), where it is frequently accompanied by iron oxides and sometimes trace amounts of chalcopyrite and sphalerite.

Chalcopyrite is a very mobile phase during metamorphism (Vokes, 1968) and in the Ardrishaig Phyllites is most commonly seen in trace amounts coexisting with pyrrhotite in quartz ± carbonate segregations. Occasionally galena is also found accompanying the pyrrhotite, as in the upper Allt Bealachuisge section (Fig. 3). Thick coatings of secondary iron oxides on some joints generally indicate weathered sulphide and at 65E/200S (Fig. 3) galena has survived as patches in limonite. However, unlike chalcopyrite, galena specks are also seen occasionally within the quartzite, notably on the shore near Aird Cottage and in the upper 2 m of BH 1. Fine-grained dark sphalerite is exceedingly difficult to identify in the field, particularly when associated with pyrrhotite and, therefore, its distribution is difficult to assess. However, it has been noted in very thin sulphidic seams, within the micaceous phyllites which crop out in the stream between 60E/75S and 75E/65S (Fig. 3), where it is mainly associated with pyrite. Its rare occurrence on some joints and its presence in the quartz-carbonate segregation, adjacent to the mineralised band in BH 1A (Fig. 8), show that is has been mobilised to a limited extent.

APPENDIX II: GEOPHYSICAL SURVEYS

THE MEASUREMENTS

The location of geophysical traverses is shown in Fig. 2 where the mineralised outcrop is at the origin, M. The surveys consisted of measurements of the earth's total and vertical magnetic field, and of induced polarisation (IP) and resistivity. Some electromagnetic measurements were made, but these showed no appreciable anomalies.

An Elsec proton magnetometer was used for total field measurements, expressed here in gammas (Fig. 9), where 1 gamma = 1nT (nanotesla). Where these were unobtainable in regions of very steep magnetic gradients, vertical field readings were made with a Jalander fluxgate magnetometer. Readings were taken at separations varying from 1 to 10 m, and instrument and diurnal drift were estimated by repeated readings at base stations at intervals of not greater than 90 minutes. Magnetic measurements on Loch Fyne were made with the detector bottle attached to the prow of a fibre-glass rowing boat. The distance of the boat from the nearest grid line (Fig. 2) was checked with a tape at the start of each traverse and visual estimation was used to keep this distance approximately constant while the tide and wind carried the boat towards the head of the loch. Radio communication between the boat and the shore provided an estimate of the boat's position on line, and inaccuracies were probably not more than 5 m.

The bulk of IP readings were taken using Huntec Mk III time-domain equipment, which measures chargeability and the remainder (because of instrument breakdown) with Geoscience Inc. frequency-domain equipment. Chargeability and frequency effect are equivalent parameters. Depth soundings along selected traverses were made with a dipole-dipole electrode array using dipole lengths of 15 or 30 m. Anomalous trends were defined with a gradient array survey, using a current electrode separation of 1000 m and a measuring (potential) electrode separation of 20 m.

Since the object of the geophysical survey was to trace the possible extension of the mineralised outcrop inland, IP and magnetic measurements were first made along line O across the outcrop to define its geophysical response. A traverse along line 75E revealed IP and magnetic anomalies (Fig. 14) whose association with the outcrop anomaly was not obvious, so additional measurements were made nearer to the shore at fairly close spacing.

MAGNETIC SURVEY RESULTS

Contours of the intensity of the earth's total magnetic field above a datum of 40 000 gamma are shown in Fig. 9.

There are a number of high amplitude, short wavelength anomalies particularly in the west of the survey area with fewer and less well defined anomalies to the north and south. The central part of the area shows relatively little magnetic variation.

On the beach the mineralised outcrop is characterised by a positive anomaly of about 400 gamma (Fig. 10) and the outcropping Tertiary dykes by negative anomalies of similar amplitude. It is likely that most, if not all, of the larger anomalies to the east of the road arise from concentrations of pyrrhotite, which is very common in the area surveyed. The trend of the anomalies is generally about east-west.

The simple positive anomaly across the mineralised outcrop on the beach extends westward for at least 80 metres into the loch, but the magnetic field is greatly attenuated by the depth of water below the detector, and so is not prominent on the magnetic field map. The anomaly also appears to extend eastwards across the road, but less than 50 m inland it is complicated by a large (almost 10 000 gamma peak to peak) negative magnetic anomaly. The magnetic field contours in this region are shown in more detail in Fig. 10, those in the region of steepest gradient being estimated from vertical field measurements, as total field readings were unobtainable. This large anomaly has a shape similar to that which would be caused by a prismatic body, highly magnetised in a direction nearly opposite to the direction of the earth's field and at a depth of 5 to 10 m below the surface, and is unlikely to be artificial.

The possible eastward extension of the anomaly over the mineralised outcrop is indicated by the dashed line in Fig. 10. The borehole which was drilled to investigate this, however, (see below, BH 2) did not intersect significant mineralisation, showing that this apparent alignment of anomalies east and west of the road is not caused by an extension of the mineralisation outcropping on the beach. The borehole was probably sited too far north or not continued far enough to intersect the source of the large magnetic anomaly.

INDUCED POLARISATION AND RESISTIVITY SURVEY RESULTS

Figs 11, 12 and 13 show plots of resistivity, chargeability and specific capacity from a gradient array survey. The main feature is the east-west trending zone of high chargeabilities and low resistivities extending across the central part of the area. The maximum measured chargeability is 186 ms compared to background values, to the north and south, of around 40 ms. A pronounced local anomaly occurs over the mineralised outcrop. The sea has some effect on the measurements made in the extreme west, on the beach, particularly on resistivity measurements using the gradient array (Fig. 11), where it tends to mask the effect of the mineralisation.

The negative IP effects flanking the anomaly over the mineralised outcrop may result from electromagnetic coupling due to sea water. Such effects can also arise from negative electrode polarisations (Phillips and Richards, 1974) or geometrical effects arising from the electrode positions relative to the mineralisation (Bertin and Loeb, 1969).

Dipole-dipole array measurements made along lines 75E and 205E indicate that the source of the large chargeability anomaly is shallower in the east (probably less than 10 m deep) than in the west, and dips towards the north. Borehole 1 was sited to investigate this anomaly.

BOREHOLE EVIDENCE

The positions of the three boreholes are shown in Fig. 3. BH 1 was drilled to investigate the extensive IP anomaly and BH 2 to find out whether the apparent eastward trend of the magnetic anomaly over the beach outcrop represented an extension of the mineralisation. BH 3 was sited to intersect the down-dip extension of the mineralised zone on the beach.

In each borehole, IP and resistivity measurements were made. They indicate (Figs 6 and 7) that the extensive IP anomaly intersected by BH 1 arises principally from minor amounts of sulphides (mainly pyrite and pyrrhotite) within the top 8 m. The 1 cm mineralised band (Figs 6 and 8) at a true depth of 2.9 m coincides with the highest chargeability and lowest resistivity measured in the hole; this band is accompanied by a sparsely sulphidic envelope up to 0.8 m on either side. Because of the low core recovery it was not possible to explain all of the borehole IP anomalies, for example that at 13.5 m in BH 1. The mineralisation occurs finely disseminated in thin seams, which explains why substantial IP effects are measured on the surface over relatively low grade mineralisation. The IP effect depends on the total surface area of contact between electronic-type conduction (as in sulphides) and electrolytic-type conduction (as in fluids), that is, effectively on the total surface area of sulphides. BH 2 (Appendix IV, Fig. 3) could not be logged satisfactorily because of water loss in a porous zone between 14 and 17 m. In particular the hole was dry above 7.5 m where any sulphide concentrations were thought most likely to occur. From the geological log (Appendix IV) it can be seen that sulphide occurs in variable, though very minor, amounts above 5.49 m (vertical depth equivalent; 4.2 m). Further evidence of the near surface occurrence of sulphide is provided by an 0.8 cm thick disc of mineralised rock found amongst the broken fragments of the weathered zone. Between 9 and 10 m the geological log indicates 'abundant pyrrhotite along micaceous partings'. However, the alignment of the magnetic contours at this point with those over the mineralised outcrop (Fig. 10) is apparently fortuitous. The source of the prominent magnetic anomaly immediately to the south was not penetrated (Appendix II).

In BH 3 the IP profile (Fig. 7) corresponds closely to the mineralisation in the core but cannot be related directly to the amount of sulphide present (up to 90 per cent) as the readings go off-scale through the mineralised zone.

APPENDIX III: GEOCHEMICAL SURVEYS

INTRODUCTION

Following work by the Applied Geophysics Unit and the Highlands and Islands Unit at the locality, a limited number of geochemical samples were collected in October 1974.

DRAINAGE SAMPLES

From the small streams draining into Loch Fyne about the locality, stream sediments (-100 mesh) and panned concentrates (-30 mesh) were collected at locations shown on Fig. 1. These were analysed by X-ray fluorescence spectrometry for Cu, Pb, Zn and Ni. Results are given in Table 1 and plotted on Figs 15 to 18. Comparison with the values obtained from the regional sampling shows that none of the stream sediments have anomalous metal values, but that some marked panned concentrate anomalies are present. Samples 677 and 686, north and south of the mineral showing respectively, are enriched in Cu, Pb, Zn and Ni, particularly Pb in sample 686 (1443 ppm Pb). Sample 688, over 500 m north of the outcrop, is similarly anomalous in these elements and, in fact, has the highest copper and nickel contents in the area. This would suggest a possible northward extension of the mineralisation, but a change in its geochemical nature. Sample 693, near Aird Cottage, is also anomalous in Cu, Pb, Zn, Ni and was further reported as containing 560 ppm As. This indicates the occurrence of similar, but geochemically distinct mineralisation, perhaps of a more basic character and related to the epidiorites of that area.

The occurrence of panned concentrate anomalies unaccompanied by stream sediment anomalies points to the presence of relatively small discrete sources of mineralisation a short distance (< 500 m) upstream from the sampling sites. This mineralisation could either be bedded, fault in-fill or joint coatings of sulphide.

SOIL SAMPLING

Soil samples were collected only in the vicinity of the sulphide outcrop within the area of the geophysical survey. Away from stream courses, cover was generally from 1 to 2 m thick, consisting of an A horizon of forest litter 10 to 15 cm thick, an irregular B horizon 15 to 20 cm thick and a gleyed C horizon developed in clay rich till and solifluction debris. Soil was collected by hand auger from the C horizon at an average depth of 79 cm, as it was considered that such material would give the most direct response. Analyses were by atomic absorption spectrophotometry for copper, lead, zinc and nickel. Low metal values, especially for the less mobile lead, were expected in this environment.

Results are shown as contoured diagrams (Fig. 19 to 22) at the same scale as the diagrams in the geophysical section. No definite anomalous zone extending from the sulphide occurrence is delineated, but some tenuous patterns do emerge. Generally, values are not high, but some anomalous values are present. For copper (Fig. 20), there are anomalies at 50E/280S (275 ppm Cu) and 250E/0 (170 ppm Cu). Such values normally indicate the presence of discrete copper mineralisation. For lead (Fig. 22), the two main areas of above average values extend inland as zones north and south of the occurrence which contain anomalous values at 250E/80W (160 ppm Pb) and 50E/200S (200 ppm Pb). Zinc (Fig. 19) is the only element to indicate a possible zone extending from the occurrence and contains anomalous values at 100E/20S (220 ppm Zn) and 200E/80N (160 ppm Zn). Nickel (Fig. 21) exhibits no pattern of high values. The coincident lead, zinc and minor copper anomaly at 250E/80N was recommended as a shallow drilling target. Coincident high Cu, Pb and Zn values are also present at 20E/80W, 150E/50W, 100E/20S, 50E/190S and 150E/20S and may indicate the occurrence of similar mineralisation.

ROCK SAMPLES

A small suite of rock samples was collected from the McPhun's Cairn outcrop and from other showings of sulphide along the shore section to the north and south. Analyses of these are shown in Table 2A. Apart from minor chalcopyrite in a quartz vein, all samples, other than those from the mineralised outcrop, show low metal values. The massive sulphide is dominantly a zinc and lead ore.

DRILL CORE

On the basis of the geophysical, geological and geochemical results, three shallow holes were drilled. Samples of the mineralisation recovered were provided by the Highlands and Islands Unit for analysis. Results are shown in Table 2B. Although similar to the metal values determined in the surface samples in that zinc and lead are the most important elements, copper is relatively higher with a maximum value of 3552 ppm Cu. The high metal values in the upper sections of boreholes 1 and 1A (samples 794 and 796) confirm that the weak geochemical anomaly drilled is directly related to mineralisation. Other soil geochemical anomalies specified above may thus be inferred to relate directly to weak mineralisation.

Table 1. McPhun's Cairn drainage samples

Number	Stream sediments, ppm				Panned concentrates, ppm			
CZC, P	Cu	Pb	Zn	Ni	Cu	Pb	Zn	Ni
677	26	40	222	34	136	296	410	184
686	18	30	117	22	181	1443	186	353
688	27	33	177	35	224	337	251	355
689	28	30	170	37	94	174	123	85
690	15	26	208	41	33	9	132	36
691	12	26	175	28	70	33	125	123
693	23	20	104	29	151	281	196	224
694	15	7	101	25	65	50	97	76
Regional threshold	48	55	310	(140)	122	97	188	(160)

Note 1. Regional threshold for Cu, Pb and Zn based on mean plus two standard deviations on log transformed values of 500 samples from Argyllshire and Perthshire. Nickel threshold based on North Scotland data

2. All analyses by X-ray fluorescence

Table 2A. McPhun's Cairn rock samples

Number	Locality	Cu	Pb ppm	Zn	Ag	Ni	As
9001	Creggans Point - disseminated pyrite	15	40	30	-	25	-
9002	North of Creggans Point - quartz vein with pyrrhotite and minor chalcopyrite	250	20	30	-	100	-
9003	McPhun's Cairn sulphide	410	20 900	74 800	-	55	700
1308	McPhun's Cairn sulphide	370	56 000	51 500	30	200	0
9004	Ardnagowan Cottage - disseminated pyrite in phyllite	10	130	390	-	60	-
9005	Ardnagowan Cottage - disseminated pyrite in epidiorite	60	60	160	-	100	-

Note: analyses by atomic absorption spectrophotometry

Table 2B. McPhun's Cairn drill core

Number CZD	Borehole	Interval (m)	Recovery %	Cu	Pb	Zn ppm	Ni	Fe %
790	3	3.66-4.57	23	117	1	204	33	6.23
791	3	4.57-7.62	8.5	3552	9687	16 746	125	16.95
792	3	7.62-10.67	8	126	107	1018	25	6.31
793	2	1.83-3.66	19	81	86	543	27	5.60
794	1	1.52-3.05	26	101	1210	6081	14	4.39
795	1	3.05-4.27	41	152	13	295	15	5.62
796	1A	1.52-3.05	25	791	885	3084	16	4.74

Note 1. Analyses by X-ray fluorescence

2. Sample 791 also contained 12 ppm Ag and 115 ppm Co

APPENDIX IV: Bore Logs

SECTION OF MCPHUN'S BOREHOLE NO. 1

Inclined Borehole 80° toward 180° Mag

Surface Level approx. 32 m O.D.

Communicated October 1975 by Institute of Geological Sciences

Date of boring or sinking March 1975 Borer Geochemical Division, IGS

One-inch Map 37 Six-inch Map Argyll 141 NW NN 00 SE (N)

958116 4M 2/75 J.F.&S. 275

Thin Sections		Thickness (Metres)	Depth from Surface (Metres)
	Upper 50% of recovered material in this section comprises assorted weathered fragments of white quartzite, greenish calcareous quartzite, segregation quartz and a few discs of sericite schist; all with rusty limonitic staining. Thin films and seams of pyrite, pyrrhotite and ?sphalerite along micaceous foliae. A few specks of galena associated with the quartzite and recrystallized quartz. Some haematite with limonite along fractures. Black manganese oxides also present in places. Foliation intersection 65° Fresh rock: slightly deformed white to pale greenish grey calcareous quartzite with smears of pyrrhotite along micaceous foliae, passes downwards into calcareous chlorite sericite schist with a number of coarse muscovite planes along which the core divides. Thin seams of sulphide (≤ 1 mm thick) carry pyrite, pyrrhotite with chalcopyrite sphalerite and trace galena. Thin zone of pale green calcareous quartzite with thin compositional banding/sandwiched by recrystallized micaceous quartzite. A little pyrite, pyrrhotite and dark sphalerite present. Calcareous quartz muscovite schist with prominent muscovite foliae. Pyrite with some pyrrhotite, chalcopyrite and sphalerite in thin seams along the foliation which is perpendicular to the core axis. Recovery 24%	2 95	2 95
	Band of aggregated sulphide, mostly pyrite and sphalerite plus a little pyrrhotite and galena. Small riders or broken fragments of micaceous material are immersed in the sulphidic matrix.	0 01	2 96
	Interlaminated coarse muscovitic material and thin psammitic layers. Sulphide occurs in very thin impersistent seams along the foliation consisting mainly of pyrrhotite, sphalerite and minor pyrite. Small irregular fractures contain quartz with pyrrhotite and chalcopyrite.	0 04	3 00
	c/forward	3 00	

Thin Sections		Thickness	Depth from Surface
		Metres	Metres
	b/forward	3 00	
	Pale green, hard, blocky calcareous quartzite with rare pyrrhotite on micaceous partings and a little fine grained pyrite/pyrrhotite along recrystallized quartz laminae. Foliation intersection 78°		
	1 cm disc of coarse muscovitic schistose material with discontinuous laminae of segregated quartz containing much disseminated pyrrhotite and chalcopyrite plus minor pyrite.	1 20	4 27
	Compact greenish micaceous calcareous quartzite with seams carrying pyrrhotite, pyrite, sphalerite together with small clots and patches of chalcopyrite. The calcareous quartzite is truncated by a shear plane (73° to core axis) oblique to the foliation (intersection 65°). The sulphide which is concordant with the foliation also abuts against the shear plane. Resumption of coarse muscovitic material with small fracture containing chalcopyrite (1 mm thick) and thin seams and streaks of pyrrhotite along the foliae. Pyrrhotite plus minor chalcopyrite also developed at the quartz-carbonate interface of segregated material.		
	13 cm of pale green medium grained calcareous quartzite which may be an original grit. Sulphide is generally scarce with the exception of an intervening band of coarse muscovitic material containing thinly banded finely disseminated pyrrhotite plus trace chalcopyrite.		
	Interlaminated coarse micaceous sheaves and foliae sandwiching thin, often lenticular calcareous psammitic laminae. Some very thin calcareous quartzites present. Undulose foliation. Sulphide very rare. Core Recovery 41%.		
	Fragmented material of the same rock type as above. Rounded, oblate and lenticular quartz segregations separated by thin films or wedges of micaceous material. Some patches of pyrrhotite.	1 83	6 10
	Micaceous calcareous quartzite with very tight minor fold closures axial planar to the foliation. Thin seams of pyrrhotite along the micaceous foliae. Undulose foliation intersection 68°.		
	c/forward	6 10	

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SECTION OF MCPHUN'S BOREHOLE NO. 1

Six-inch Map (County and Quarter Sheet) Argyll 141 NW NN 00 SE (N)

Thin Sections		Thickness Metres		Depth from Surface Metres	
	b/forward	6	10		
	Laminated micaceous material with thin planar or lenticular quartz and/or carbonate segregations. A few small patches of pyrrhotite. 25 cm: Fragmented pale green calcareous quartzite with smeared specks of pyrrhotite on foliae passing into blocky calcareous quartzite which may be an original grit. It is very pale greenish grey in colour, medium grained with some grading. Directional fabric. A little fracturing. Some free carbonate. Recrystallized quartz laminae. Sulphide more or less absent. 2 cm disc of laminated micaceous material with pyrrhotite smeared on foliae particularly at the margins of the psammitic lenticles. Core Recovery 22%				
	Flaky crenulated calcareous chlorite muscovite schist with coarse muscovitic bands and thin laminae and lenticular quartz ± carbonate segregations. Thin discontinuous seams of pyrrhotite along foliae. A little pyrite and trace chalcopyrite also present. Large irregular quartz/carbonate knot contains a large elongate patch of pyrrhotite. 9 cm of very pale greenish grey thin platy calcareous quartzite with micaceous partings. (Laminated micaceous quartzite.) Rare pyrrhotite on micaceous foliae. 2 cm quartz-carbonate segregation with some chloritic selvage contains a few patches of pyrrhotite at the quartz-calcite interface. Core Recovery 8%	2	30	8	40
	Fairly massive blocky quartzite. Initially some diffuse greenish banding but becoming more homogeneous and lighter in colour with depth. The lower 21 cm is essentially white quartzite. Directional fabric. A little fracturing. Rare pyrite on micaceous partings or associated with thin recrystallized quartz laminae.	0	33	8	73
	c/forward	8	73		

Thin Sections		Thickness Metres		Depth from Surface Metres	
	b/forward	8	73		
	Platy micaceous quartzite passing downwards into calcareous chlorite sericite schist with quartz ± carbonate segregations containing patches of fine grained pyrite/ pyrrhotite. The rock is very fragmented: evidently a lot of core loss. Recovery 3% Two pieces of greenish banded calcareous quartzite at the end of this section.	2	85	11	58
	9 cm of small blocky fragments of white quartzite becoming greenish grey and more calcareous with depth. Strong directional fabric. Pale green calcareous quartzite with thin discontinuous seams and streaks of pyrrhotite/minor pyrite. Patchy smears on foliation partings. Some wandering hairline fractures infilled by quartz. Foliation intersection 64°. Core Recovery 10%.	3	52	15	20
	Massive white quartzite. Rare tiny cubes and patches of pyrite.	0	13	15	33
	Very fragmented core: micaceous quartzite and calcareous chlorite sericite quartz schist passing downwards into bent and contorted calcareous chlorite sericite schist. Pyrrhotite common as smears on micaceous foliae and as specks in thin psammitic laminae. Carbonate is a conspicuous constituent of the lower 26 cm of core. Finely disseminated sulphide is present in some lenticles of free carbonate. Core Recovery 28%.	1	74	17	07
	END OF BOREHOLE			17	07

NOTE These rocks belong to the Ardrishaig Phyllite formation. The micaceous material (which was mostly lost cf. the quartzite) shows all gradations from schist to phyllite, but for convenience the term 'schist' is used throughout this log.

SECTION OF McPhun's borehole no 2

Inclined borehole 50^{0} toward 180^{0}

Surface Level approx 10m O.D.

Communicated Oct 1975 by IGS

Date of boring or sinking April 1975 Borer IGS Geochemical Division

One-inch Map 37 Six-inch Map Argyll 141 NW NN 00 SE (N)

958116 4M 2/75 J.F.&S. 275

	Thickness Metres		Depth from Surface Metres	
Weathered zone	1	83	1	83
0-10cm: Broken fragments (discs) of rusty calc chlorite sericite schist plus a few quartz fragments. 0.8cm disc of mineralised rock. Threaded sulphide consisting mainly of fine pyrrhotite and chalcopyrite surrounding clots of free carbonate and quartz. Some minor sphalerite and trace galena is also present.				
10-25cm: three core lengths. 3cm segregation of admixed quartz and calcite sandwiching small riders of schist. Small fine grained patches of pyrrhotite with trace pyrite and chalcopyrite sometimes in or adjacent to the schist relicts. Sulphide generally scarce. 7cm of segregated quartz with rusty iron staining. Fractures with films of haematite, along which the quartz readily breaks. Some rare films of pyrite. Rather rotten chlorite selvage survives in some cavities. 5cm of compact calc sericite (chlorite) schist. Relatively fresh rock: only a few narrow rusty bands concordant with the foliation (52^{0} to core axis). Sulphide very rare to absent. Core recovery 13.5%				
Fresh rock.				
0-18cm: Calc chlorite sericite schist with thin siliceous laminae	1	83	3	66
6cm of flaky-platy schist with thin recrystallised quartz laminae and lenticles/blebs of carbonate. Very tight-isoclinal minor/micro folding axial planar to the foliation. Irregular patches and seams of pyrrhotite along the foliae. Pyrite and trace chalcopyrite also present.				

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SECTION OF McPhun's borehole no 2

Six-inch Map (County and Quarter Sheet) Argyll 141 NW NN 00 SE (N)

	Thickness Metres		Depth from Surface Metres	
3cm of segregated quartz and minor calcite with some chlorite and coarse muscovite selvage. Small riders of relict schist, No sulphide. 6cm of flaky-platy schist with rare sulphide. 3 cm of schist containg finely disseminated and threaded pyrrhotite. Sulphide also occurs as smears on foliae and sometimes borders the siliceous laminae. 18-22cm: Pale greenish grey fine grained calc quartzite. Distinct colour banding due to minor amounts of micaceous material which contains finely disseminated pyrrhotite. Carbonate infills hair line fractures and tension gashes. 22-35cm: Buckled flaky-platy calc chlorite sericite schist with small blebs of carbonate and thin calcite filled fractures. Sulphide generally scarce but for a few threaded seams of pyrrhotite. Core recovery 19%	1	83	3	66
0-25cm: Flaky-platy calc chlorite sericite schist with an indistinct lamination. Some small lits of recrystallised quartz-carbonate. Irregular seams and streaks of pyrrhotite often bordering the thin siliceous laminae or lenticles of carbonate. Sometimes the seams merge into areas of rich pyrrhotite dissemination 25-26cm: Quartz segregation 26-33cm: White to pale green thinly banded calc quartzite with a few micaceous partings. Some minor folding and buckling. A few thin seams of pyrrhotite (0.5mm thick) are very persistent along the foliation and are offset by calcite filled fractures. 33-43cm: Thin broken discs of flaky-platy calc chlorite sericite schist with a slightly undulose foliation. Sulphide is generally sparse. One disc (o.6cm thick) is notably rich in sulphide. Dense dissemination and a 2-3mm aggregated seam of pyrite-pyrrhotite. The sulphide surrounds small clots of calcite. Core recovery 24%	1	83	5	49

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SECTION OF McPhun's borehole no 2

Six-inch Map (County and Quarter Sheet) Argyll 141 NW NN 00 SE (N)

Thin sections		Thickness Metres		Depth from Sur Metres	
	Flaky-platy calc chlorite sericite schist with blebs of recrystallised carbonate. Slight flexuring of the foliation. (70^o to core axis) Sulphide sparse to absent Core recovery 12%	2	13	7	6
	<u>0-36cm:</u> Continuous section of core <u>36-42cm:</u> Fragmented core 2cm quartz segregation with large patches of coarse pyrrhotite occurring in assocation with interstitual carbonate or at the contact with the schist. Calc chlorite muscovite schist with a fine compositional lamination defined by the coarse muscovite layers. Small areas impregnated with remobilised carbonate. Sulphide is very scarce (a few specks of pyrrhotite) Foliation intersection 50^o <u>42-47cm:</u> Thinly banded pale greenish calc quartzite with micaceous partings. Some highly contorted handed quartzite with abundant pyrrhotite along the partings passing downwards into fairly uniform tight grey calc quartzite (3cm) and then 3 cm of soft schistose material. Thinly banded very pale greenish grey calc quartzite with diffuse seams and discontinuous streaks of pyrrhotite (54.5-57cm) <u>57-110cm:</u> Fairly compact dark grey-green calc chlorite sericite schist. Sparse sulphide; patchy smears on foliae and irregular patches associated with quartz carbonate segregations	3	35	10	9
TS62015 (DX81) (103cm)	Thin quartz and minor carbonate segregations at 85cm, 97cm and 106.5-110cm Foliation intersection 64^o Core recovery 34%				
	Very fragmental calc muscovite schist with some muscovite development. Sulphide very scarce Very poor recovery of core 7%	2	75	13	7
	Muscovite schist (hydromica schist) and some quartz muscovite schist (recrystallised quartz laminae separated by narrow bands or partings of coarse muscovite). Minor carbonate. Sparsely distributed patches and specks of pyrite/pyrrhotite Core recovery 100%	0	27	13	9

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SECTION OF McPhun's borehole no 2

Six-inch Map (County and Quarter Sheet) Argyll 141 NW NN 00 SE (N)

	Thickness		Depth from Surface	
	Metres		Metres	
C/F			13	99
Greenish slightly calcareous quartzite. Sulphide absent. Core recovery 100%	0	12	14	11
Soft porous zone: water completely lost. Exceedingly poor core recovery 3% (A few broken fragments of muscovite schist and quartz muscovite schist).	2	96	17	07
Platy calc chlorite sericite schist with rare seams of pyrrh otite along foliae 12-19cm: Rock becoming more quartzitic with depth 19-25cm: Thinly banded white greenish calc quartzite. A few prominent seams of pyrrhotite along the micaceous partings. Calcite infills fractures. Foliation intersection 73° Core recovery 16%	1	52	18	59
0-3cm: Flaky-platy dark calc chlorite, sericite schist with a prominent seam (2mm) of threaded pyrrhotite. Foliation inter-section 45° 3-24cm: Light grey-bright green variably banded calc quartzite with thin diffuse carbonate seams. Occasional development of small patchy smears of pyrrhotite on micaceous foliae A number of thin seams of pyrrhotite (18-22cm) Foliation intersection 72°. Core recovery 19%	1	26	19	85
END OF BOREHOLE			19	85

Note

These rocks belong to the Ardrishaig Phyllite formation. The micaceous material shows all gradations from schist to phyllite, but for convenience the 'schist' is used throughout this log.

SECTION OF McPhun's borehole no 3

Vertical Borehole

Surface Level OM O.D.

Communicated Oct 1975 by IGS

Date of boring or sinking April 1975 Borer IGS Geochemical Division

One-inch Map 37 Six-inch Map Argyll 141 NW NN 00 SE (N)

958116 4M 2/75 J.F.&S. 275

[Th]in Sections		Thickness Metres		Depth from Surface Metres	
	Sand and shingle. No recovery	1	30	1	30
	Assorted fragments of calc chlorite sericite schist and segregated quartz/carbonate with minor amounts of calc quartzite. The fragments are fairly fresh. No sulphide in the schist. A few patches of pyrrhotite in or at the margins of the segregations. Core recovery 10%	2	36	3	66
	Fairly soft, flaky calc chlorite sericite schist with occasional muscovite development. Some diffuse seams of free carbonate. Sulphide is quite common throughout. Small sporadic patches or specks, and discontinuous seams of pyrrhotite which sometimes merge to form threaded areas in the rock. Foliation dip 8^{o} 4.5-6cm: Schist interleaved with segregated quartz containing a fairly large patch of pyrrhotite/chalcopyrite Also a prominent seam of solid pyrrhotite in the schist nearby. No obvious enrichment of sulphide with depth. Core becoming more fragmented towards the base of this section. Core recovery 23%	0	91	4	57
	MINERALIZED ZONE (precise thickness unknown) Abrupt change to highly mineralised rock. 0-2cm: Calc sericite schist with recrystallised quartz/ carbonate. Some intense buckling and folding. Concordant seams of sulphide, predominantly galena/ sphalerite. Some areas flooded with sulphide - mainly pyrite and pyrrhotite with subordinate galena and sphalerite. Sulphide in the flooded areas occurs either as a dense skeletal nework or as solid welded masses. Total sulphide content approximately 30% 2-4.5cm: Compact calc chlorite sericite schist with seams and spots of carbonate. Abundant seams of pyrrhotite along foliae which sometimes coalesce into small patches or merge into a threaded network. Total sulphide content 10-15%	2	05	7	62

	Thickness	Depth from Surface
	Metres	Metres

TS62013 — Depth from Surface: 7 62
(DX79) 4.5-8cm: Andalusite sillimanite cordierite biotite
hornfels :BEACH PEBBLE FROM SURFACE? Break in drill
run may possibly indicate an approximate depth of 6.4m
8-15cm: Mineralised muscovite schist with a few bands
and lenses of segregated quartz. Some fairly coarse
muscovite development. The sulphide is generally
concordant with the foliation where it is restricted
to the granular quartzite material interstitial to
the coarse muscovite sheaves. The sulphide pervades
the granular matrix producing a closely threaded network.
From 8-12 cm the rock contains mainly pyrite/ pyrrhotite
with minor amounts of sphalerite and chalcopyrite and
traces of galena. The chalcopyrite is dominantly
associated with quartz segregations.
Total sulphide content 35-40%
From 12-15 cm the rock is less mineralised but the
sphalerite and galena are better developed. No
chalcopyrite present.
Total sulphide content approximately 8%
PTS 15.5-22.5cm: Massive ore with 80-90% sulphide.
Predominantly pyrrhotite with lesser amounts of
pyrite, chalcopyrite and sphalerite and subordinate
galena. Some small patchy areas of quartz and
carbonate. The pyrrhotite is generally fine grained
and clearly demonstrates a planar fabric on broken
surfaces. Chalcopyrite forms diffuse wispy patches
and also occurs adjacent to the gangue.
Sphalerite develops the largest grain size and is
mostly found in or at the margins of the quartz/
carbonate gangue, accompanied by smaller amounts
of galena.
Dark acicular crystals of probable amphibole aligned
with the foliation.
Remainder of section*: Small broken fragments of
schist, calc quartzite and segregated quartz/ carbonate
which are relatively unmineralised. Some patchy
pyrrhotite and sphalerite associated with the
segregations.
*NB These fragments may not belong to this section:
marker may have moved.
Core recovery 8.5%

0-3cm: White-green calc quartzite with crenulated — Thickness: 3 05 — Depth from Surface: 10 67
micaceous partings.
Foliation dip 26°
3-25cm: Calc chlorite muscovite (sericite) schist
Some well developed thin bands of coarse muscovite
sandwiching the granular siliceous material.
Sulphide sparse (0-17cm).... a few thin seams of
pyrrhotite along foliae.
From 17-25cm
Total sulphide content approximately 5%
Discontinuous seams of fine grained pyrrhotite
(and sphalerite) up to 3mm thick. Trace chalcopyrite
occurs with segregated pyrrhotite.

SECTION OF McPhun's borehole no 3

Six-inch Map (County and Quarter Sheet) Argyll 141 NW NN 00 SE (N)

thin sections		Thickness Metres		Depth from Surface Metres	
				10	67
	Foliation dip 37-66° Core recovery 8%				
	0-15cm: Broken fragments of calc chlorite sericite schist and calc muscovite schist. Evidence of buckling: foliation dip becoming more or less vertical. Sulphide concentration comparable with section above. It is generally confined to seams but occasionally forms irregular patches (≤0.6cm diam) associated with recrystallised quartz-carbonate. One fragment of platy calc quartzite with much recrystallised calcite contains appreciable amounts of sulphide: chiefly pyrrhotite with lesser amounts of pyrite and trace chalcopyrite. 15-30cm: Flaky-platy calc (chlorite) sericite schist. Sulphide scarce except for a few small patches and streaks of pyrrhotite and minor chalcopyrite at 25cm. From 25 to 30 cm: rock becoming less chloritic. 30-35cm: Fairly homogeneous greenish calc quartzite. Some minor tight folding axial planar to the foliation which dips at 18°. 35-44cm: Crumpled calc sericite schist with many seams, patches and streaks of fine pyrrhotite. Some thinly banded greenish micaceous calc quartzite with similar amounts of sulphide. Core recovery 18%	2	44	13	11
TS62014 (DX80) 52cm)	Soft and flaky calc chlorite muscovite (sericite) schist with well developed planes of coarse muscovite along which the rock splits. 0-27cm: Some buckling and minor contortion. Foliation dip 46° The muscovite planes give the rock a laminated appearance. Sulphide is scarce: a few seams and patchy smears of pyrrhotite along foliae. 28cm: Muscovite schist Foliation dip 64° A number of seams of pyrrhotite (~1mm thick) associated with carbonate. Also some pyrite and trace chalcopyrite. 40cm and 56cm: Bands of segregated quartz/carbonate 1-2cm thick. 33cm and 41cm: thin ribs of greenish calc quartzite about 1cm thick 44cm and 57cm: prominent thin seams of pyrrhotite also disseminated in quartz-carbonate material 57-58cm: some contortion Corerecovery 28%	2	13	15	24

	Thickness		Depth from Surface	
	Metres		Metres	
			15	24
Calc chlorite muscovite (sericite) schist Some planar muscovite development. Foliation dip 13° increasing with depth to 16° Some minor contortion. Sulphide generally scarce apart from 12cm, 50-52cm, and 59cm where there is a notable concentration of pyrrhotite in threaded seams and filaments. Segregation of quartz ± minor carbonate occasionally with patches of pyrrhotite occur at 18-20cm; 38-40cm; 42-44.5cm; 55-56.5cm; and 78-82cm. Thin greenish calc quartzite bands which are usually contorted and somewhat recrystallised, and often with gashes filled by carbonate occur at 24cm, 37cm, 54cm, and 66-70cm. Sulphide absent. Core recovery 42%	2	07	17	31
Quartz + minor carbonate segregation with patches of coarse pyrrhotite. Core recovery 100%	0	09	17	40
0-22cm: Soft compact dark calc chlorite sericite schist with diffuse seams and lenticles of recrystallised carbonate. Some minor contortion and buckling. Sulphide sparse: a few seams of pyrrhotite. 22-41cm: Thinly banded greenish calc quartzite. Some parts have undergone intense minor contortion. In the vicinity of tight folds axial planar to the foliation, free carbonate is quite abundant in elongate patches and seams. From 38to 41 cm the calc quartzite appears more recrystallised and is mainly white or light grey in colour. Pyrrhotite occurs as streaky patches. Foliation dip 38° 41-47cm: Compact dark calc chlorite sericite schist. Core recovery 19%	2	45	19	85
Calc chlorite muscovite (sericite) schist with coarse muscovite planes that sometimes impart a laminated appearance. Sparse sulphide: very thin discontinuous seams of pyrrhotite along foliae. Foliation dip 27° Section includes a number of calc quartzite horizons:- 30-40cm: Highly contorted laminated greenish calc quartzite with thin diffuse seams and wisps of carbonate. Some crenulated micaceous partings. Small clots, elongate patches and weak disseminations of pyrrhotite	1	49	21	34

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SECTION OF McPhun's borehole no 3

Six-inch Map (County and Quarter Sheet) Argyll 141 NW NN 00 SE (N)

Thin sections		Thickness Metres		Depth from Surface Metres	
				21	34
	40-42cm: Homogeneous pale greenish-grey calc quartzite with a few patchy smears of pyrrhotite along foliae. 54-56cm: Pale green calc quartzite. Core recovery 38%				
	0-2.5cm: Dark calc chlorite sericite schist. 2.5-5.5cm: Pale greenish grey banded calc quartzite. Patchy smears of pyrrhotite along the micaceous partings. Foliation dip 21° 5.5-17.5cm: Segregated quartz + minor carbonate with a little chloritic selvage. Rare patches of pyrrhotite. Thin bands of green calc quartzite (7.5-8.5cm) 17.5-23cm: Greenish banded calc quartzite. Some minor folding axial planar to the foliation dip at 3°. Crosscutting fracture dipping at 70° offsets the bands and is infilled with calcite. 23-105cm: Fairly compact calc chlorite muscovite (sericite) schist. Relatively uniform thinly laminated rock with prominent muscovite planes. Sulphide is scarce. Some minor contortion (63-70cm) accompanied by recrystallised carbonate. Foliation dip 13° 105-110cm: Green micaceous calc quartzite. Samll fractures infilled with calcite. Sulphide absent. 110-128cm: Contorted schist with prominent sheaves of coarse muscovite. A few recrystallised quartz laminae + some discontinuous seams or streaks of cf rare pyrrhotite. 128-137cm: Calc chlorite muscovite (sericite) schist. Undulose foliation. 137-150cm: Highly folded pale dark green banded micaceous calc quartzite. No sulphide. Hair-line fracture with calcite infill. 150-160cm: Calc chlorite sericite schist with lits of recrystallised carbonate. Relatively undisturbed with a foliation dip of 22°. Rare sulphide: a few smears of pyrrhotite on foliae. Core recovery 35%	4	57	25	91
	End of Borehole			25	91
	Note These rocks belong to the Ardrishaig Phyllite formation. The micaceous material shows all gradations from schist to phyllite, but for convenience the term 'schist' is used throughout this log.				

APPENDIX V: OFFSHORE GEOLOGICAL SURVEY

PURPOSE OF DIVE

To assess whether orebody exposed on beach at McPhun's Cairn can be traced offshore.

METHOD

A series of seven traverses were made parallel to the beach at varying water depths offshore between 3 and 20 m, across the supposed strike of the orebody.

RESULTS

The sea floor consisted of coarse gravel with scattered rounded pebbles forming an extension of the beach for 5 m offshore from low water mark to a depth of 5 m (below low water mark). In this region the sea floor formed only a gentle gradient of 5°. The gravelly sea floor terminated abruptly against a homogeneous medium clean sandy bottom. This bottom continued offshore for a distance of 15 m, to a depth of 20 m (below low water mark) and gradually increasing in gradient. Below 20 m the bottom became more silty and the gradient increased to 30° to 50°. There was no evidence of any outcrop present on the sea floor.

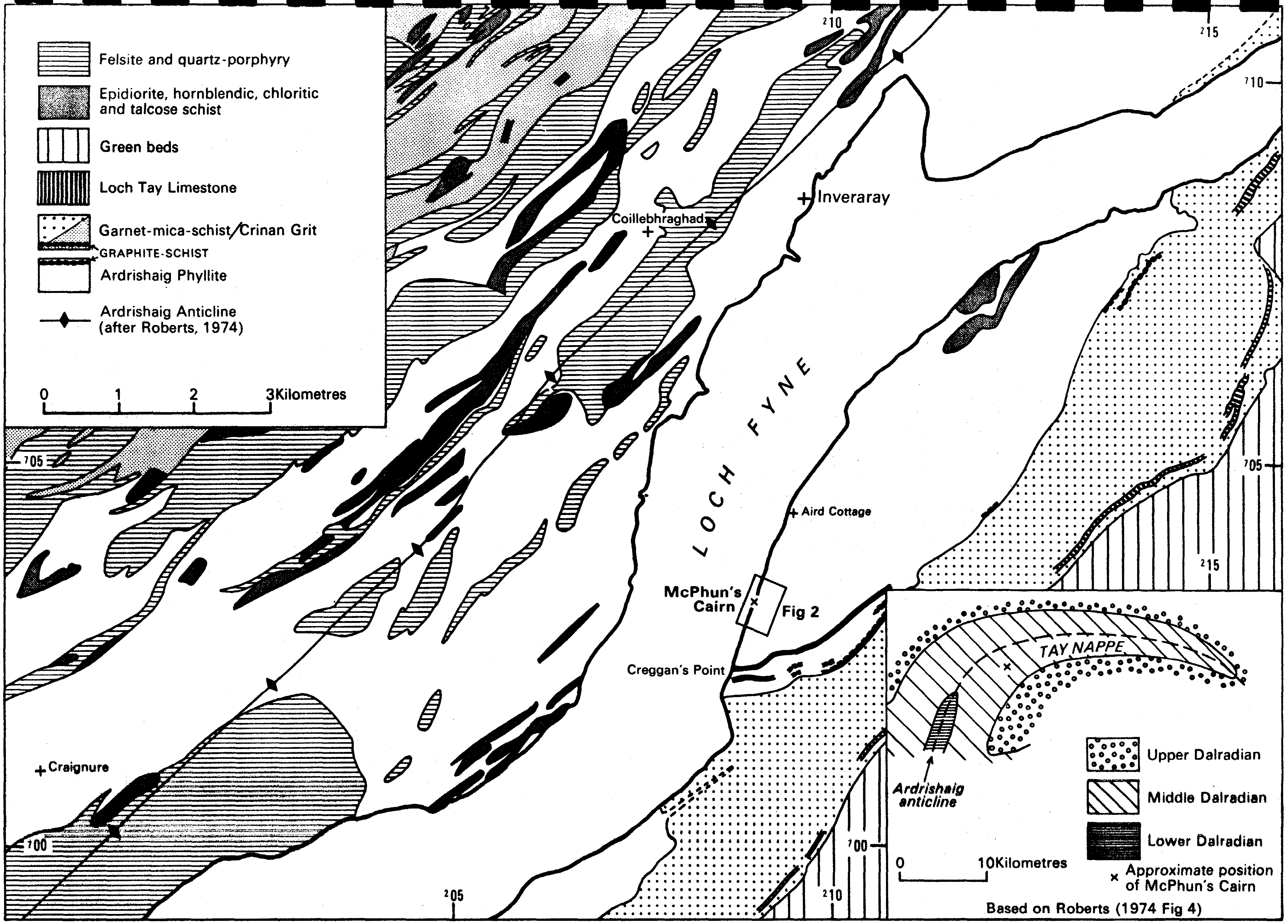


Fig. 1 McPhun's Cairn: Location and general geology

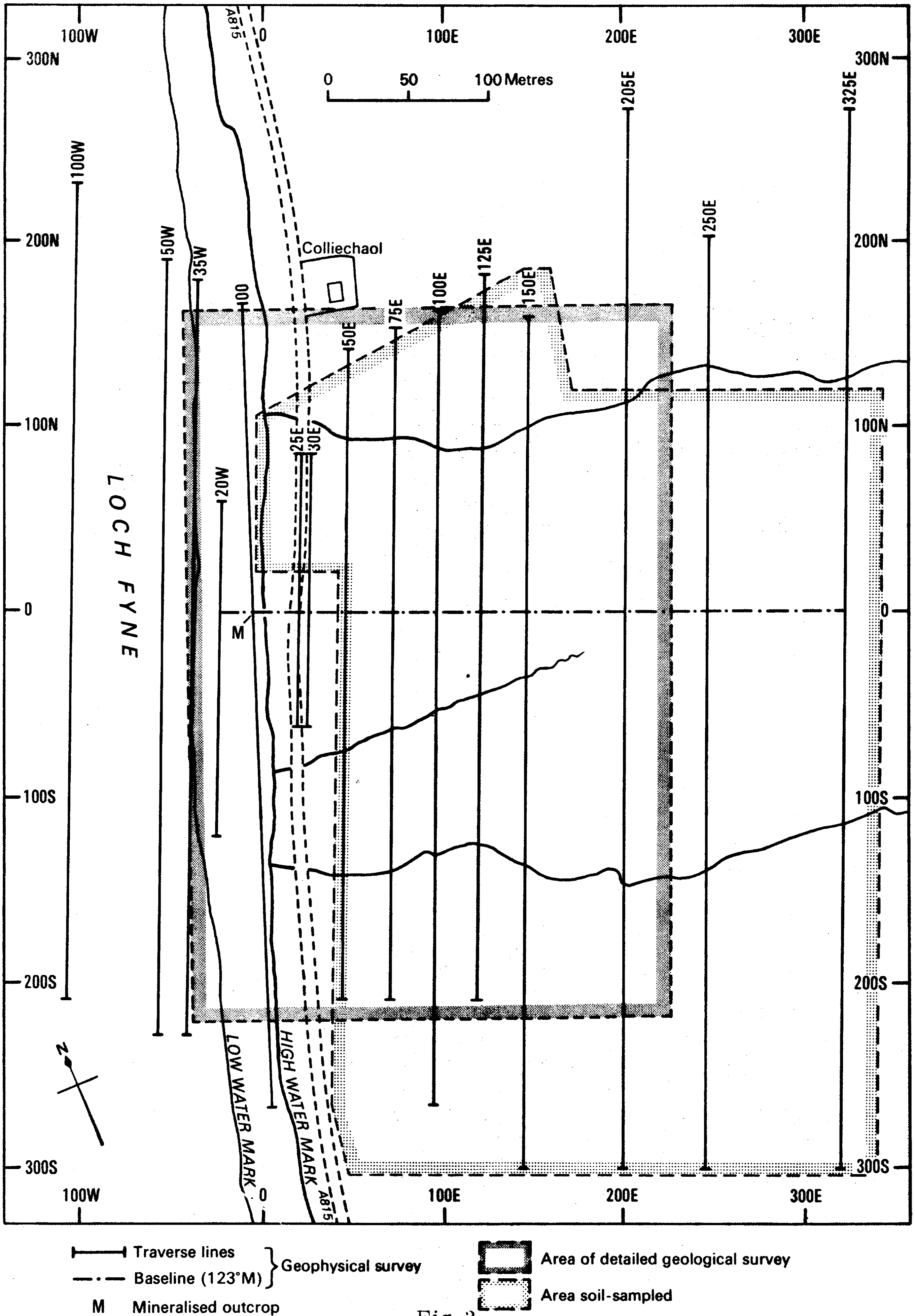


Fig. 2

Location of geological, geophysical and geochemical surveys in the area of McPhun's Cairn, Argyllshire

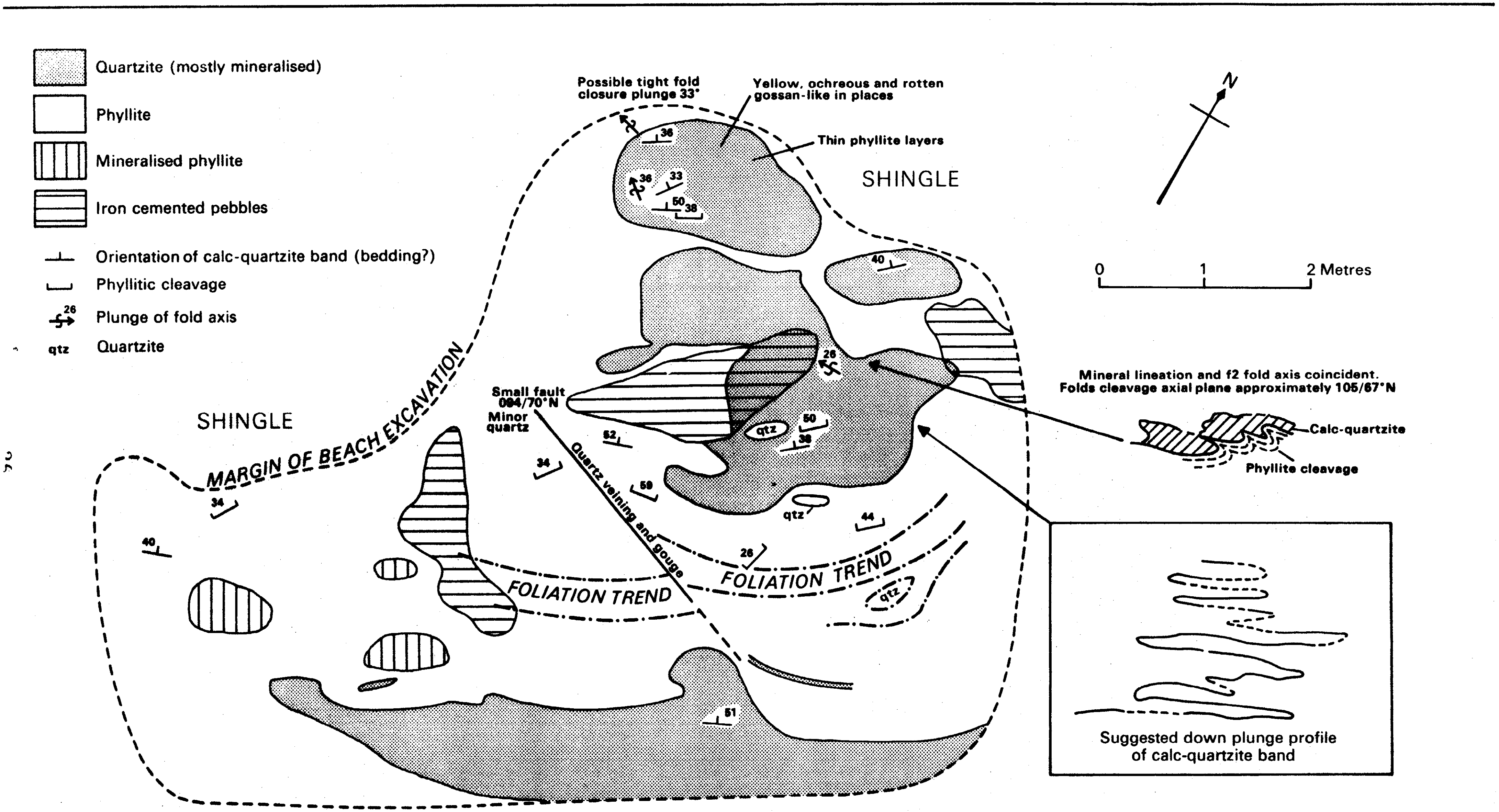


Fig. 4 **Geological map of the mineralised outcrop with inset showing down-plunge profile of calc-quartzite band**

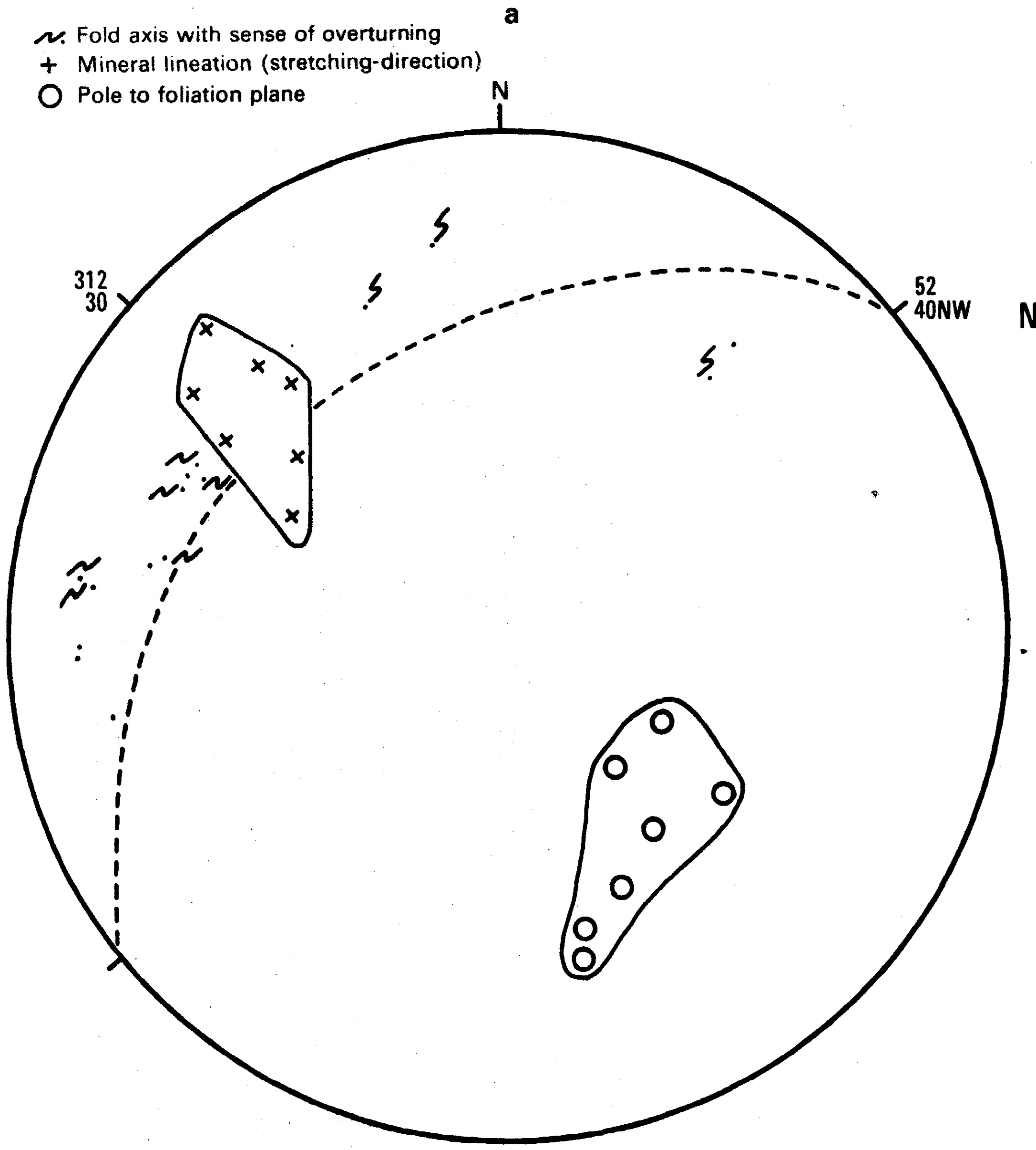


Fig. 5a
Equal-area plot of minor structures, Aird cottage to Creggans, Loch Fyne

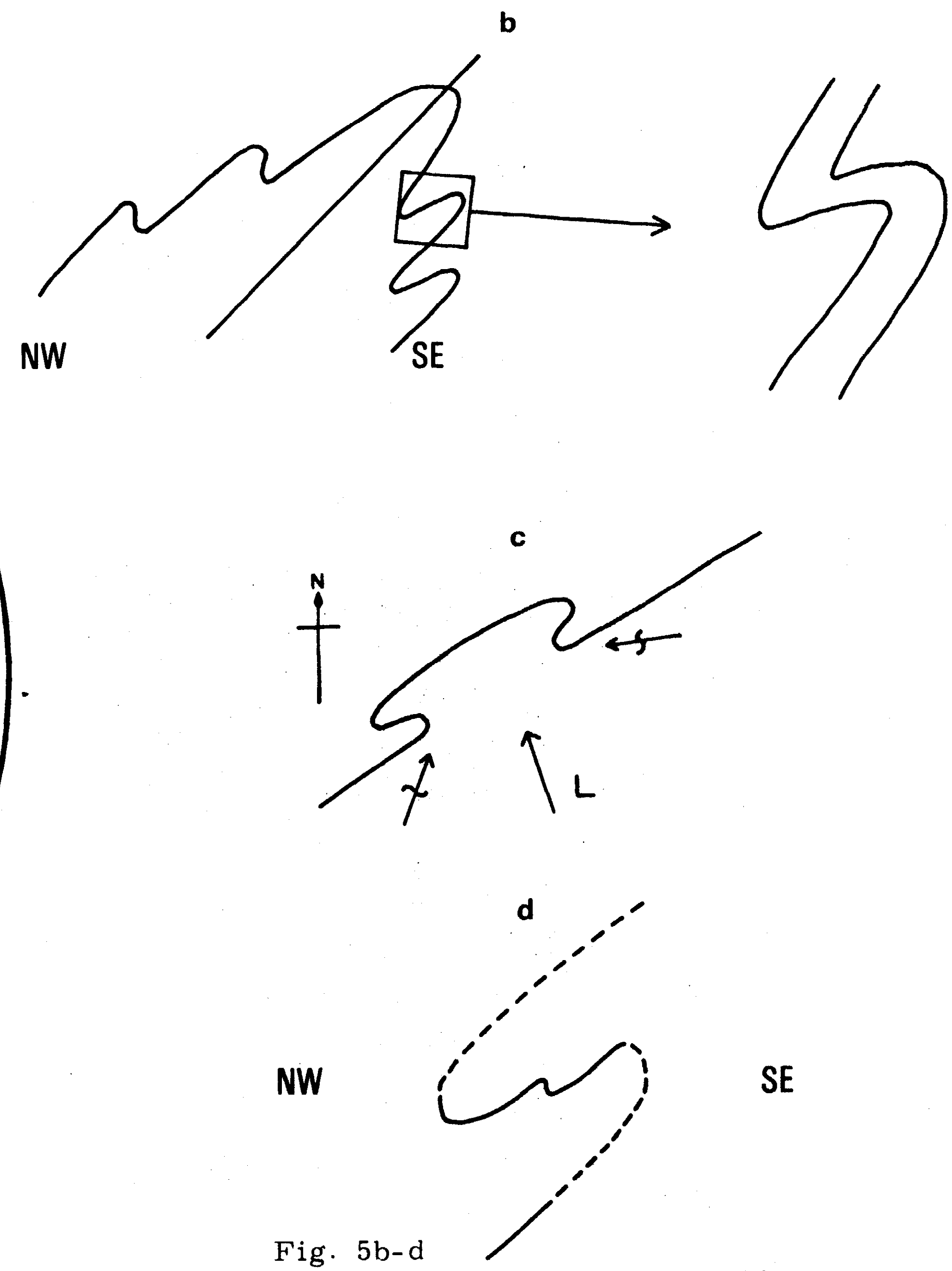


Fig. 5b-d
Minor folds in Ardrishaig Phyllite and their relationship to major structures

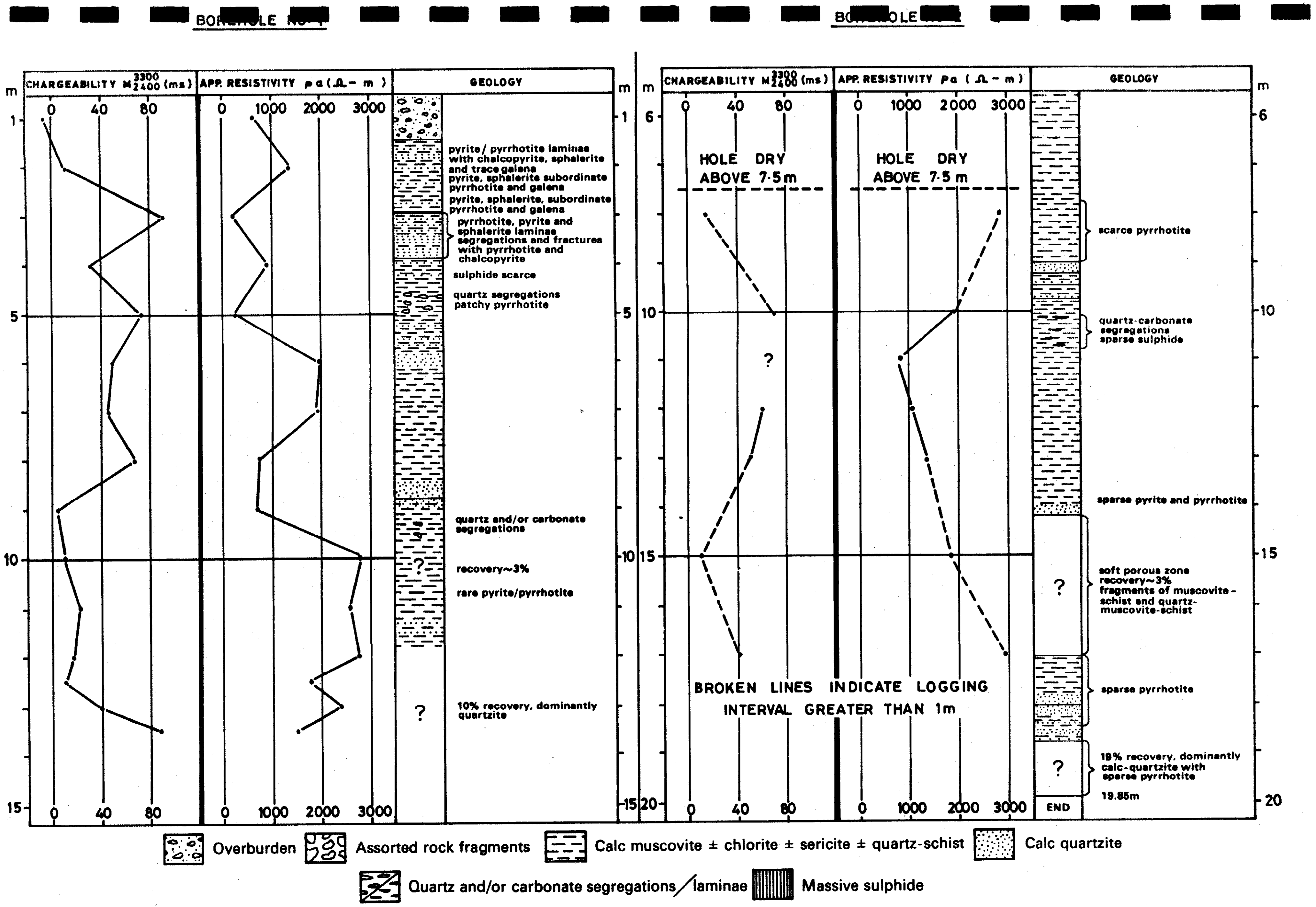


Fig. 6 Geological and geophysical graphic logs of boreholes 1 and 2

BOREHOLE No 3

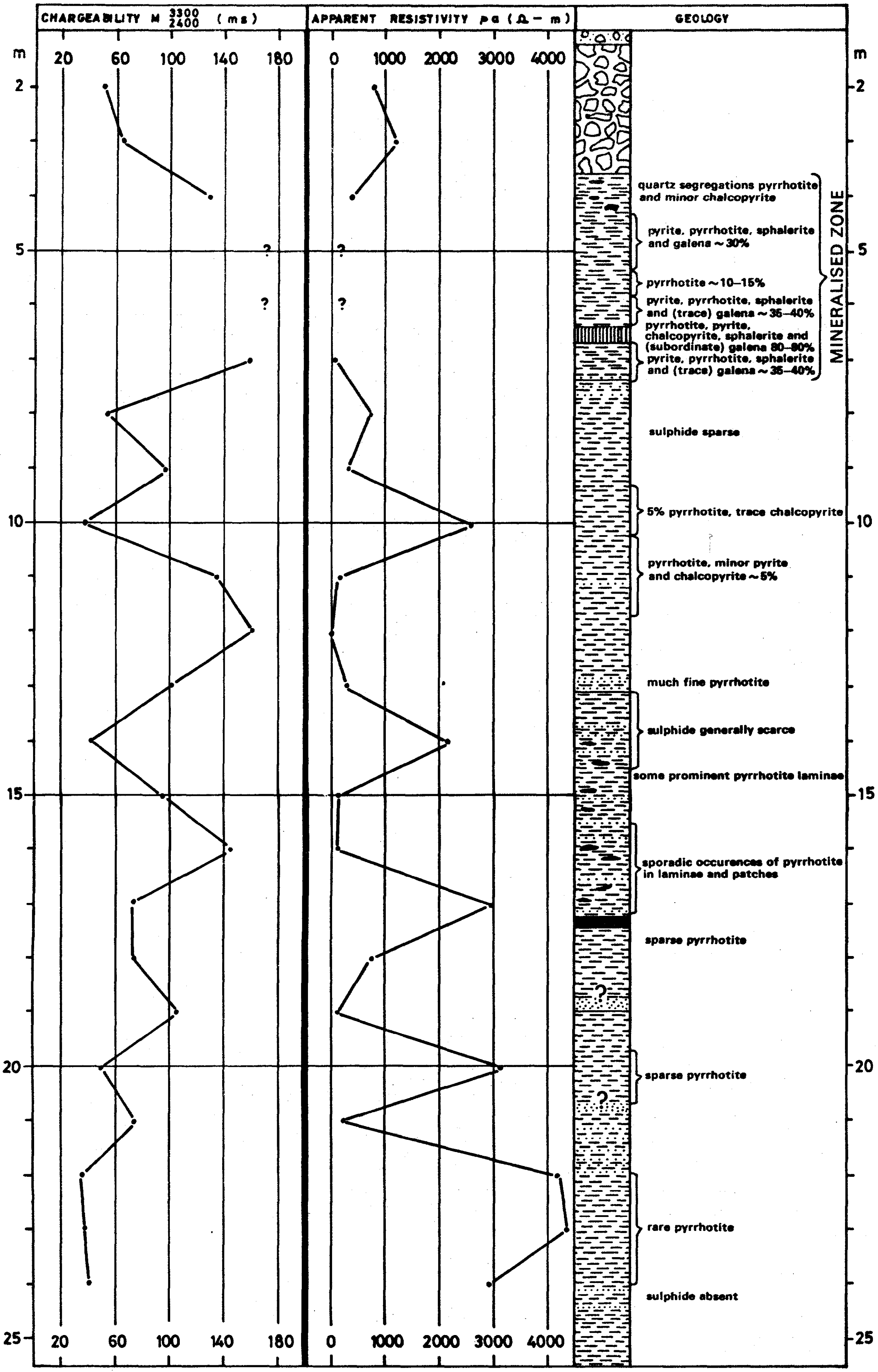
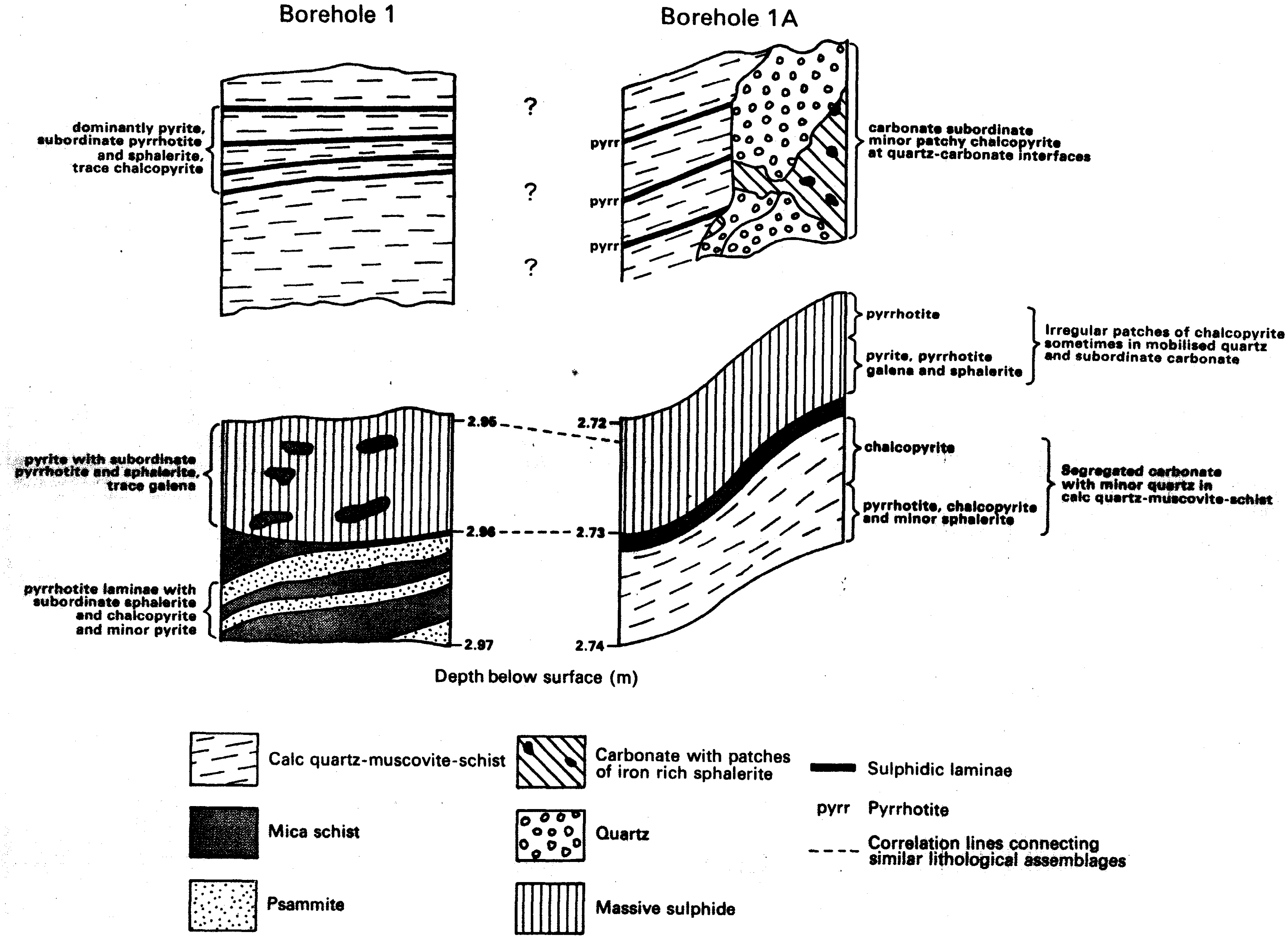


Fig. 7 Geological and geophysical graphic logs of borehole 3

Fig. 8 Sketch of the mineralised zone in Borehole 1 and Borehole 1A



Total magnetic field map

Magnetic fields are with reference to a datum of 40 000 gamma.
Contour interval is 250 gamma, but larger in areas of steep gradient.
Stippled areas indicate lows

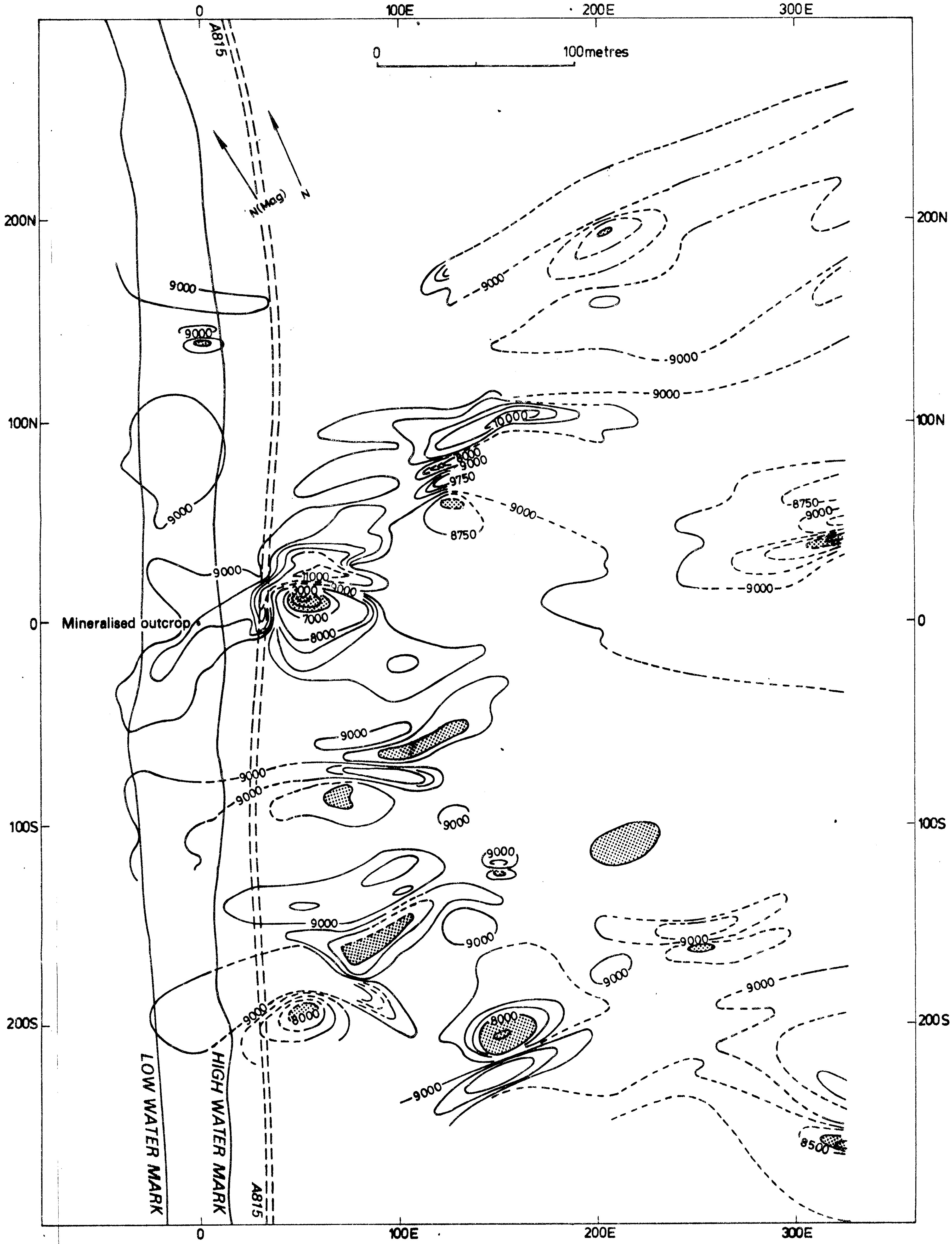
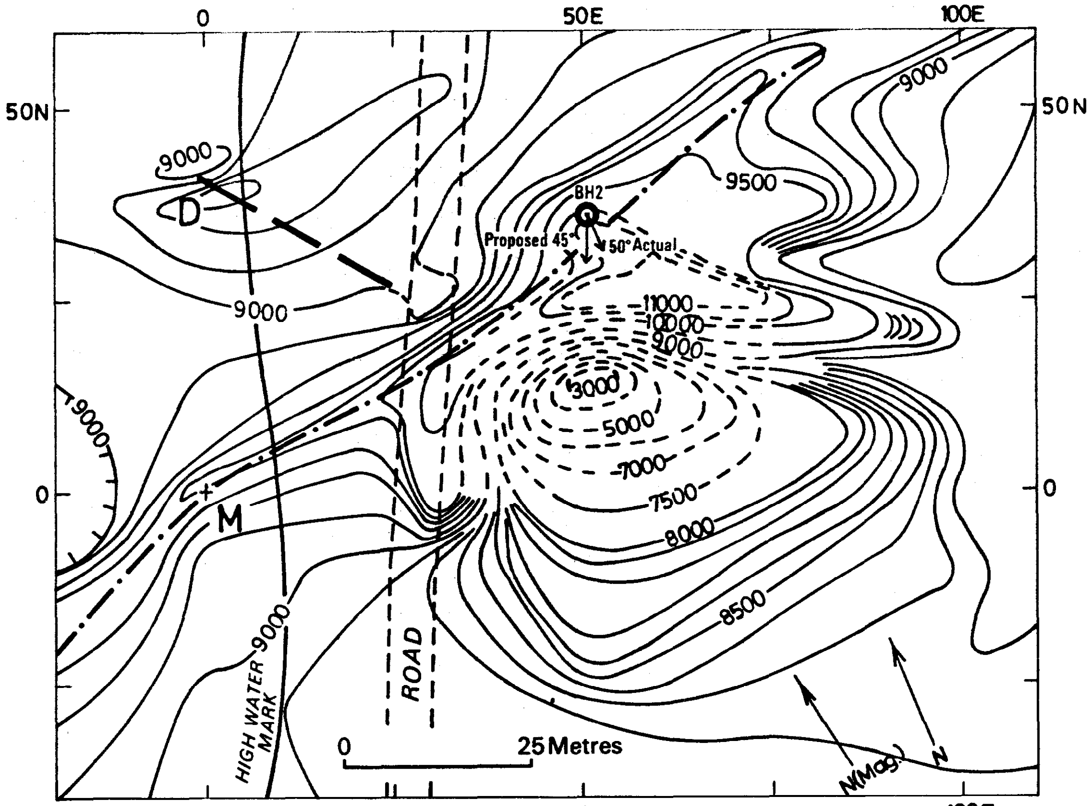


Fig. 9



Possible trend of anomaly over mineralised outcrop — Position of dyke M - Mineralised outcrop

Contour interval: 100 gamma, except where dotted

Total magnetic field showing the detail in the vicinity of the mineralised outcrop

Fig. 10

Map of apparent resistivity

Measurements made using gradient array with current electrodes on line 205E 500 metres north and south of the origin. Receiving dipole length: 20 metres

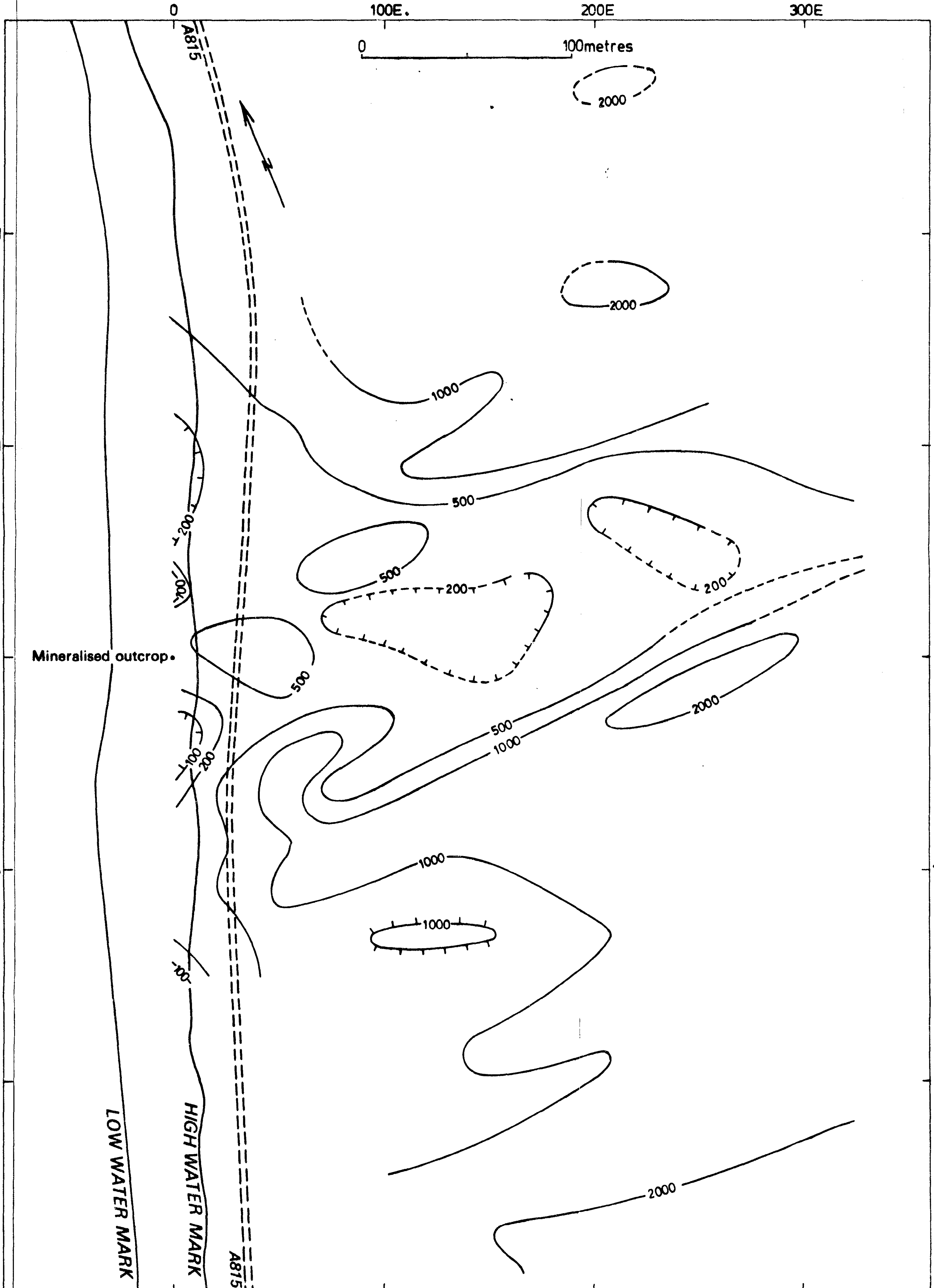
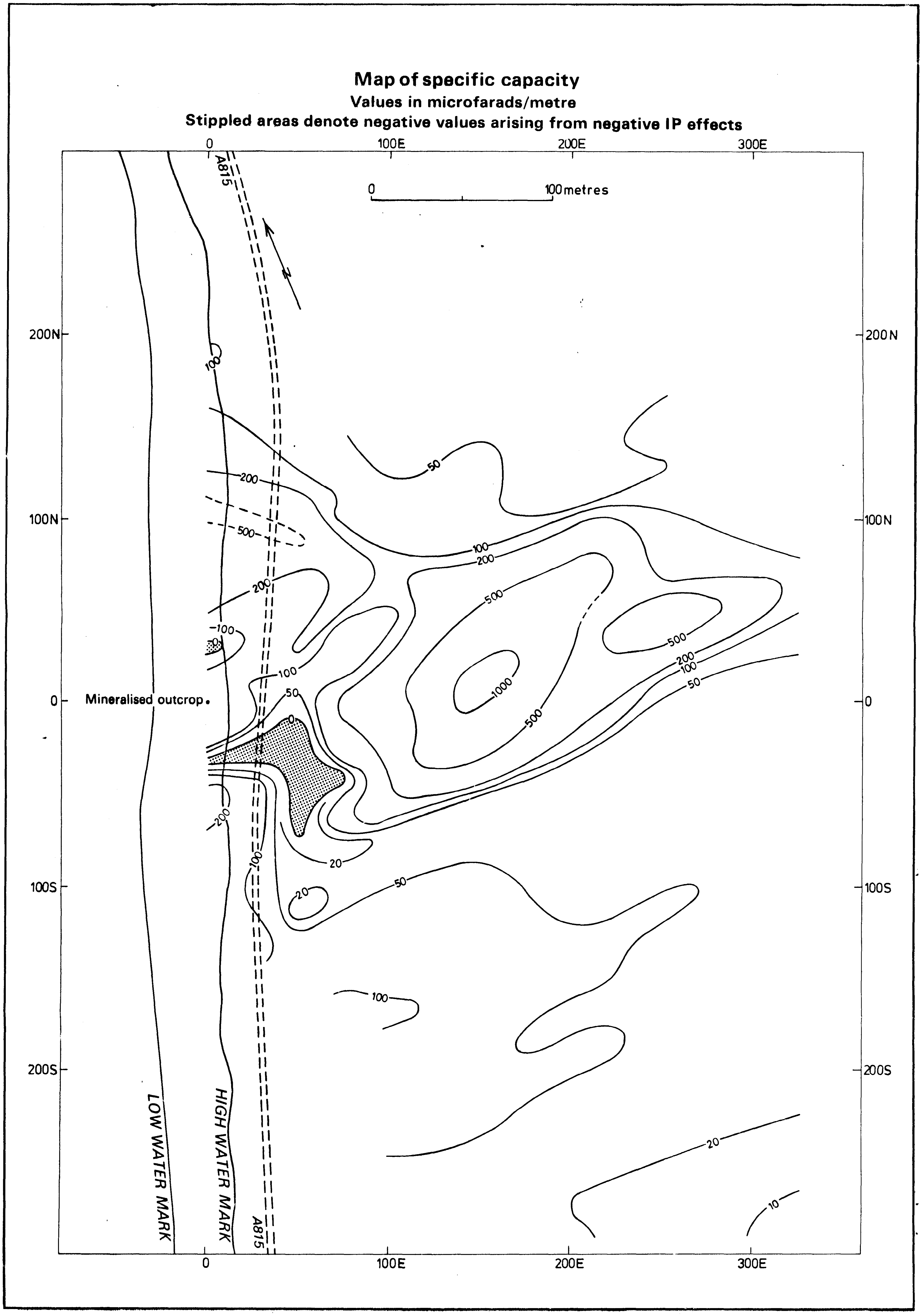


Fig. 11

Map of chargeability

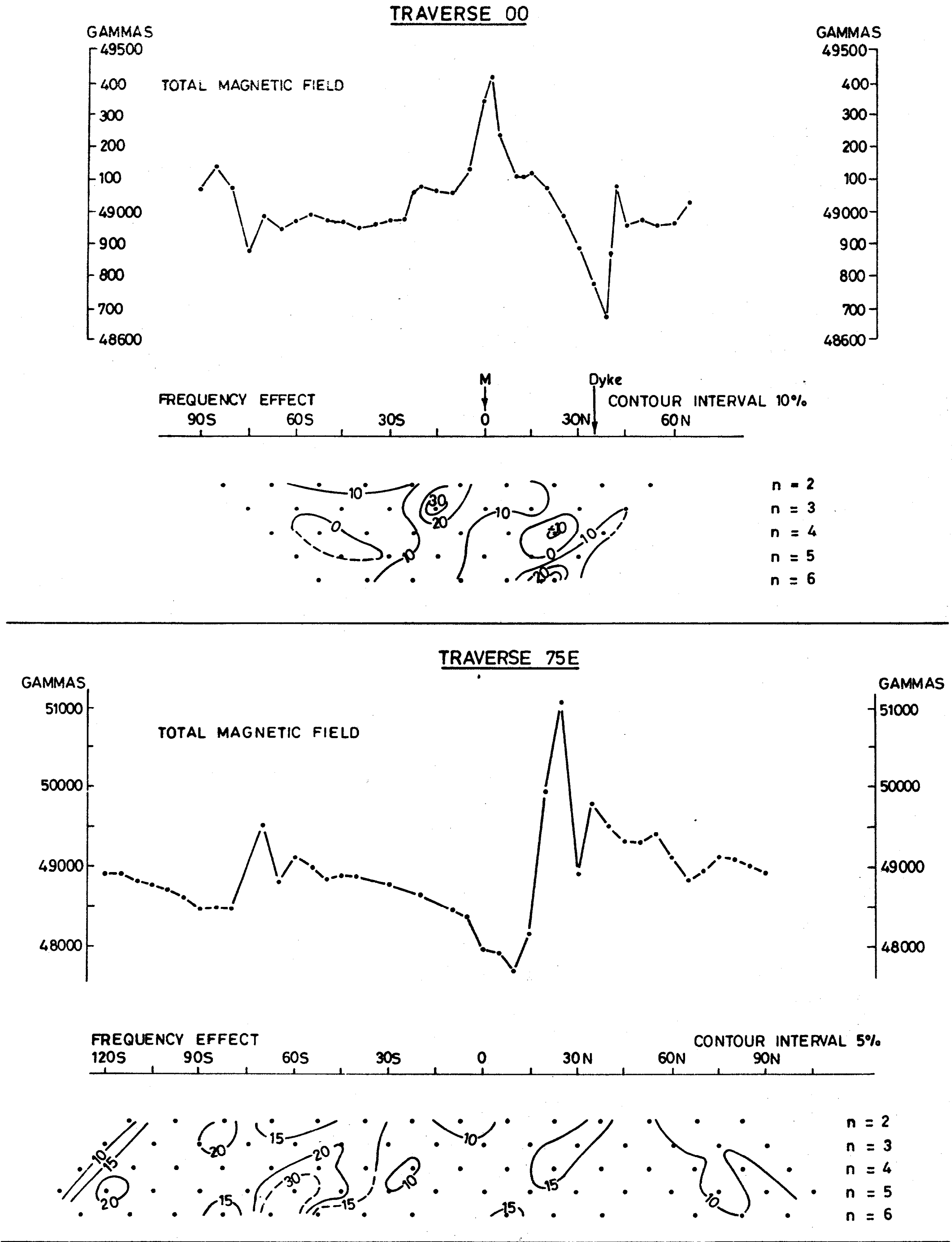
Measurements made using gradient array with current electrodes on line 205E 500 metres north and south of the origin. Receiving dipole length: 20 metres

Fig. 12



Map of specific capacity
Values in microfarads/metre
Stippled areas denote negative values arising from negative IP effects
0
100E
200E
300E
0
100metres
A815
N
200N
100N
0
100S
200S
Mineralised outcrop
LOW WATER MARK
HIGH WATER MARK
1000
500
200
100
50
20
10

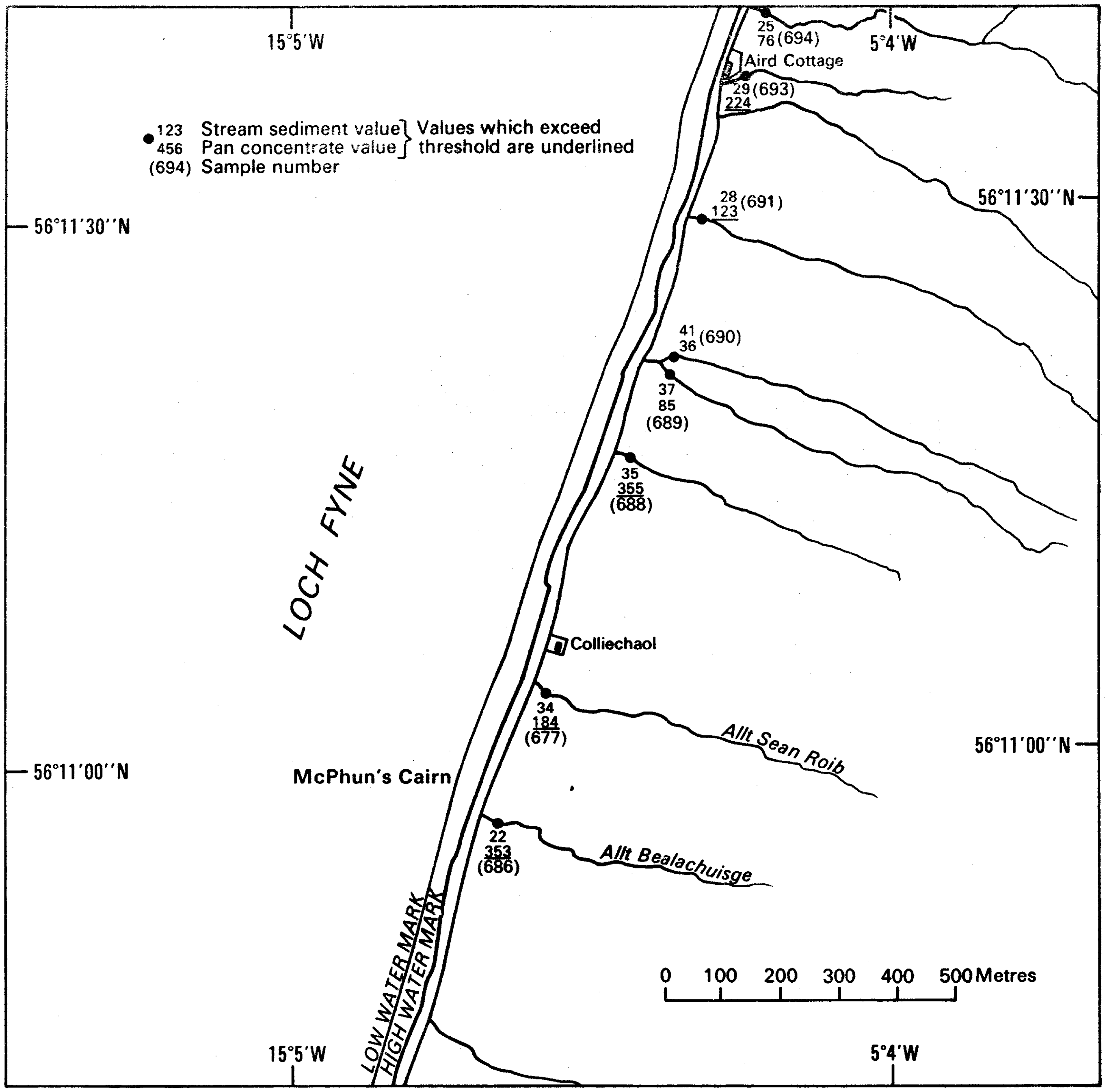
Fig. 13



NB. Different magnetic scale and IP contour interval on the two lines

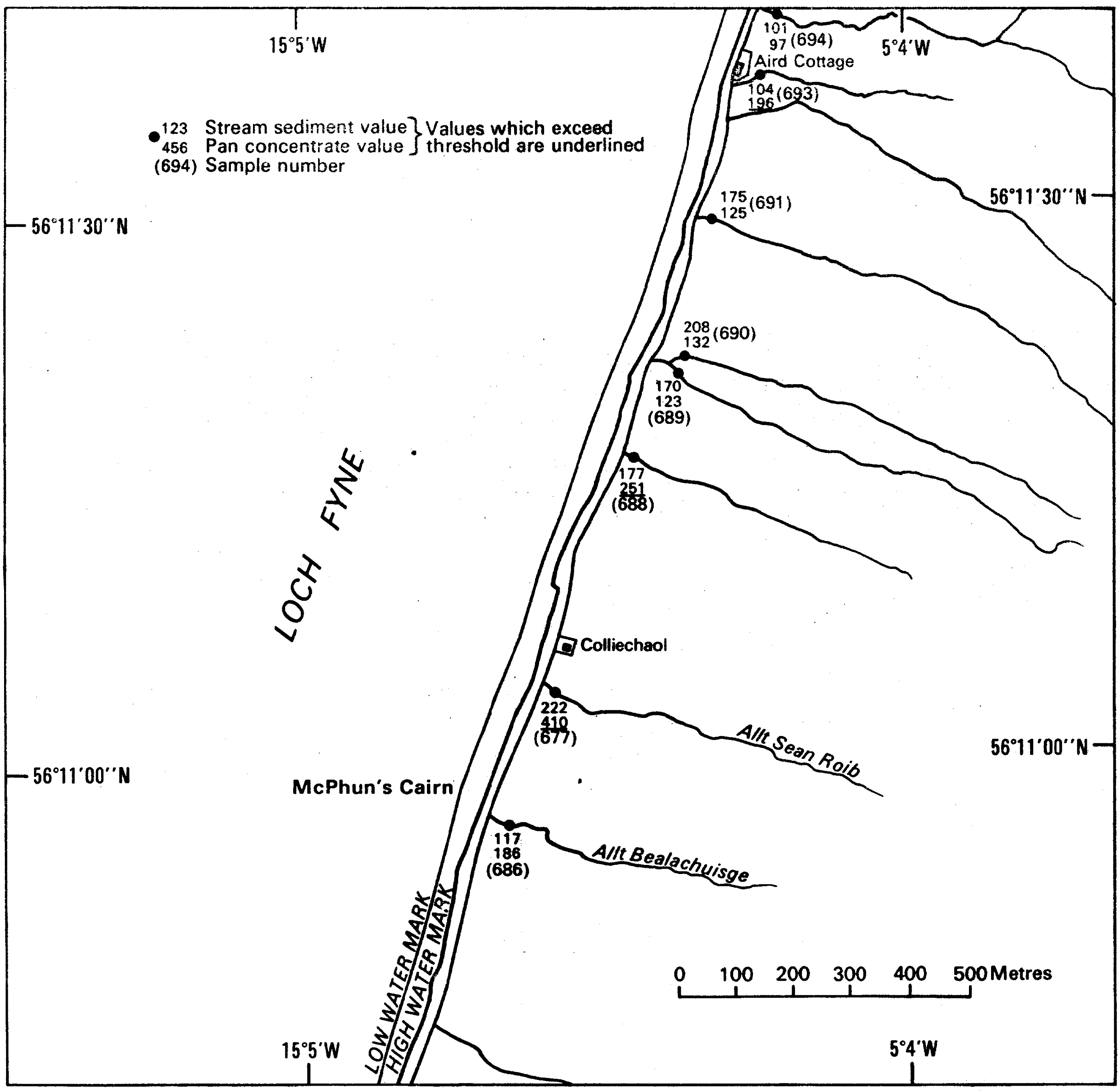
Fig. 14

Magnetic and IP results on traverses 00 and 75E



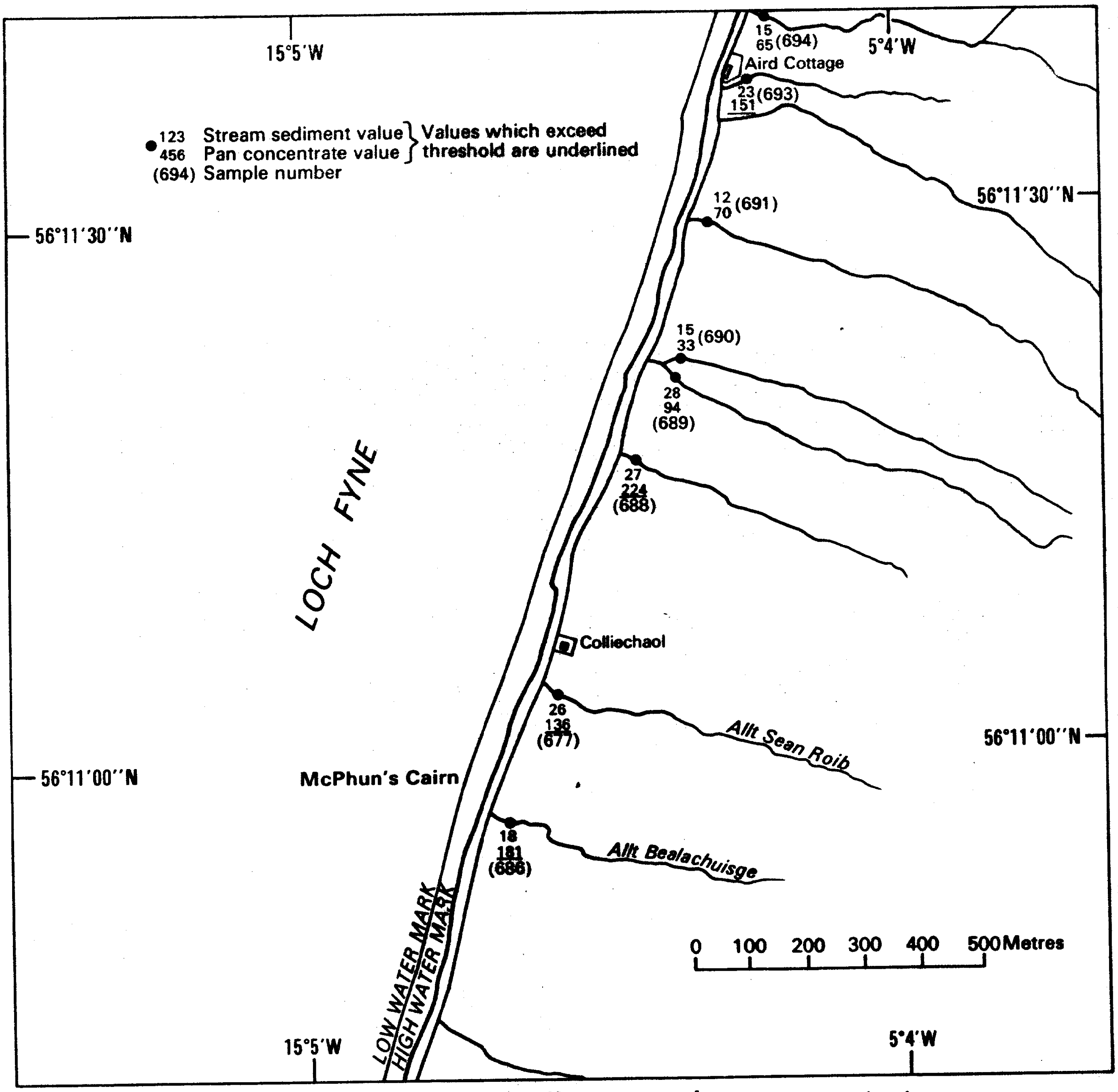
Nickel (ppm) in stream sediments and pan concentrates

Fig. 15



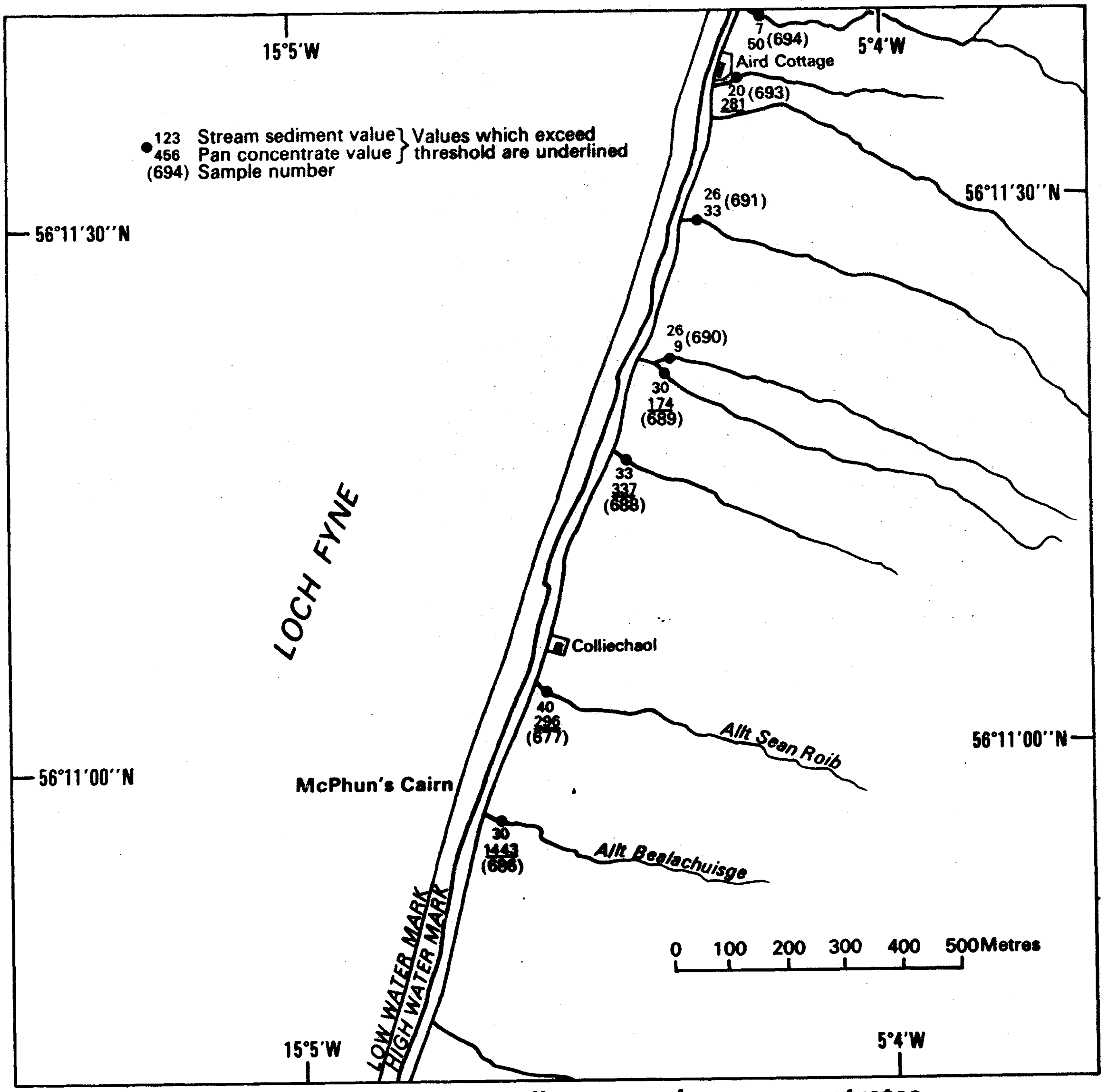
Zinc (ppm) in stream sediments and pan concentrates

Fig. 16



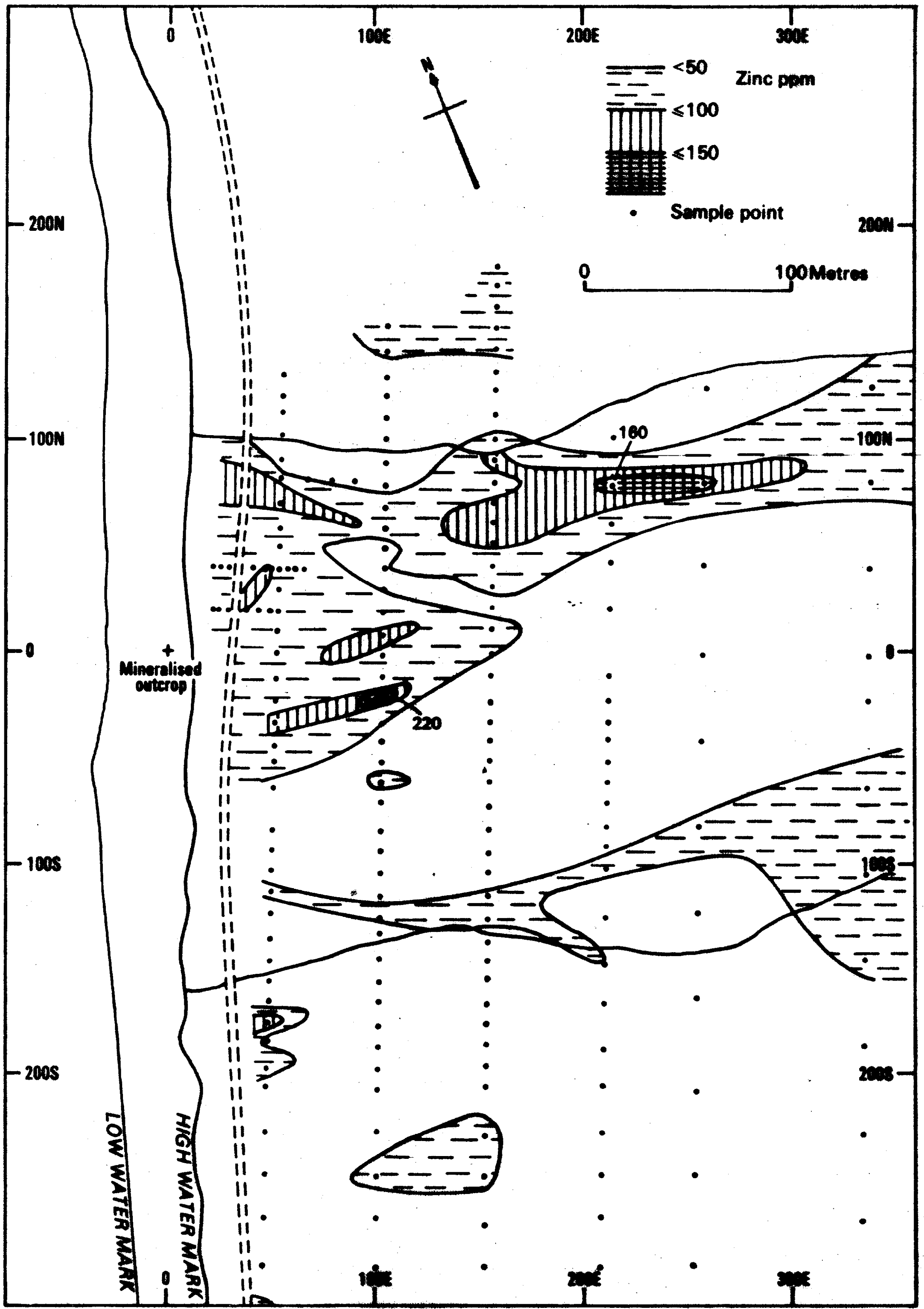
Copper (ppm) in stream sediments and pan concentrates

Fig. 17



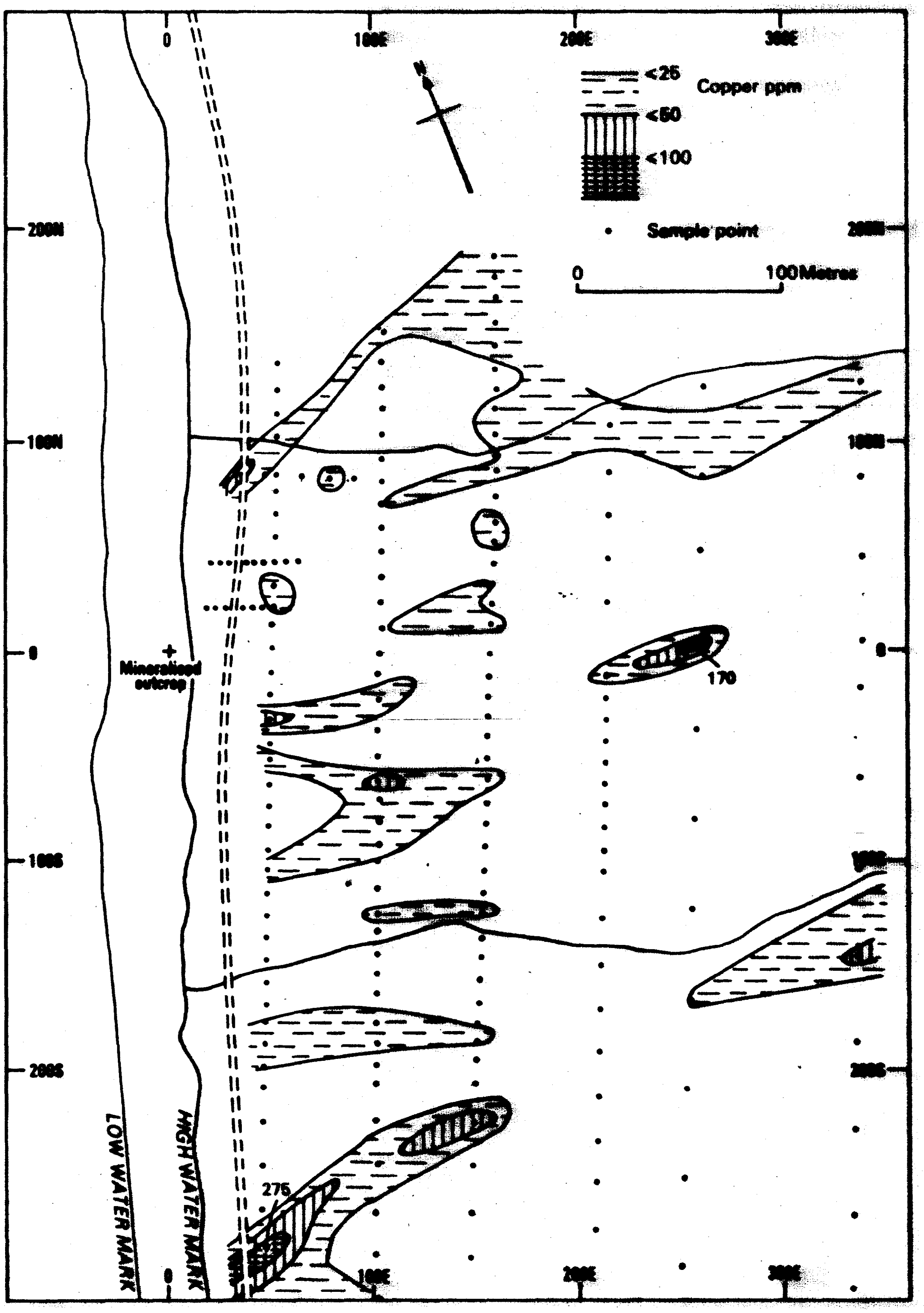
Lead (ppm) in stream sediments and pan concentrates

Fig. 18



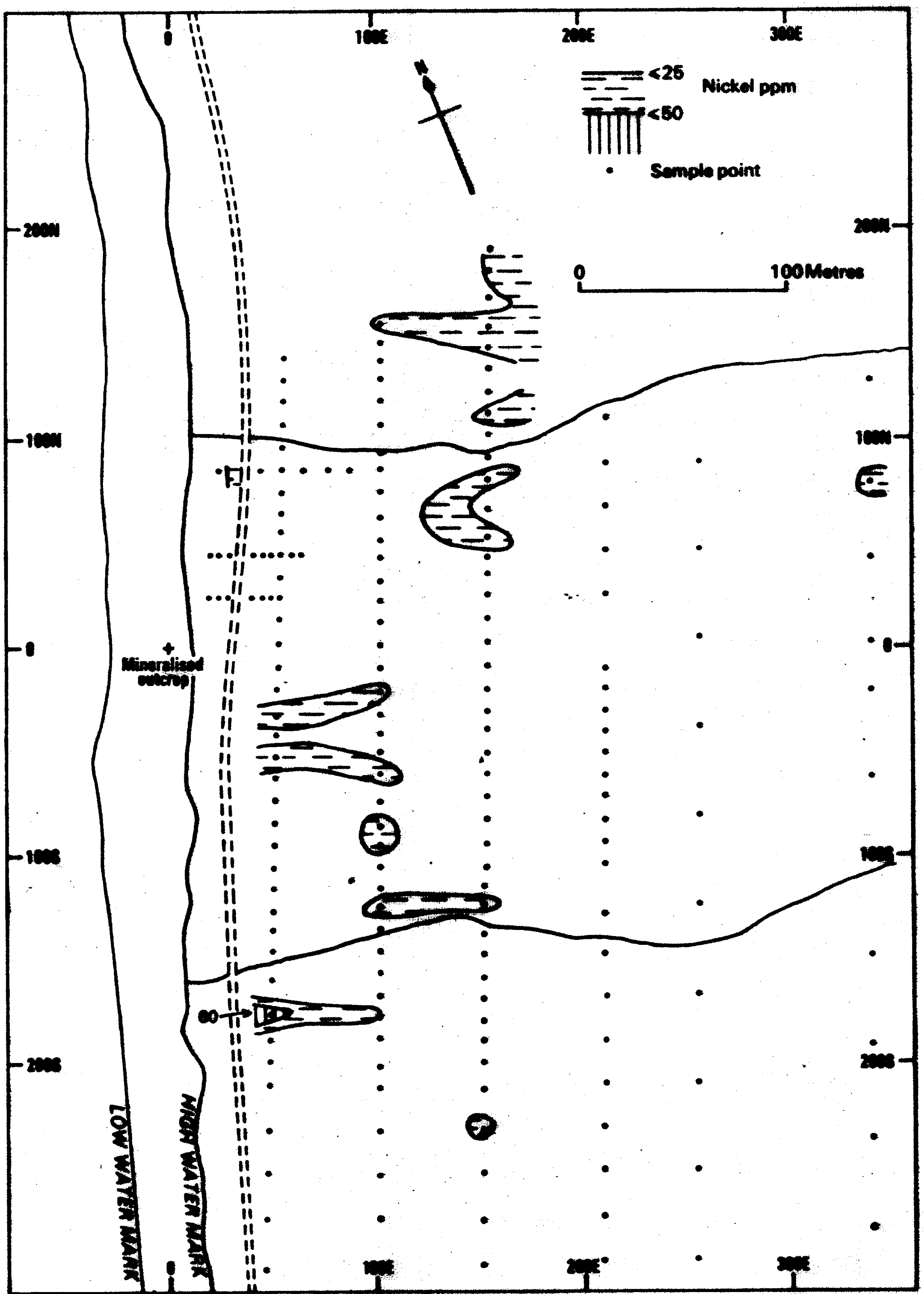
Contoured map of zinc in soils

Fig. 19



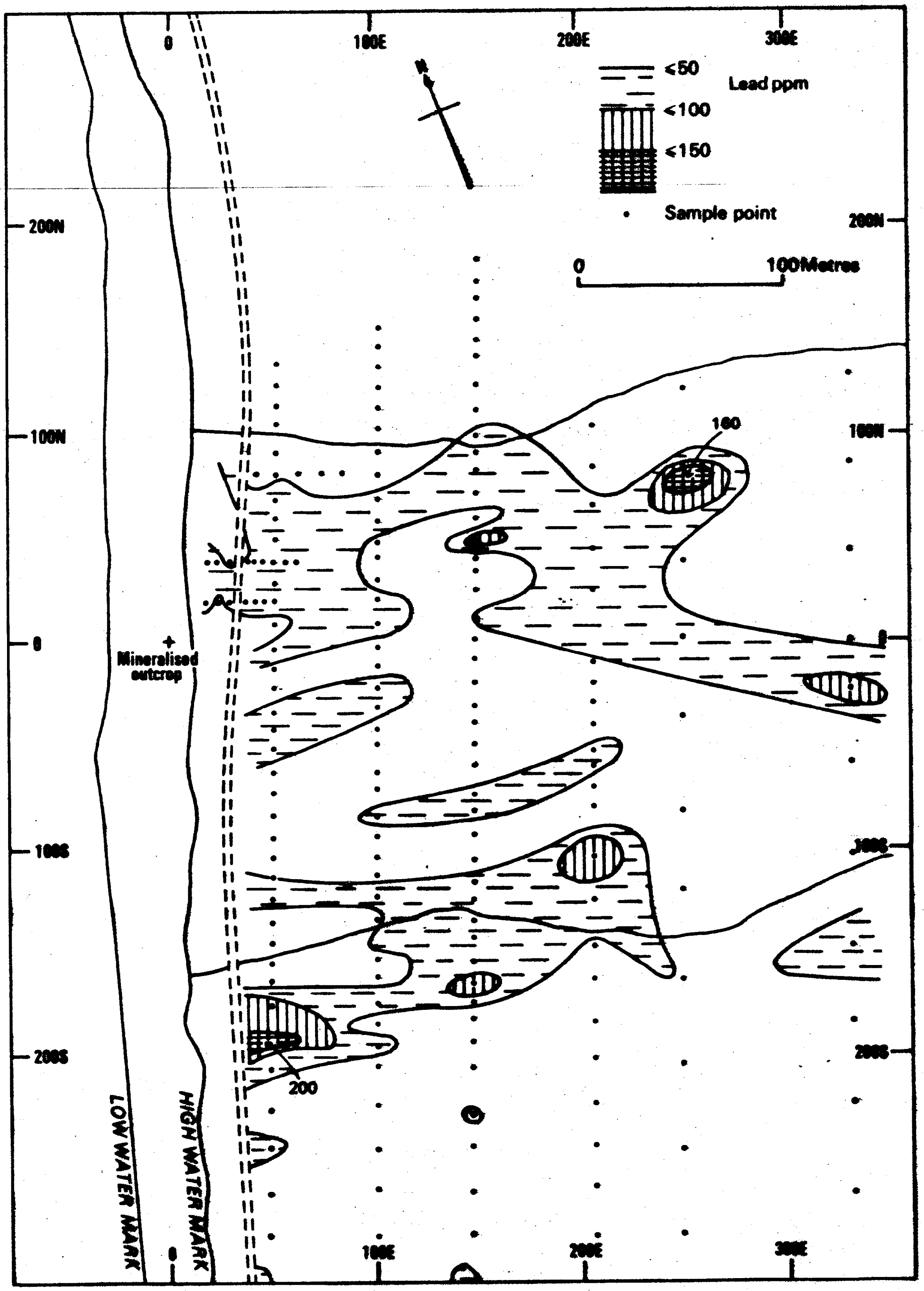
Contoured map of copper in soils

Fig. 20



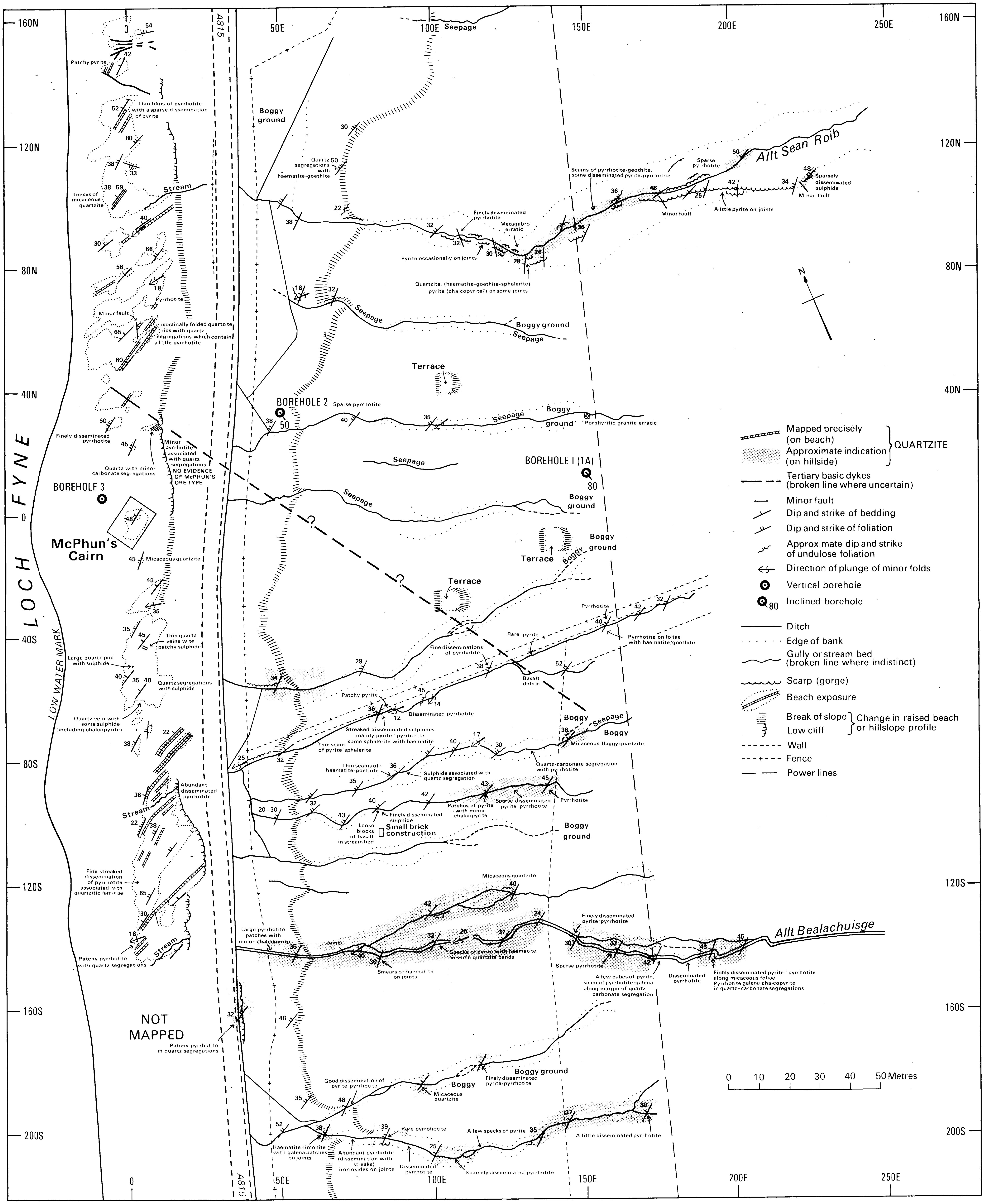
Contoured map of nickel in soils

Fig. 21



Contoured map of lead in soils

Fig. 22



Geological map of the area around McPhun's Cairn