Natural Environment Research Council

Institute of Geological Sciences

Mineral Reconnaissance Programme Report No. 8

Investigation of stratiform sulphide mineralisation in parts of central Perthshire

A report prepared for the Department of Industry

This report relates to work carried out by the Institute of Geological Sciences on behalf of the Department of Industry. The information contained herein must not be published without reference to the Director, Institute of Geological Sciences.

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Investigation of stratiform sulphide mineralisation in parts of central Perthshire

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Summary

Stimulated by favourable reconnaissance studies and the prospect of Scandinavian-type massive sulphide deposits in the Scottish Caledonides, a combined geological-geochemical-geophysical investigation of stratiform sulphide mineralisation in the Dalradian rocks of central Perthshire was undertaken between 1973 and 1975.

Initial detailed geological mapping in the area north and west of Loch Tay confirmed the presence of a weak but persistent zone of pyritic mineralisation, and subsequent reconnaissance surveys showed it to have considerable lateral extent. However it was found to contain only minor amounts of chalcopyrite and no other base metal sulphides. In addition chemical analyses of rock samples collected over this zone showed that copper, despite being the most abundant base metal, seldom averages more than 60 ppm though locally it exceeds 1000 ppm. Also a limited number of gold analyses failed to confirm a previous report of anomalously high concentration.

Intersections of the pyrite zone with major north-east trending tear faults were considered favourable sites for the development of vein mineralisation of the type formerly worked at Tyndrum. Although IP and magnetic measurements over four such intersections showed some significant anomalies, they showed poor correlation with concentrations of base metals in soils. It is concluded that the IP anomalies arise principally from graphitic material and/or disseminated pyrite, and the magnetic anomalies from pyrrhotite.

Although, in central Perthshire, the pyrite-rich zone appears to have only low concentration of base metals its presence is considered to be significant and it was recommended that the surveyed area be extended along the strike towards the south-west, where in the region of Loch Fyne several small strata-bound deposits of base metals are known to occur.

INTRODUCTION

Within the Swedish Caledonides the Seve-Koli nappe complex is dominated by lower Palaeozoic phyllites (both graphitic and calcareous) interbedded with acid and basic volcanic rocks and tuffites. This succession in the Stekenjokk area contains strata-bound sulphide deposits of economic proportions (Zachrisson, 1971). In 1968 Zachrisson visited the Scottish Caledonides and the following year Mr G. S. Johnstone of the Highlands and Islands Unit paid a return visit to Sweden. A product of these exchanges was the recognition of comparable lithological assemblages within the Ordovician/Silurian succession of Stekenjokk and the late Precambrian to Cambrian (Dalradian rocks) of the Scottish Caledonides, which in turn kindled interest in the possibility of strata-bound sulphides in the Scottish rocks. The most favourable horizon appeared to be in the Argyll (Middle Dalradian) Group where green beds are associated with calcareous schist. Preliminary reconnaissance field work in the area north of Loch Tay and examination of the original 6 inch geological maps indicated the presence of a stratigraphically controlled zone of weak sulphide mineralisation.

The sulphide mineralisation where seen consisted principally of pyrite but locally small amounts of chalcopyrite were identified. In addition one rock specimen revealed an anomolously high gold content. Further partial analyses also indicated that geochemically the horizon was sufficiently distinct to warrant further investigation.

Between Loch Fyne and Pitlochry the mineralised zone has no fewer than five intersections with major faults. By analogy with the possible fault-related mineralisation in the Tyndrum area, it was considered that the other intersections might be sites of significant sulphide concentrations.

The aim of the investigation described in this report was twofold:

i. To undertake a detailed appraisal of the lateral extent and economic prospects of the sulphide zone.

ii. To ascertain whether significant sulphide concentrations occur where the zone is cut by major NE-SW faults. Geological, geophysical and geochemical methods were used.

GEOLOGY AND GEOLOGICAL SURVEYS

Procedure

The ground north and west of Loch Tay (Fig. 1) was selected as the most favourable area for a detailed survey principally on the results of the preliminary geological reconnaissance. In this area the sulphide zone crops out on both north and south flanks of a large synform (Fig. 2). Mapping on a scale of 6 inches to 1 mile was mostly confined to stream sections but also included examination of parts of the Lawers-Tarmachan summit ridge to ascertain the background sulphide content outside the suspected enriched zone. This detailed survey was supplemented by reconnaissance visits to other outcrops on the same horizon between Glenshee and Loch Fyne. Further reconnaissance surveys were undertaken prior to the geophysical work at intersections of the sulphide zone with major faults. More detailed geological surveys were subsequently carried out in all areas where significantly anomalous geophysical responses were obtained.

Results

General Geology [Fuller details in Appendix I]

The area surveyed comprises the following succession of Dalradian formations:

Ben Lui schist (stratigraphic top)
Sron Bheag schist
Ben Lawers schist
Ben Eagach schist
Carn Mairg quartzite (stratigraphic bottom)

These formations consist mainly of metamorphosed sedimentary rocks but "green beds", probably of volcanic origin, are found in the Sron Bheag schist and Ben Lawers schist.

During the Caledonian Orogeny these rocks were thrown into a great recumbent fold (the Tay Nappe) and in the area north and west of Loch Tay the succession is inverted. However as the rocks are the right way up in other parts (eg Glen Lyon) the term 'top' is used in a stratigraphic sense throughout. A limited number of later intrusions ranging in composition from acid to ultrabasic are also present.

Mineralisation [Fuller details in Appendices II and V]

General

Outwith the pyrite zone (described below) the Ben Lawers schist displays minor showings of pyrite and chalcopyrite, with pyrrhotite only rarely present. Chalcopyrite is much less common than pyrite in the schists but its abundance appears to increase adjacent to the metavolcanic horizons. Chalcopyrite and pyrite are occasionally present in ubiquitous quartz segregations.

In the other formations pyrite is normally the only sulphide present but the junction between the Ben Lawers and Ben Eagach schists at the northern end of Lochan na Lairige (Fig. 2) contains minor pyrite, pyrrhotite, galena and chalcopyrite in quartz segregations.

Pyrite zone

Over most of the 58 km of boundary mapped (Fig. 2) the presence of a definite horizon of weak, mainly pyritic mineralisation near the top of the Ben Lawers schist was established. The reconnaissance survey indicated that the zone probably extended along the strike from Glenshee to Loch Fyne.

In the area north and west of Loch Tay (Fig. 2) it varies from 10 to 330 m in width, attaining a maximum possible thickness of 180 m, and lies some 10 to 400 m below the base of the Ben Lui schist. The intervening ground is mostly occupied by the variable lithologies of the Sron Bheag schist formation.

The sulphide content is the only factor which delineates the pyritic zone, since the host rock is fairly typical Ben Lawers schist with no obvious change in form or character. The boundaries of the horizon appear to be quite sharp, and within its cross-strike limits the tenor varies erratically with considerable range in sulphide content (Tables I-VI). The pyritiferous rock generally contains not more than 5 per cent sulphide, but thin units within the sequence are notably enriched, with a sulphide content exceeding 20 per cent.

The predominantly pyritic mineralisation takes the form of banded disseminations in both the pelitic schist and calc quartzite horizons. Pyrite typically occurs as single crystals and grains scattered throughout the rock, with a definite elongation of individual crystals along the foliation.

The grain size of pyrite varies from a few mm to over 1 cm, with a tendency for individual crystals to be slightly coarser where more sparsely distributed in the rock or associated with metamorphic segregations. The crystal form is generally the cube, though pyritohedra have been observed.

Some mobilisation and recrystallisation of sulphides together with quartz and/or carbonate has taken place during the Caledonian earth movements.

Within the sulphide zone chalcopyrite is only present in trace or minor amounts and is generally associated with pyrite. There is a notable concentration of chalcopyrite in the upper half of the pyritiferous zone in a road cutting in Glen Lochay [NN 538 354]. Although it may occasionally be found very sparsely distributed in the schist, chalcopyrite is most commonly seen in or adjacent to concordant quartz-carbonate segregations. These segregations are well displayed in the sulphide-rich bands in the Auchtertyre section (160-200 m) where chalcopyrite is also seen as irregular threads and filamentous patches within the rock.

GEOPHYSICAL SURVEYS

While it was known that the former workings for lead, copper and zinc at the Tyndrum mines were in fault veins, not strata-bound, it was noted that one interpretation of their occurrence could be related to solution and re-deposition from the pyrite zone as they tended to occur where fault and zone intersected.

To investigate the possibility of analogous sulphide concentration, detailed geophysical work was carried out in selected areas (Fig. 3) of the pyrite zone where it was cut by major NE-SW trending wrench faults. A further site where the Bridge of Balgie fault runs close to the previously worked lead vein on Meall Luaidhe was also investigated.

Procedure

Induced polarisation (IP) and resistivity surveys comprised the major effort in all areas, with magnetic surveys providing additional information. IP measurements were made in the time-domain using the Huntec Mk. III IP system (Hutchins, 1971) in colinear dipole-dipole array. At most of the locations the separation between the centre points of the transmitter and receiver dipoles was varied between 2 and 6 times the dipole length. This effectively gives a measure of the IP effect and resistivity at different depths.

Magnetic surveys consisted of measurements of the total intensity of the earth's magnetic field in gammas (where 1 gamma = 1nT), using an Elsec proton precession magnetometer.

Results

Detailed descriptions of the geological and geophysical surveys are presented in Appendix III. The following conclusions have been drawn:

a. Pubil

Significant chargeability anomalies occur within a band up to 300 m wide, on the east side of the fault, within the Sron Bheag schist (Fig. 4). An analysis of 5 specimens from this zone showed that they all contain an abundance of 'carbonaceous granules', sometimes containing crystals of graphite (Appendix VI). It is concluded that this is the principal cause of the large IP anomalies. Certain of the anomalies which apparently have associated magnetic disturbances (particularly on line 230 S) may be caused in part by metallic sulphides which include pyrrhotite.

b. Cashlie

There is no geophysical evidence to support the existence of a fault, and the alignment of the IP and resistivity contours parallel to the limestone band indicates continuity across the supposed fault (Fig. 5). The lack of magnetic or geochemical correlation with the principal anomaly suggests that it may be caused by a narrow band of carbonaceous material, or possibly a band containing pyrite.

c. Corrycharmaig

The only indication of an enrichment of mineralisation associated with the pyritous horizon and the Bridge of Balgie fault is a small zone of higher chargeabilities trending NE-SW in the east of the area surveyed (Fig. 24). The largest IP effects occur close to the eastern end of a serpentinite intrusion and may reflect its extension in this direction.

d. Easter Achtar

Chargeabilities are generally low here. The highest values coincide with the topographical feature which is thought to define the fault plane, and hence may be due to graphite or clay gouge. On one traverse there is an associated magnetic anomaly, but it may be related to the nearby overhead power lines.

e. Meall Luaidhe

Results obtained from IP and magnetic surveys provide no indication of an extension of the vein, but EM traverses nearer the known exposure may prove more informative.

GEOCHEMICAL SURVEYS

i. Rock Sampling

Procedure

To assess the content and distribution of the common base metals within the pyritiferous zone, six cross-strike sections (Fig. 6) were rock sampled and analysed. The sections sampled serve to demonstrate the variations seen in lithology and sulphide content of the pyrite zone, and were chosen because the exposures are fairly continuous. A limited programme of gold analyses was undertaken on the knowledge that a sample of mineralised Ben Lawers schist from the pyritous zones south of Lochan na Lairige had yielded 0.13 ppm gold (Analytical and Ceramic Unit Report No. 15, 1969). In addition samples from sulphide-rich horizons thought to be equivalent to that of the pyrite zone of Loch Tay, but in the Loch Fyne area, showed anomalously high gold values.

Results [Fuller details in Appendix IV]

The results obtained from the rock sampling carried out across this zone (Tables I-VI) and from the regional geochemical survey show a low average base metal content and support the field evidence that copper is the only significant base metal present. Copper concentrations over four of the sections sampled average 60 ppm and range up to 340 ppm. However, in the Brerachan Water section, near Pitlochry, where metabasic rocks are common, the average and maximum are 140 and 1270 ppm respectively, whereas the even higher values at Auchtertyre (average 360 ppm, maximum 1600 ppm) may reflect the proximity of the section to Tyndrum. The results also show that apart from the Auchtertyre section where sphalerite is certainly present, chalcopyrite is the only ore sulphide to occur in the zone. Lead and zinc concentrations are comparable with non-sulphide-bearing rock and the variations in their concentration generally occur more in response to lithological changes than to sulphide content. Lead and zinc are undoubtedly present in trace quantities associated with pyrite and chalcopyrite, but the total sulphide content is too low for this contribution to exert any real effect on their distribution. Gold values are related to the sulphide content and do not show any anomalous concentration (maximum 0.042 ppm).

ii. Soil Sampling

Procedure

Subsequent to the geophysical survey at Pubil and Cashlie, limited geochemical soil sampling was used to evaluate the anomalies. Samples were collected by hand auger at 60 cm depth across the main anomalies along the geophysical traverse lines. Till and head cover is generally 0.5 m to 2 m thick and it was considered that metal values in soils would reflect the presence of any significant sub-outcropping ore bodies.

Results

a. Pubil

All metal values (Figs. 7, 8) were low (maximum values of 80 ppm Cu, 40 ppm Pb and 130 ppm Zn) and it was concluded that no further examination of the anomalies by drilling was justified. The copper values display (Fig. 8a) weak anomalies sub-parallel to the fault, with all of the higher values east of the main dislocation and thus presumably related to weak enhancements in the Sron Bheag schist.

b. Cashlie

Till and head was from 0.3 to 1.5 m thick with a significant amount of down-slope solifluction. Metal values were very low (maximum values of 30 ppm Cu, 40 ppm Pb and 160 ppm Zn). The higher values, particularly for zinc, were related to seepage areas, some of which precipitated iron hydroxides. No significant pattern of higher values correlating with the geophysical anomalies is apparent from contoured maps of the metal values (Figs. 8b, 9) and no further work was proposed.

CONCLUSIONS

The present work has confirmed the existence of a narrow zone of weak stratiform sulphide mineralisation close to the top of the Ben Lawers schist, which extends along the strike from Glenshee in Aberdeenshire to Loch Fyne, Argyllshire. However, despite initial encouraging results in Glen Lochay the proportion of base-metal sulphides is generally small or non-existent.

There is strong evidence that the sulphides are synsedimentary and although there is an almost total absence of meta-igneous rocks within or immediately adjacent to the pyrite zone, a volcanic genesis from a distant source cannot be entirely ruled out. In this respect it is significant that the anomalies which have been detected (by the regional geochemical survey) in the Ben Lawers schist outwith the pyrite zone appear to correlate with areas containing meta-igneous rocks. However, present indications are that no significant quantities of strata-bound chalcopyrite are present in the Ben Lawers schists. Returning to the original parallel with the Stekenjokk area it is tempting to suggest that this absence reflects the lack of acid valcanic rocks. However in the Roros (Rui & Bakke, 1975) district, Norwegian Caledonides, massive stratiform sulphides (pyrite and pyrrhotite with chalcopyrite and galena) occur in rocks which are considered (Gee and Zachrisson, 1974) to belong to a southerly extension of the Seve-Koli nappe but are without acid volcanic horizons. Although the host rocks of these Norwegian deposits contain thin (?) meta tuffs Rui and Bakke (1975) stressed that the origin of the ores was not clearly volcanogenic.

Both geological and geophysical surveys failed to demonstrate significant increases in base-metal sulphide content where the mineralised zone is cut by major faulting. This conclusion, along with the low lead and zinc concentrations in the pyrite zone, suggests that the sulphides in the Tyndrum mining district were not derived from the adjacent metasedimentary rocks. It would seem more likely that the metals migrated up the fault zone from a deep-seated source or from another horizon and the relatively higher zinc content of the Auchtertyre section may be taken as evidence of some diffusion into the surrounding schists.

These studies in the Loch Tay area were terminated mainly because of the general lack of evidence of economic sulphides. The geophysical anomalies are probably caused by pyrite and graphite and it was therefore decided not to investigate them further by means of boring. However, in view of the along-strike persistence of the pyrite zone and the presence in the Ardrishaig phyllite (lateral equivalent of the Ben Lawers schist) of small ore deposits a similar investigation in the Loch Fyne area might prove more rewarding, relying mainly on geochemistry was undertaken and will be reported later.

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APPENDIX I

GEOLOGY OF THE AREA NORTH AND WEST OF LOCH TAY (Figs. 10A-10S)

Previous research

The area lies within the boundaries of one inch Geological Sheets 46 (Balquhidder), 47 (Crieff), 54 (Rannoch) and 55 (Blair Atholl). Descriptive memoirs have been published only for Sheets 54 and 55. Work subsequent to the primary survey has been usefully summarised by Johnstone (1966) though that of Elles (1926) merits particular attention since it is concerned primarily with the Ben Lawers area. The conclusions of Elles (1926) and Elles and Tilley (1930) regarding the Glen Lyon section were however disputed by Bailey and McCallien (1937). Excavations carried out in connection with the Breadalbane hydro-electric project during the 1950's provided much new exposure and whilst the tunnel records were discussed in detail by Johnstone and Smith (1965), Treagus's(1964) new structure synthesis was based on the examination of new rock cuttings.

Structure

The Dalradian Supergroup (Harris and Pitcher, 1975) consists of metasedimentary and meta-igneous rocks of late Precambrian to early Palaeozoic age which attained their present forms and disposition during the Caledonian earth movements. The earliest identifiable episode of folding involved the formation of immense nappe complexes and most of the rocks of the Southern Highlands lie within part of the Tay Nappe, a recumbent anticline closing to the south-east (Shackleton, 1958). The rocks of the Loch Tay area form part of the lower limb of this major fold with the important consequence that the established stratigraphical succession is now inverted. To the north of the area being discussed, the rocks occur on the lower limb of the complementary structure underlying the Tay nappe, the Ben Lui syncline, and in consequence the stratigraphical succession is the right way up. Later folding of the large nappes produced broad open structures having predominantly steeply dipping axial planes. The major example in the area of this later generation of folding is the northeasterly plunging Ben Lawers synform (Fig. 2). Elles (1926) invoked a slide (the Ben Lawers slide) to explain an apparent metamorphic hiatus at the junction between the Ben Lawers and Ben Lui schists. Although Bailey and McCallian (1937) rejected this interpretation, on the north limb of the Ben Lawers synform there is strong evidence (eg possible slide rocks and the local absence (Fig. 10P) of the Sron Bheag schist) of movement at this horizon on the south side. The absence of infolded Ben Lawers, Sron Bheag and Ben Lui schist strongly suggests the supposed slide was operative during the formation of the Ben Lawers synform. The junctions between the Ben Eagach and Ben Lawers schist have been interpreted as thrusts (Elles, 1926) but strictly speaking the more northerly is a normal fault. These thrusts were considered by Elles (1926) to belong to the episode of major folding which produced the Ben Lawers synform. However, at the northern end of Lochan na Lairige the southernmost junction is affected by minor folds associated with the formation of the above mentioned synform. Hence it would seem that movement on these planes was initiated early in this episode of folding.

The east-west extent of the Lawers-Tarmachan range is delimited by two major subparallel dislocations, the Loch Tay and Bridge of Balgie faults (Fig. 2). The Loch Tay fault has a north-easterly trend with a net sinistral displacement of 5.5 km. The Bridge of Balgie or Killin fault (Smith, 1961) trends more north-north-easterly and has a net sinistral displacement of not more than 3.5 km. Other smaller faults in the area north and west of Loch Tay generally show a north-south trend. Like the major dislocations these faults have not produced wide breccia zones. Movements are confined to several narrow bands of shear between which lie broken strata. In many areas their presence is detected only by strata displacement and conspicuous gullying.

Stratigraphy and lithology

The metasedimentary rocks of the area investigated belong to 5 main lithostratigraphical units which are shown in stratigraphical order on page 2. However, it should be remembered that in this area the rocks are inverted.

Carn Mairg Quartzite

Observations on the Carn Mairg quartzite were restricted to the outcrops at the northern end of Lochan na Lairige where the formation forms the core of a small synform. The quartzite consists mainly of a greyish white uniform rock, but pebbly horizons were also recorded.

Ben Eagach Schist

Thrusting and faulting on the north limb of the Ben Lawers synform has resulted in the frequent juxtaposition of the pyritiferous zone of the Ben Lawers schist and the Ben Eagach schist, and where possible the survey was extended into the dark schist. A thin limestone band is occasionally present at the junction of the two formations but in this area the Ben Eagach schist mostly comprises a fissile graphitic rock.

Ben Lawers Schist

Because the Ben Lawers schist is made up dominantly of calcareous and pelitic rocks the boundary with the Sron Bheag schist is generally sharp and unequivocal. Over much of the area the rocks are within the greenschist facies of metamorphism and comprise calcareous chlorite-muscovite-quartz-schists with small amounts of biotite and albite. Many of the schists appear to contain two carbonates (calcite and (?) ferroan dolomite) whilst epidote is only occasionally present. A higher metamorphic grade is evident on the north limb of the Ben Lawers synform with green biotite and hornblende growing at the expense of chlorite. In the more pelitic horizons rare garnets have been recorded. Bands and lenses of quartzite and calc quartzite occur at several horizons throughout the schists but are particularly prominent near to the junction with the Sron Bheag schist. The thicker horizons are of the order of 2-3 m thick but exceptionally may be up to 15 m. The calc quartzite bands, which figure prominently as hosts to the pyrite mineralisation, comprise an extremely friable white to pale buff massive rock with conspicuous brown and black iron staining on the weathered surface. In thin section they are seen to consist of a granoblastic aggregate of quartz, albite and carbonate (calcite and (?) ferroan dolomite) with epidote and chlorite.

A thin band of white or pink crystalline marble, seldom more than a few centimetres thick has been recorded structurally below the main calc quartzite in the pyritiferous zone. It is only locally developed, the occurrences being confined to the streams draining Creag na Caillich and a road cutting in Glen Lochay (Fig. 10M).

The dull grey (?) graphitic schist of the Edramucky Burn section (Fig. 10P) was considered by Elles (1926) to be an infold of Ben Eagach schist. Other sections, however, reveal intimate interbedding of the rock type with calc schists and it is possible that these dark schists are a facies variation within the Ben Lawers schist.

Sron Bheag Schist

Elles (1926) recognised a distinct lithological assemblage at the junction of the Ben Lawers and Ben Lui schists to which she applied the name Sron Bheag schist. Johnstone and Smith (1965), because they noted, in the tunnels, additional lithologies to those described by Elles invoked the name Transition Group. However, it is probable that the two names are synonymous and that these rocks are the lateral equivalents of the 'Farragon Group' of the Tummel area (Sturt, 1961). Since there is limited knowledge of the existence of the Sron Bheag schist outwith these areas it is omitted from Fig. 1.

The Sron Bheag schist comprises principally quartz-schist and quartzite with thin bands of mica-schist and garnet-mica-schist. These rocks are similar in many respects to the Ben Lui schist and in some areas the junction between the two groups is difficult to define. However the additional presence of a considerable thickness of hornblende-schist, together with a few horizons of calc-chlorite-schist, dull grey schist and limestone, serves to distinguish the Sron Bheag schist from the Ben Lui schist in most areas. In certain sections the quartzites are noticeably flaggy with thin micaceous partings and may represent slide rocks.

Ben Lui Schist

Because the investigation was primarily concerned with the survey of a zone of sulphide mineralisation within the Ben Lawers schist only the basal part of the Ben Lui schist was examined in detail. It is made up dominantly of rather monotonous finely crystalline quartz-mica-schists in which garnets are generally present. A distinctive fine banding caused by elongated aggregates of quartz is often apparent. Rare limestone bands occur locally.

Pre-Caledonian igneous rocks

In the Sron Bheag schist the more massive hornblende-schist bands are almost certainly meta-basic igneous rocks but whether they are of extrusive or intrusive origin is not certain. Many bands however consist of finely interbedded hornblende-and quartz-schists with the darker rocks dominant overall, though locally the quartz-schists may predominate. These rocks are thought to be metamorphosed admixtures of basic tuffs and quartzose sediments and hence resemble the green beds of the 'Farragon Group'.

Probable meta-igneous rocks are very common in the Ben Lawers schist though their frequency of occurrence appears to decrease towards the Sron Bheag schist. The rock type most commonly encountered is a dark dominantly chloritic schist which forms apparently concordant bands ranging in thickness from a few centimetres to several metres. They are readily identified in the field by their massive appearance and the absence of the quartz lenticles and stringers which pervade the adjacent metasediments. These meta-igneous rocks are less variable in appearance and lack the fissility and sericite content of the metasediments. They are regarded as metavolcanic rocks, a conclusion supported by their close association with finely striped calc chlorite-schists which (excepting the general absence of hornblende) appear very similar to the striped hornblende-schists of the Sron Bheag schist. But for a few relict plagioclase laths the original texture and mineralogy has been replaced by a granoblastic aggregate of quartz, epidote, calcite and chlorite (or hornblende in the higher-grade rocks).

Other types of meta-igneous rocks encountered in the Ben Lawers schists are much less common. Probable metagabbroic intrusions occur as masses in excess of 2 m in thickness. Presumably as a result of their greater bulk the metagabbros are less strongly deformed than the metavolcanic rocks; a foliation has developed only in certain zones and, in the more undeformed parts, a relict ophitic texture has survived. The dominant rock type consists of a coarse aggregate of pale green hornblende (with marginal chlorite) and plagioclase which shows all stages of replacement by epidote, quartz and carbonate. Bodies of finer grained amphibolitic rocks, ranging up to 5 m in thickness have been recorded in the Ben Lui schist, Sron Bheag schist and Ben Lawers schist. They are usually concordant with the earliest foliation but some have been found with margins that are cross-cutting. Boundinage is fairly common. Hornblende-schist with or without garnet and biotite is the dominant rock type of these bodies which are assumed to be meta-basalts and meta-dolerites. The only ultrabasic intrusion within the area is the serpentinite body which cuts Ben Lui schist at Corrycharmaig (Fig. 10F).

Post-Caledonian intrusive rock

Post-tectonic intrusions in the area are represented by narrow (generally less than 1 m) basic dykes. On Creag na Caillich (Fig. 10N) the Ben Lawers schists have been contact-altered by a sill-like body of appinite up to 50 m thick (Harry, 1952).

APPENDIX II

SULPHIDE MINERALISATION

Ben Lawers Schist

A definite horizon of weak, mainly pyrite mineralisation has been delineated in the Ben Lawers schists and has been shown to have considerable persistence along the strike (Fig. 1). In the area north and west of Loch Tay (Fig. 2) it varies from 10 to 330 m in width, attaining a maximum possible thickness of 180 m, and lies some 10 to 400 m below the base of the Ben Lui schist. The intervening ground is mostly occupied by the variable lithologies of the Sron Bheag schist formation.

The sulphide content is the only factor which distinguishes the pyritic zone, since the host rock is fairly typical Ben Lawers schist with no other obvious special features. The boundaries of the horizon appear to be quite sharp, and within its cross-strike limits the tenor varies erratically with considerable range in sulphide content (Figs. 11-13; Tables I-VI). The pyritiferous rock generally contains $\leqslant$ 5 per cent sulphide, but thin units within the sequence are notably enriched with the sulphide content exceeding 20 per cent.

The predominantly pyritic mineralisation takes the form of banded disseminations in both the pelitic schist and calc quartzite horizons. Pyrite typically occurs as single crystals and grains scattered throughout the rock, with a definite concentration along certain layers. Trace quantities of chalcopyrite and/or pyrrhotite sometimes accompany the pyrite.

The grain size of pyrite varies from a few mm to over 1 cm, with a tendency for individual crystals to be slightly coarser where more sparsely distributed in the rock or associated with quartz segregations. The crystal form is generally the cube, though pyritohedra have been observed.

Some mobilisation and recrystallisation of sulphides together with quartz and/or carbonate has taken place during the Caledonian earth movements.

The pyrite in the pelitic material is either in the form of a fine dissemination (crystals $\nless$ 2 mm) or as isolated cubes 3 to 8 mm across. The crystals sometimes attain larger dimensions. In the rich bands the sulphide occurs as a dense dissemination and is fairly equigranular and evenly distributed. Although the pyrite is concentrated along certain layers there is no evidence that individual cubes are other than entirely randomly orientated. Often it is found that the thin pyritiferous seams represent calc quartzite laminae along which the pyrite has preferentially grown. Although these laminae are subject to small scale lensing or incipient boundinage the pyrite is found to faithfully follow their line.

The form and habit of pyrite in the schist may vary considerably from normal cubic outlines. The crystals usually appear (Fig. 14) as elongated cubes, and lensed, barrel-shaped, rhombohedral or diamond-shaped forms are not uncommon. Tabular pyrite crystals contained by the foliation commonly have a dimensional ratio of 1:2:4 or 1:4:4, though ratios of 1:3:9 have been recorded. This elongation is obviously the product of growth under the confining pressure of diagenesis and/or regional metamorphism. Where strain-slip cleavage is strongly developed, curved, bent, or sigmoidal tabular forms are sometimes seen within the microlithons. Some tabular crystals are also aligned with the slip-strain cleavage. Clearly, crystals were developing at different stages throughout the successive deformation episodes and must be considered syntectonic to some degree. There is at the same time good evidence that many of the crystals were deformed during the development of the major cleavage in the rocks and hence are probably of pre-tectonic origin. Pyrite is often well developed in the calc quartzite horizons. These horizons are more common in the middle of the pyritic zone and their occurrence is often coincident with the climax in sulphide concentration. While the calc quartzites are usually highly pyritiferous, the sulphides can exhibit a marked selectivity for certain narrow bands within a particular horizon. Thus a pyrite-enriched band may occur adjacent to a barren one, often with a noticeable concentration at the boundary. In contrast to the pelitic schist, the pyrite grain size becomes larger and more varied with increasing sulphide concentration in the calc quartzites.

The pyrite has the following modes of occurrence in the calc quartzites:

i. A fine streaked dissemination of elongate cubes orientated with the foliation.

ii. A more uniform dissemination of crudely aligned cubes ($\nless$ 3 mm), shreds and patches (maximum dimensions $\nless$ 5 mm).

The host rock of type (i) tends to be less massive and more highly folded than that containing type (ii) which probably explains the high degree of crystal elongation of the pyrite. In both instances the pyrite also concentrates into thin seams parallel to the foliation. These enriched seams are very variable in thickness and take the form of ill-defined strings studded with coarsely crystalline pyrite and clots of loosely aggregated pyrite often merging into a network of discontinuous thin threads of fine pyrite.

The richer bands of both types often contain small blebs and pockets of recrystallised quartz which envelope the pyrite. In flaggy calc quartzite thin recrystallised quartz laminae often develop. Pyrite cubes elongated parallel to the foliation often occupy the full width ($\nless$ 1.5 cm) of these quartz lits. Small cross-fractures and partings in the calc quartzite may also contain remobilised pyrite accompanied by quartz and/or carbonate. Most segregated material is concordant with the foliation. However occasionally large discordant irregular quartz segregations occur where the calc quartzite horizons have been fractured. In these segregations the pyrite either occurs as loose aggregates of irregular form or large malformed crystals up to 4 cm across. Some elongation of the pyrite along the foliation usually takes place and rounded or oval forms are not uncommon.

Recrystallised quartz occupies the pressure shadows of the larger sporadic pyrite cubes (≯ 3 mm). Other cubes show a fine granular texture or are often mantled by very fine pyrite which forms a lenticular envelope. Most of these must have been pretectonic or early syntectonic and have probably undergone cataclasis and recrystallisation.

Crystals in the size range 0.5-3 mm which belong to type (ii) frequently possess ragged edges though their cubic outlines are often partially or wholly preserved. They also have a sieved texture, the result of granular quartzo-feldspathic inclusions which in some instances resemble the surrounding schist. However in other examples the pyrite appears to have been corroded.

There are also a subordinate number of well-developed striated cubes of pyrite with perfect crystal form which are scattered randomly through the calc quartzite and are considered to be post tectonic. Apart from Allt a' Bhorland [NN 554 361] where the pyrite content is as much as 20 per cent, the thin marble sometimes found in the pyritiferous zone seldom contains an appreciable quantity of sulphide. The mode of occurrence of the pyrite in the marble is very similar to that in the calc quartzites:crystals up to 2 cm across are crudely aligned in seams, though possibly a little more randomly distributed. They seldom have a perfect crystal form: they are often wedge-shaped and/or have curved crystals faces or form interpenetrant twins. They often exhibit an irridescent tarnishing which is rarely seen elsewhere.

Within the sulphide zone, trace or minor chalcopyrite is generally associated with the pyrite. There is a notable concentration of chalcopyrite in the upper half of the pyritiferous zone exposed in a road cutting in Glen Lochay [NN 538 354]. Although it may occasionally be found very sparsely distributed in the schist, chalcopyrite is most commonly seen in or adjacent to concordant quartz/carbonate segregations. Quartz predominates in these segregations, and usually forms a central lenticular core surrounded by carbonate (Fig. 15a). The carbonate may also occur interstitially to the quartz in less differentiated segregations. Sulphide concentrations containing chalcopyrite develop at the boundaries of the segregations (Fig. 15b). The quartz cores of the segregations are invariably barren. Carbonate-free quartz segregations have been found with marginal chalcopyrite, particularly where the surrounding rock is decidedly cupriferous. These segregations are well displayed in the sulphide-rich bands in the Auchtertyre section (Fig. 13, 160-200 m) where chalcopyrite is also seen as irregular threads and filamented patches within the rock.

The sulphide mineralisation associated with the quartz/carbonate segregations consists of pyrite with subordinate chalcopyrite forming composite patches that rarely exceed 1 cm across. Chalcopyrite with its allotriomorphic habit forms irregular patches, smears and specks in close association with the pyrite. It is often seen to cement broken or cracked pyrite crystals and weld them into irregular aggregates and formless patches.

Outwith the pyrite zone the Ben Lawers schist displays minor showings of pyrite and chalcopyrite, pyrrhotite being only rarely present. The form of the pyrite in the schist is extremely variable, ranging from discrete crystals seldom larger than a few millimetres to irregular aggregates or, more rarely, thin seams parallel to the foliation. Occasionally larger crystals have developed in the more quartzose horizons. There appears to be no lithological control however over the development of the very large crystals of pyrite on the summit of the ridge between Meall Tarmachan and Creag na Caillich ridge [NN 586 388 to 563 378] where crystals show significant elongation which McNair (1908) concluded was the result of simple shear. The zone in which they are found can be traced for several tens of metres along the strike though it seldom exceeds a few centimetres in thickness. Other similar zones containing very large pyrite crystals were located but it is not known whether they represent the same horizon repeated by folding.

Chalcopyrite is much less common than pyrite in the schists but its abundance appears to increase adjacent to the metavolcanic horizons. Chalcopyrite and pyrite are occasionally present in the ubiquitous quartz segregations.

Sron Bheag Schist

Fine disseminations of pyrite and, more rarely, pyrrhotite were frequently encountered in the hornblende-schists and quartz-schists of the Sron Bheag schist formation. In Glen Lochay, Glen Lyon and Fin Glen a thin horizon of quartz-schist some 15-20 cm thick and occurring between two hornblende-schist bands is noticeably enriched in pyrite. The pyrite in the Falls of Lochay section [NN 543 351] mainly occurs as discrete crystals up to 0.5 cm in size but in Glen Lyon and Fin Glen it is present as a fine dissemination.

Pre-Caledonian Igneous rocks

Pyrite is common in the hornblende-schists and amphibolites regarded as meta-gabbros and meta-basic dykes. The concentration however is not anomalously high for such rocks. Copper minerals have seldom been recorded in the metagabbros outwith the Lochan nan Cat area. In the metavolcanics pyrite is rare, but locally there may be minor concentrations of chalcopyrite with associated malachite.

Ben Lawers - Ben Eagach Schist junction

Slight mineralisation was noted at the junction between the Ben Lawers schist and the Ben Eagach schist at the northern end of Lochan na Lairige (Fig. 10D). Along the contact, which is probably a slide contact, there is the occasional development of remobilised quartz carrying pyrite, pyrrhotite, galena, and chalcopyrite. Sturt (1961) recognised a similar type of mineralisation near the same horizon at several localities south of Loch Tummel. He states that the mineralisation in that area appears to be later than the F_3 movements.

APPENDIX III

GEOPHYSICAL SURVEYS

a. Pubil (Fig. 3)

General Geology

The rocks in this part of Glen Lyon lie on the lower limb of the recumbent Ben Lui syncline and in contrast to the assemblages in the Loch Tay area are the right way up. East of the Garabal fault the overall dip of the bedding is to the south or south-east, but in the Pubil area (Fig. 16) the disposition of the rocks suggests there has been a subsequent modification by southerly-plunging folds.

The area surveyed is traversed by the north-north-east trending Garabal fault and a conspicuous zone of crush is evident in the Allt Phubuill (Fig. 16). Johnstone and Smith (1965) suggest that this crush lies along the principal line of dislocation in a fracture zone that is up to 0.5 km wide. Thus west of the fault the Ben Lawers schist is intensely contorted, disrupted and frequently brecciated. East of the fault, however, the Sron Bheag schist shows little disruption. The north-south fault in Allt Camaslaidh (possibly a splay of the main fault) has little attendant crush.

The Garabal fault forms the boundary between the Sron Bheag schist and the Ben Lawers schist. All rocks have undergone amphibolite facies metamorphism and in the Ben Lawers schists there is evidence of subsequent minor retrogression. Presumably as a result of the higher metamorphic grade garnetiferous schists in the Sron Bheag schist are more abundant than in the Loch Tay area. Although the succession in the Sron Bheag schist is again dominated by siliceous rocks, calcareous horizons are also more common than to the south. The hornblende-schists are predominantly of the more massive type (p. 7) and are occasionally transgressive. The calcareous horizons are contained in bands of silvery-green biotite-muscovite-quartz-schist and generally occur as rounded or lensoid blocks.

Several horizons in the Sron Bheag schist have a dull grey 'graphitic' colour and in thin section were seen to contain abundant carbonaceous granules (Appendix VI). The same colouration is apparent in dark compact schists of restricted occurrence which show occasional banding and resemble hornblende-schists (eg CX304, 306). No amphibole was however seen in thin sections though it is possible that, like biotite, the mineral has been pseudomorphed by fairly disseminated sulphide and carbonaceous material.

The Ben Lawers schists (Fig. 16) comprise mainly calc hornblende-biotite-muscovite-quartz-schists in which a garbenschiefer texture is frequently developed. Bands and lenses of quartzite and calc quartzite are common; those of (meta-igneous) hornblende-schist less so. An unusual feature of the abundant quartz and quartz-calcite segregations is the occasional presence of feldspar.

Pyrite is sparsely distributed throughout the Sron Bheag schist both within rocks and on joints. Concentrations in the calc and hornblende-schists are high relative to the siliceous-schists but the highest values occur in the dark compact schists (Appendix II) where the mineral is generally stratiform. The pyrite zone (Fig. 16) in the Ben Lawers schist which extends NW of the fault has an across-strike width of 160 metres. It contains only pyrite but the occasional presence of associated malachite suggests that some of the sulphide present might be cupriferous. Traces of pyrrhotite are present both in the Ben Lawers and Sron Bheag schist.

Apart from sparse finely disseminated pyrite and rare chalcopyrite with malachite the crush zone is devoid of mineralisation. There is no apparent increase in the sulphide content of the pyrite zone towards the crush; neither is this area enriched (cf Table I with II and V) relative to pyritiferous Ben Lawers schists remote from these major faults.

Geophysical Investigations

Magnetic, IP and resistivity measurements were made along the traverses shown in Fig. 16. The total intensity of the magnetic field was sampled at intervals varying from 5 to 15 metres depending on the field gradient. Measurements of chargeability (IP effect) and resistivity were made using the 'dipole-dipole' electrode array with dipoles 30 metres long and centre-to-centre separations ranging from 60 to 180 metres.

Fig. 17 shows the results obtained on traverse O, crossing the estimated line of the Garabal fault and extending well into the Ben Lawers schist on one side and the Sron Bheag schist on the other. The IP and resistivity results are presented in the form of a 'pseudo-depth-section'. To the west of 200 E the magnetic field profile is relatively featureless apart from a 100 gamma anomaly about 50 metres west of the Allt Phubuill stream, and chargeability values are low. East of 200 E the magnetic field becomes disturbed and the values of chargeability increase substantially.

The situation is complicated by the Hydro-electric tunnel which crosses the traverse obliquely at about 320 E (Figs. 4 and 16). The coincidence of high chargeability, low resistivity and a magnetic anomaly close to the tunnel suggests that it is affecting the geophysical measurements. However, on other lines the largest anomalies do not occur over the tunnel and the chargeability map in Fig. 4 confirms that it has only a limited effect. Resistivities are generally high and vary considerably from under 1000 ohm metres to over 10000 ohm metres. Lower values occur over the stream (Allt Phubuill) and around 200 E where the change in the values of the chargeability and magnetic field takes place, but there is no indication of any significant change in resistivity between Ben Lawers and Sron Bheag schists.

The differing geophysical response of the two groups of rocks indicated by the results for line O is clearly illustrated by comparing the profiles for line 250 N (Fig. 18) and 230 S (Fig. 19), though on the more northerly line the geophysical discontinuity lies about 180 metres east of the mapped position of the fault. This line (250 N) lies partly in the rocks of each group. To the west of 470 E the profiles show low chargeabilities and a smooth magnetic field; to the east, the field shows some variation and there is a large increase in chargeability. Line 230 S, lying almost entirely in Sron Bheag schist to the east of the fault, shows larger magnetic and chargeability anomalies along most of its length. However the values decrease to near background again in the extreme east (beyond 260 E) indicating that the source of the anomalies lies within a band about 300 metres wide to the east of the fault.

This is confirmed by the chargeability map presented in Fig. 4 which shows contours at a dipole separation of 60 metres (smallest separation, minimum depth of penetration). The line of the geophysical discontinuity is indicated and it is suggested that this may represent the true position of the Garabal fault. The contours also indicate the effect the tunnel has on IP measurements, and this can easily be distinguished from the main feature - a linear high chargeability anomaly trending approximately NNE.

To the west of this anomaly, chargeabilities are low in spite of the metallic mineralisation observed in Allt Phubuill, implying that this mineralisation is not sufficient to cause an appreciable IP effect.

The correspondence between the highest IP and magnetic anomalies on line 230 S (Fig. 19) indicates that the anomalies here arise in part from metallic mineralisation with some magnetic component (probably pyrrhotite or ilmentite). The anomalies at the western end of the line (centred near the base-line at O) indicate a source at depth, dipping to the west, whilst those in the east (230 E) suggest a more disseminated source (there being no associated resistivity expression) near to the surface.

On line 250 N (Fig. 18) the negative magnetic anomaly at the west end of the traverse occurs over a mound in the topography and is unaccompanied by anomalous electrical values. It may be caused by a dyke (a small outcrop having been located in Allt Phubuill) or possibly an artificial source perhaps related to the Hydro tunnel, (Fig. 4).

Fig. 20 (line 110 S) gives an example of an IP anomaly (at about 230 E) which does not extend to the surface and so is not revealed by the shallow level plot of Fig. 4. It is not obvious whether it is associated with the magnetic anomaly at 250 E.

Petrographic notes on specimens collected from the area of high chargeability are given in Appendix VI. In conclusion significant chargeability anomalies occur within a zone about 200 m to 300 m wide, on the east side of the fault, within the Sron Bheag schist (Fig. 4). An analysis of 5 specimens from this zone showed that they all contain an abundance of 'carbonaceous granules', sometimes containing crystals of graphite (Appendix VI). It is concluded that this is the principal cause of the large IP anomalies. Certain of the anomalies, which apparently have associated magnetic disturbances (particularly on line 230 S), may be caused in part by metallic sulphides which include pyrrhotite.

b. Cashlie (Fig. 3)

Initial reconnaissance work and desk studies outlined this area as a possible site for sulphide enrichment at the intersection of an approximate north-south trending fault with the weakly mineralised pyritiferous horizon (Fig. 21). Preliminary inspection showed pyrite to be present in the stream 150 m west of the supposed fault line. However subsequent geological investigations have led to the conclusion that this supposed fault is absent. Unpublished work by M. McGregor suggests a continuity of strike inferred from limestone outcrops (Fig. 21). Though this limestone horizon was not recognised in the Allt Cashlie section during this current investigation, calcareous lithologies are present where the limestone might be expected to intersect the stream. There now seems to be little evidence for a fault; any apparent discontinuity can be explained by NW-SE flexures which would tend to support McGregor's interpretation. Thus, there is little chance of local fault-controlled sulphide enrichment, though this does not preclude any purely strata-bound concentration.

Geology

The area surveyed consists of Ben Lawers schist with a weakly developed pyrite zone on the higher ground towards the north, overlain by Sron Bheag schist on the lower slopes (Fig. 21). There is a similar disposition of rock groups to that found east of the Garabal fault at Pubil (p. 11); they are situated on the south-west flank of a south easterly plunging antiform. Apart from stream sections, exposure is mostly confined to the higher ground where there are a large number of craggy terraces and scarps. The Sron Bheag schist consists of both calcareous and siliceous lithologies with hornblende-schist. The main rock types include massive-flaggy quartzites with rare pebbly horizons, micaceous quartzites, calc quartzites, quartz-mica-schists, siliceous garnet-mica-schist, calc quartz-mica-schists and calc chlorite-muscovite-schists. As well as distinct hornblende-schist bands, there is the occasional development of hornblende in the calc and calc-quartz-mica-schists. The more pelitic rock types are usually garnetiferous with a tendency for the garnets to become smaller and fewer in number near to the Ben Lawers schist.

Loose blocks of dark grey schist, and black biotitic schist with a thick weathered iron oxide surface were found amongst the float and the stream debris. However much of this material may have been derived from the Ben Eagach schist on an Grianan (NN 481428). One stream exposure, consisting of very dark, almost black biotite-schist with sparse finely disseminated pyrite lies 75 m upstream of a ruined footbridge on a small stream east of Allt Cashlie (Geophys. Traverve Line 300 S; 110 E).

Geophysical Investigation

Fig. 21 shows the arrangement of geophysical traverses, along which the parameters measured were the same as at Pubil.

Contour maps of apparent resistivity and chargeability corresponding to a dipole separation of 90 metres (ie n = 3 dipole lengths or 90 metres between the centres of the receiving and transmitting dipoles) are shown in Fig. 5. There is no feature corresponding to the mapped fault, but a prominent anomaly running parallel to the geological strike was measured in the south-east of the area surveyed. Values of the resistivity fall to less than 100 ohm metres compared to a background of several thousand ohm metres, and chargeabilities reach over 70 milliseconds compared to a background of about 20 milliseconds. A contour map of specific capacitance (chargeability/resistivity x 1000), Fig. 22a shows the anomalous zone more prominently.

Fig. 23 presents the pseudo-sections and magnetic profile for line 240 S which show that the anomalous values are highest at depth (lowest in the case of resistivity). The anomaly must be enhanced and distorted to some extent by the oblique angle which its source makes with the traverse. The gap in the magnetic profile around 380 E signifies a prominent magnetic anomaly of unknown amplitude; the magnetic gradient was too steep to be measured by a proton magnetometer, which was the only instrument available. The feature is not seen in any other traverse, so its source must be of limited strike extent and may not therefore be associated with the source of the resistivity and chargeability anomalies; it is clearly narrow and near to the surface.

A second magnetic anomaly of about 400 gamma is centred at 150 E on this line and coincides with a weak chargeability 'high' and resistivity 'low'. Although these chargeability and resistivity anomalies are much weaker than those to the east, it is possible to trace them north-eastwards, parallel to the geological strike, on the contour maps in Fig. 5; there is also some indication of a similar extension of the magnetic anomaly, indicated by the dotted line in Fig. 22b.

In conclusion there is no geophysical evidence to support the existence of a fault, and the alignment of the IP and resistivity contours parallel to the limestone band indicates continuity across the supposed fault (Fig. 5). The lack of magnetic or geochemical correlation with the principal anomaly suggests that it may be caused by a narrow band of carbonaceous material, or possibly a band containing pyrite.

c. Corrycharmaig

Geology

The geological map of the area (Fig. 24) is based on the six inch mapping of the original survey but also includes amendments recorded during subsequent economic investigations (Anderson and others, 1949) and the present work.

Corrycharmaig is situated (Fig. 2) on the northern limb of the Ben Lawers synform and is underlain principally by Ben Lawers and Ben Lui schist. Flaggy quartzites and quartz-mica-schists of the Sron Bheag schist form prominent crags south of Dun Garbh Beag but their easterly along-strike extension into the surveyed area was not established. Near the contact with the Sron Bheag schist the Ben Lui schist is cut by a roughly elliptical shaped ultrabasic body with a maximum diameter of 550 m. The dominant rock is an antigorite - serpentinite but most of the western side comprises a talc-breunnerite rock. The intrusion is presumed to be of pre- or early Caledonian age because the crude foliation is parallel to that of the surrounding schists.

The Bridge of Balgie fault is shown as running west of Allt Coire Charmaig, but no shattering was observed in the tributary stream south-east of Dun Garbh Beag. However there is some evidence of faulting in Allt Coire Charmaig suggesting the fault may, like the Garabal fault (p. 11) comprise a zone of fracturing.

The presence of the pyrite zone in the Ben Lawers schist was established in the stream south of Dun Garbh Beag but its lateral extent and width, because of poor exposure, are not known. No evidence of copper mineralisation was seen in this zone but disseminations of chalcopyrite and pyrite were occasionally observed in meta-igneous (hornblende-schist) horizons. Chromite is sporadically distributed through the serpentinite with a noticeable concentration on the northern margin.

Geophysical Investigations

The location of the geophysical lines is superimposed on the geological map on Fig. 24. The main area of investigation was in the vicinity of the Bridge of Balgie fault where it was expected that it should intersect the mineralised zone.

Initially, EM, magnetic and IP measurements were made along lines 80 NE to 80 SW inclusive, but the magnetic results were rendered uninterpretable by the presence of magnetic boulders originating from the serpentinite intrusion and there were no appreciable EM anomalies. Efforts were therefore concentrated on IP measurements which proved more useful.

The resistivity and chargeability results along line 40 NE shown in Fig. 25 are representative of those obtained on other lines. The principal anomaly at the north-west end of the profile was the subject of further measurements along extended traverses on lines 40 and 120 NE which are described below. Elsewhere there is no great variation: chargeabilities tend to rise with depth, reaching a maximum at dipole separation n = 4 (corresponding to a true depth of perhaps 40 metres). The most significant rise in chargeability is that at 50 NW since it is associated with marginally lower resistivities and extends to adjacent lines, as indicated by the zone of weak IP anomaly on Fig. 24. This may reflect an increased concentration of sulphides, or a variation in the clay content. No appreciable anomalies were measured on lines further to the south west (80, 320 SW) though they all show an increase in chargeability with depth. The only effect over the mapped pyrite zone (Fig. 24) on line 320 SW is a reduction in resistivity which is likely to be caused by wet ground around the stream junction.

The anomaly at the north west end of the profile shown in Fig. 25 was further investigated by extending lines 40 and 120 NE and using a 40 metre dipole array to give more information at depth. The results (Fig. 26) define an anomalous zone of substantially increased chargeabilities and reduced resistivities extending to depth on both lines. The zone is adjacent to the serpentinite intrusion and runs close to a small stream (Fig. 24). It is possible that it is caused by an extension of the serpentinite to the east, as it is known that serpentinite can give rise to large IP effects (Seigel, 1967).

In conclusion, the only indication of an enrichment of mineralisation associated with the pyritiferous horizon and the Bridge of Balgie fault is a small zone of higher chargeabilities trending NE-SW in the east of the area surveyed (Fig. 24).

d. Easter Achtar (Fig. 3)

Geology

The Loch Tay fault is thought to intersect the top of the Ben Lawers schist approximately 300 metres south of Easter Achtar (Fig. 27) but as no unambiguous exposure exists immediately west of the fault, this could not be confirmed. The fault line appears to be defined by a row of small bluffs east of the road. Smears of breccia were recorded on some faces but for the most part they comprise hornblende-schist with thin horizons of mica-schist.

Geophysical Investigations

The location of the geophysical traverses is shown in Fig. 27; the topography rises steeply to the east and west from about 100 metres either side of the fault. The principal traverses (00, 230 N and 660 N) have their origins beside the road and the extra short traverses are tied to these. IP and resistivity measurements were made with 30 metre dipoles and a constant dipole separation of 90 metres between them (ie centre to centre, n = 3). These were supplemented by depth sections using several separations (n = 2 to 6) in areas of increased chargeability.

No large or extensive anomalies were found. West of the road chargeabilities were low, being generally less than 15 milliseconds, but values above 25 milliseconds were measured on line 00 at the greatest dipole separation (ie n = 6, corresponding to greatest depth of investigation) near 410 W (labelled A on the figure). No comparable values were measured on lines 100 N and 100 S however. Magnetic anomalies were generally less than 50 gamma.

East of the road, chargeabilities were higher, reaching 30 milliseconds, with lower restivities than in the west of the area; the higher values occur in the vicinity of the topographic bluffs believed to define the fault. Best geophysical indications of mineralisation are around 100 E on line 660 N where chargeabilities of over 25 milliseconds occurred together with a magnetic anomaly of about 400 gamma, but it is not clear what effect the power lines in the vicinity had on the magnetic results. Similar values of chargeability were recorded at about 150 E on lines 280 N, 230 N and 180 N, (labelled B on the figure) coinciding with a topographic rise, and on line 00 at about 75 E.

e. Meall Luaidhe (Fig. 3)

Geological and geophysical work was carried out over the trace of the Bridge of Balgie fault near to the location of a NE-SW trending lead vein exposed on the north-west flank of Meall Luaidhe (Fig. 28). The Allt Bail a' Mhuilinn stream section which traverses the possible south-easterly extension of the mineralised vein reveals scattered mineralisation that is particularly well developed in fault breccias and shear zones associated with the main fault. The geophysical surveys were conducted in order to determine whether significant metalliferous concentration occurs along the Bridge of Balgie fault and to locate possible extensions to the known mineral vein.

Geology (Fig. 28)

In the stream section to the south of the fault the exposed rocks are flaggy siliceous garnet-mica-schists of the Ben Lui schist formation. These rocks dip gently to the south or south-south-east, exhibit very little disturbance, and are entirely devoid of sulphides. Traversing northwards through the fault zone one passes through variable lithologies, possibly of Lower Dalradian age, and thereafter into flaggy psammitic rocks of the Moines.

Rock types within the fault zone and for a relatively short distance to the north consist mainly of flaggy quartzites, micaceous quartzites and quartz-schists which are sometimes garnetiferous. There is also a conspicuous zone of massive bedded quartzose grits overlain by a green calcareous chlorite-mica-schist, containing large sporadic pyrite cubes, which grades into the quartzites. Bands of garnetiferous hornblende-schist, garnet-mica-schist, quartz-chlorite-garnet-mica-schist, grey siliceous mica-schist and thin metavolcanic horizons are also present. The more competent quartzites and more siliceous rock types contain most of the sulphides, mainly pyrite and galena but sometimes with lesser amounts of chalcopyrite, sphalerite and/or pyrrhotite. The mineralisation is structurally controlled, being generally confined to joint planes, shear zones and thin fault breccias, often accompanied by a certain amount of quartz or calcite. Sulphide mineralisation is also present in the Moine rocks, with the concentration apparently decreasing with increasing distance from the main fault line.

The main fault zone of the Bridge of Balgie fault trends at about 55 degrees. There are a number of breccia zones often flanked by laminated cataclasite and sheared or mashed quartz rock with much recrystallised quartz. In the breccias the galena occurs as a fine dissemination associated with pyrite or as scattered cubes up to 0.5 cm diameter. It is seen as smears on shear surfaces in the more micaceous material. Late basaltic dykes (5-6 m thick) have been intruded into some fault zones and have enveloped areas of breccia. A few barren quartz veins up to 60 cm thick are also found.

Geophysical Investigations

Geophysical measurements of the total magnetic field and induced polarisation/resistivity were made over the traverses shown in Fig. 28. The IP measurements were obtained using the dipole-dipole array, with dipoles 30 metres long and centre-to-centre separations varying from 60 to 180 metres.

Resistivities were generally high, of the order of 3000 ohm metres, except in the vicinity of the stream where values dropped to less than 1000 ohm metres. East of the fault, chargeabilities were generally less than 10 milliseconds on all lines except on traverse 00 near and over the stream where values of up to 25 milliseconds were observed. West of the fault on traverses 60 S and 180 S, a broad zone of higher than background chargeability was found between 60 W and 300 W. Maximum values of greater than 40 milliseconds were measured on traverse 180 S. The IP effects may be caused by an extension of the disseminated mineralisation seen in the stream. There was little magnetic fluctuation on any of the lines.

The results provide no indication of an extension of the vein, but EM traverses nearer the known exposure may prove more informative. This was not possible at the time because of instrument failure.

APPENDIX IV

BASE METAL GEOCHEMISTRY

Choice of sections

To assess the content and distribution of the common base metals within the pyrite zone six cross-strike sections (Fig. 6) were selected for detailed rock sampling and analysis. The sections sampled demonstrate the variations seen in lithology and sulphide content of the pyrite zone. The following account will first cover the pyrite zone in 'normal aspect' and then the variations of it that have been found. Only the three graphically illustrated sections (Figs. 11, 12, 13) and the Allt Phubuill section (Table IV) will be described, since they cover all the essential features.

Sampling procedure

The sampled sections were chosen because of their fairly continuous exposure across the pyrite zone. They were divided into 10, 20 or 25 m intervals, and a rock chip was taken at every metre division in a particular sample length, where exposure permitted. Hand-specimens 8-10 cm in diameter were taken for a 10 m sample length, whereas chips 2-5 cm in diameter, walnut size, were sufficient for the larger intervals. Visual sulphide estimates were made as the sampling was carried out.

Methods of Analysis

The rock samples were crushed, sub-sampled and powdered prior to analysis for Cu, Pb, Zn, Ag, Mo, Ni and Fe by Atomic Absorbtion Spectrophotometry (AAS) and for Au by Neutron Activation Analysis (NAA). Hot nitric-perchloric acid digestion of the rock powders for AAS analysis, as used by IGS, will extract all of the metals from sulphides but only partially from silicate minerals. Thus, where metals are in the silicate lattice, such as Pb in feldspar or Cu and Zn in ferromagnesians (amphibole, biotite), their concentration will be underestimated.

Geology

The Allt a' Bhorland stream section (Fig. 11, Table I) about 3 km NNW of Killin can be regarded as a typical development of the pyrite zone. The rocks are dominantly calc chlorite-sericite-schists with prominent calc quartzite horizons that reach their maximum development in the middle of the zone. The pyrite seldom exceeds 3-5 per cent in the schists but can form more than 20 per cent by volume in the quartzites.

At Brerachan Water (Fig. 12, Table II) some 8 km NE of Pitlochry, the sampled stream section traverses part of a thick sequence of hornblende-schists and amphibolites - the Farragon Group - that lie at the same stratigraphic level as the Sron Bheag Schist in the Loch Tay area. The Farragon Group also includes laminated hornblendic rocks with intercalations of chlorite-schist and quartzose material that is often calcareous. There is no clearly defined division between the Farragon Group and the Ben Lawers schist as is common with the corresponding formations in the Loch Tay area. It will be noticed (Fig. 12, Table II) that hornblende-schists/amphibolites and chloritic metavolcanic horizons continue to occur sporadically in the Ben Lawers sequence throughout the section.

In the Auchtertyre section (Fig. 13, Table III) the Ben Lawers schists are interdigitated with a thick sequence of fairly uniform saccharoidal quartzites, micaceous quartzites and quartz-mica-schists. Pebbly horizons were not recorded in the stream section but are present on the nearby slopes of Beinn Chaorach. In the Crom Allt section 2 km to the south-west of Auchtertyre, the Ben Lawers schist within the pyrite zone is very siliceous, but true quartzite is absent. The section in Allt Gleann a' Chlachain, about 5 km to the NNE indicates also that the pyrite zone is fairly siliceous and contains thick calc quartzites. It is possible that the very siliceous nature and the presence of quartzites could represent a local facies change in the Ben Lawers schist sequence, possibly presaging the major change in conditions that led to widespread turbidite sedimentation characterised by the incoming of the Ben Lui schists. If this is the case, then these rocks could be classed as Sron Bheag schist material. Nevertheless, it is emphasised that the position of the pyrite zone at Auchtertyre with respect to the base of the Ben Lui Schist is comparable with other parts of the belt.

In the Allt Phubuill stream section (Table IV), 1 km NNW of Pubil, rocks of the pyrite zone occur in a zone of faulting (Fig. 16). The stream section is on the line of the Garabal fault and exposes several prominent dislocations separating areas of severe buckling, brecciation and shearing. The principal fault planes occupy a prominent stream gorge trending at 25-30°. They separate highly sheared and contorted Ben Lawers schists north-west of the fault from flaggy micaceous quartzites and quartz-mica-schists of the Sron Bheag schist formations to the south-east. The stream section was sampled across the main smash zone and extended over contorted rocks of the pyrite zone (Table IV).

Geochemical Characteristics

Within normal pyrite zone material as typified by the Boreland Stream section (Fig. 11) both average and maximum percentage sulphide estimates tend to climax structurally in the middle or upper half of the sections. Probably because of the fairly large sampling intervals there is a poor correlation of percentage sulphide and copper contents although both values tend to peak in the same sample interval. The sample interval 140-160 m in the Boreland Section (Fig. 11) gave the maximum recorded copper content of 340 ppm (Av% pyrite = 1%; Max% pyrite = 20%) for normal pyrite zone material. However, mineralogical examination of samples from this section showed them to be devoid of chalcopyrite.

Generally, where copper values exceed 200 ppm, chalcopyrite was identified in the field. Zinc values in normal pyrite zone material tend to be low, commonly in the range 50-70 ppm (Max. 130 ppm). However, in the Allt a' Bhorland section where the massive sulphide-bearing calc quartzites are well developed, the zinc content is unusually low (10 ppm). Lead values are consistently very low (10-30 ppm) except for sample interval 240-260 m in the Allt a' Bhorland section which yielded a relatively high value of 90 ppm.

As can be seen from the results from the Brerachan Water section (Fig. 12) the sulphide and base metal contents of the meta-igneous rocks which lie structurally below the pyrite zone vary more erratically than within the zone described previously. The pyrite is generally more abundant, but has a more erratic distribution than normal pyrite zone material. High sulphide contents generally correspond with intervals where massive amphibolite or hornblende-schist is the sole representative rock type. This is also reflected by the copper contents to a limited extent. Except for interval 20-30 m which contains part of a thick unit of hornblende-schist giving higher sulphide contents, the laminated hornblendic admixture gives very low copper values ($\leq$25 ppm). It is distinctly separable from the massive hornblende-schists regarding copper, zinc and to some extent lead contents.

The pyrite zone of Brerachan Water shows a closer correlation of zinc values (10-80 ppm) and total sulphide contents than normal pyrite zone material. Copper values (10-125 ppm) show a similar trend, but it will be noticed that, unlike zinc, the copper contents relative to total sulphide are somewhat higher in the presence of hornblende-schists and chloritic metavolcanic rocks.

When compared with more typical pyrite zone material it is seen that the copper and zinc values from the sampled section at Auchtertyre are much higher relative to the total sulphide content ($\leq$0.8 per cent pyrite) (Fig. 13). This is explained by the presence of a number of thin pelitic bands which are very rich in base metal sulphides. For instance, the interval 180-200 m giving the highest recorded copper and zinc values has sulphide contents 0.1 per cent for ninety per cent of its length.

Copper and zinc contents are exceedingly variable. Copper values range up to 1400 ppm but are mostly limited to values less than 430 ppm, whereas zinc values range up to 4500 ppm but are generally below 1800 ppm. In contrast with the other sampled sections zinc values are more often greater than copper values. From a graphical plot of copper versus zinc two distinct trends are recognisable lying along lines with slopes of Cu:Zn = 7.5 and Cu:Zn = 1:12 but these do not show any obvious relationship to differing rock types.

Lead values from the Auchtertyre section mostly range between 10 and 20 ppm and are similar to those of the normal pyrite zone material as typified by the Allt a' Bhorland section. Sample interval 40-60 m gave 160 ppm lead, and it is worthy of note that this sample also gave the highest recorded zinc : copper ratio of approximately 17:1. However, there is no apparent relationship between the lead and zinc values in the Auchtertyre section.

From Table IV it can be readily seen that there is a uniformity in total sulphide and base metal contents throughout the Allt Phubuill section. Copper values reach a broad maximum of 90-100 ppm midway through the section. Zinc values increase slightly from 50 ppm to 60-70 ppm further upstream corresponding to an increase in the schist:quartzite ratio. Lead values are comparable with those obtained from normal less disturbed pyritic zone materials (i.e. 10-30 ppm).

Discussion

Copper

In normal pyrite zone material (eg. the Allt a' Bhorland section) there is no apparent relationship between copper content and lithology because of the overwhelming effect of the sulphide present (Fig. 11). In the Brerachan Water section (Fig. 12) copper contents are higher where samples contain metabasic rocks, and in the Auchtertyre section (Fig. 13) the higher copper values are coincident with a higher proportion of pelite. It must be emphasised however that even in these sections the high copper is more likely reflecting the increased sulphide contents.

As might be expected, the association of copper with iron sulphide content overwhelms the background effects caused by incorporation in Fe-Mg silicates or oxides. Apart from chalcopyrite, which occurs in trace amounts in sulphide-enriched areas, pyrite is the main host for copper. The coincidence of high copper and high sulphide contents is fairly well demonstrated in the sampled sections. Where the relationship apparently breaks down, trace chalcopyrite is present but is seldom accompanied by much pyrite.

Zinc

In normal pyrite zone material (Fig. 17) variations within the zinc values (10-130 ppm) are consistent with those given for similar metasediments in the published literature (Wedepohl and others, 1974). The variations can be attributed to changes in lithology and therefore it is assumed that zinc is mainly incorporated in the Fe^{2+} and Mg^{2+} silicates such as biotite, chlorite and amphibole.

The massive amphibolites and hornblende-schists of the Brerachan Water section (Fig. 12) give a range of zinc values (50-130 ppm: Av 102 ppm) that is comparable to the published data for these rock types (Van der Kamp, 1970). The section indicates a sharp drop of zinc content where interlaminated hornblendic and calc quartzose material predominates (10-60 ppm: Av 25 ppm). Thus, with the exception of Auchtertyre, the zinc contents for the sampled sections reflect the rock types present. However, where the background zinc content is fairly constant, as in the pyrite zone of the Brerachan Water section (Fig. 12), it is possible to relate minor variations to changes in sulphide content. It can be concluded that insignificant amounts of zinc are normally associated with the sulphides and that sphalerite is unlikely to occur.

In the Auchtertyre section there is no correlation of zinc values with lithological variations. The high zinc values occur in those sample intervals with relatively high sulphide content. Thus it is concluded that the zinc in the Auchtertyre section is mainly associated with the sulphide phases, and that sphalerite may occur locally in minor concentrations. Mineralogical work has confirmed the presence of sphalerite in a specimen from sample interval 180-200 m at Auchtertyre. The sphalerite occurs as patches ($\leqslant$ 1 mm diam) in the pressure shadows of some large pyrite crystals.

Lead

As with zinc, the lead values obtained from the sampled sections lie within the range of values expected from the rock types present. The variation in the values, although small, may be attributed to the relative amounts of pelite and quartzite. Only two samples gave lead contents higher than the normal range for these rock types (Table I; III). It is assumed that within these sample intervals some of the lead may be associated with the sulphides and/or present as trace galena. In this respect it should be noted that during mineralogical work on a variety of specimens from the pyrite zone, galena was not identified (Appendix V).

Van der Kamp (1970) gives a range in lead values for Dalradian amphibolites as 7-82 ppm (Av 20 ppm). The amphibolites and hornblende schists of the Brerachan Water section (Table II) give values consistent with this.

Gold

A limited programme of gold analyses was undertaken on the knowledge that a sample of mineralised Ben Lawers schist from the pyritiferous zone south of Lochan na Lairige had yielded 0.13 ppm gold (Analytical and Ceramic Unit Report No. 45, 1969). In addition samples from sulphide rich horizons thought to be equivalent to that of the pyrite zone of Loch Tay but in the Loch Fyne area showed very high anomalous gold values. Of the seventeen samples of pyrite zone material analysed, however, only three had gold values greater than 0.02 ppm.

0.026 ppm	- Allt a' Bhorland	(140-160 m)
0.028 ppm	- Glen Lochsie	(0-25 m)
0.042 ppm	- Auchtertyre	(180-200 m)

Although significantly greater than the average crustal abundance of gold (0.004 ppm) these values are not exceptional in sulphide bearing rocks. Both pyrite and chalcopyrite may contain up to 0.5 ppm gold even in strata (Vakhrushev and Tsimbalist, 1967) containing no free gold.

It is concluded that most of the gold is associated with the sulphides, particularly in cupriferous material, and that there is no evidence to suggest the presence of free gold.

APPENDIX V

PETROGRAPHIC NOTES ON SOME SPECIMENS COLLECTED FROM THE ROCK-SAMPLED SECTIONS

Introduction

To achieve a measure of the overall base-metal levels along the sections, the samples for geochemical analysis were collected by chip sampling at 1 metre intervals, where possible, along successive 10, 20 or 25 metre lengths. However, the mineralogical specimens represent particular points on the sample length and are unlikely to have base-metal levels identical with those of the geochemical samples. In some cases copper phases are not present in the thin section even though a metal anomaly has been specified. Indeed, there are cases in which the rocks collected for mineralogical examination proved to be devoid of sulphides altogether. This must be borne in mind when comparing the mineralogical observations given below with the apparently corresponding metal levels.

The field numbers given in Table VII correspond to those of the geochemical samples. However, in three cases more than one mineralogical specimen was collected from a sample length. In these cases (CZR 555, 556 and 557) the field number is given together with the distance along the section in question.

Table VII: Rock specimens examined by optical microscopy.

Stream section	Samples Investigated field number	polished thin section number
Glen Lochsie	CZR 511	2279
	522*	2149
	523	2280
	524*	2236
Brerachan Water	703	2150
	709	2151
	711*	2250
	717*	2251
	707	2243
Auchtertyre	609*	2242
Allt a' Bhorland	551	2281
	553*	2249
	555.10m	2144
	555.15m	2282
	556.10m	2237
	556.11m	2145
	557.0 m	2146
	557.10m	2147
	558	2238
	561*	2239
Roromore	565	2240
	567	2283
	568	2284
	570	2285
Allt Phubuill	572	2148
	573	2241

*denotes specimen collected from a sample interval (Appendix IV) which showed anomalously high levels of copper.

Mineralogical notes

a. Glen Lochsie samples

CZR 511 (pts 2279) - Biotite-hornblende-epidote-schist; finely banded rock in which the lithology varies from quartzite with less than 5 per cent mafics by volume*, to micaceous mafic schist whose quartz-content is not more than 30 per cent by volume. The major lithologies are medium-grained biotite + quartz + epidote showing good schistosity, coarse-grained hornblende + quartz + biotite + epidote + sulphides, coarse-grained chlorite + quartz + hornblende + sulphide + epidote, and coarse-grained quartz + minor sulphide + hornblende + epidote. The tectonic fabric is complicated by cross-cutting planes of local (less than 1 cm) movement.

Opaque minerals comprise about 4 per cent by volume of the rocks, and consist of pyrite and magnetite with minor amounts of chalcopyrite and hematite. The pyrite occurs as anhedral, sub-rounded grains and clusters of polygonal grains generally greater than 0.02 mm diameter. The magnetite occurs as angular subhedral crystals up to 1 mm in diameter and as minute rectangular grains in the finer lithologies. Chalcopyrite occurs as irregular blebs mantling pyrite and as minute patches within pyrite. Hematite is present as thin replacement veinlets in magnetite. Although the sulphides and oxides are frequently grown alongside one another they are seldom in contact and there is no evidence of interaction between them. There is, however, a loose spatial affinity between pyrite concentrations and oxide concentrations, both having a marked preference for biotite and chlorite-rich parts of the rock. In addition, there is a tendency (repeatedly noticed in these rocks) for the ore-grains to possess a habit and grain-size in harmony with their host silicate matrix. This fact, together with the absence of mineral veining from this rock, suggests that the sulphides were of early development rather than formed during a post-tectonic episode of hydrothermal mineralisation.

CZR 522 (pts 2149) - Calcareous chlorite-schist: mixed lithology rock dominated by the assemblages chlorite + quartz + epidote + hornblende + zircon and calcite + quartz + epidote. No systematic pattern of schistosity is present although irregular laminations are

*All estimates given of volumetric proportions are solely based upon visual estimations.

strongly developed in chlorite-rich patches. The calcareous lithology forms crudely vein-like areas enclosing patches of mafic material, and in some cases the lamination in chlorite patches is orientated in sympathy with the margins of adjacent vein-like calcareous patches. The mineralogical distinction between the calcareous and non-calcareous materials is not entirely clear cut, some of the mafic material having an appreciable calcite content. It is difficult to draw any conclusions regarding the likely development of the irregular fabric of this rock.

The distribution of opaque grains is uneven. The total opaque content is about 2 per cent by volume. The assemblage of ore minerals is pyrite, pyrrhotite and chalcopyrite. Pyrite occurs as isolated irregular grains up to 0.2 mm in diameter and in clusters of small (about 0.1 mm diameter) crystals. Pyrrhotite occurs as irregular patches occasionally 0.5 mm in width but generally smaller than this, physically separated from the pyrites. Chalcopyrite occurs as core-like inclusions in pyrrhotite and as irregular outgrowths on pyrite. The total chalcopyrite content is less than 0.1 per cent by volume. In many cases there appears to be a spatial association of the sulphides with calcite grains, but this is not always so, some pyrite and pyrrhotite grains being apparently wholly enclosed in chlorite segregations. Evidence of remobilisation of the sulphides is provided by one point at which very thin pyrite veinlets developed along the cleavage plans of a chlorite patch.

CZR 523 (pts 2280) - Strongly laminated schists of mixed lithologies; the thin-section shows adjacent bands with the assemblages quartz + biotite + epidote and quartz + anthophyllite + chlorite + biotite + probable pyrophyllite. The latter assemblage is extremely depleted in calcium, a fact in keeping with the absence of carbonate from this rock.

The opaque assemblage, pyrrhotite + pyrite + chalcopyrite occurs as irregular grains and clusters throughout the rock. The two Fe-sulphides are very rarely found in contact with one another. Pyrrhotite is present in great excess over pyrite, and chalcopyrite is an accessory constituent present as inclusions in pyrrhotite. The total sulphide content is of the order of 3 or 4 per cent by volume. No iron oxides are present.

CZR 524 (pts 2236) - Mica-schist; 50-60 per cent by volume of this rock is composed of sheaves of alternating crystals of biotite and muscovite which are intensely deformed by a second-phase strain-slip cleavage. Chlorite is a minor constituent occurring as ragged crystals which cross-cut the cleavage. Quartz and a minor amount of plagioclase occur through the rock both as polygonal grains forming irregular clusters in those parts of the rock which have low mica contents, and as elongate "eyes" contained in the micaceous material. Zircon is an accessory and prisms of epidote are a common though minor constituent. No Fe oxide minerals are present.

The opaque assemblage is pyrite + chalcopyrite. Pyrite occurs as euhedral grains and clusters of grains. The larger of these are sited in large quartz eyes while the smaller ones are frequently flanked by strain-shadows in which randomly orientated chlorite is developed. These textural relationships indicate that the pyrite was present in the rock when the cleavage developed. Chalcopyrite occurs as small irregular patches developed on the outer surfaces of pyrite and as stubby veinlets within pyrite clearly developed by replacement. The total sulphide content is probably of the order of 10 per cent by volume, although this is difficult to estimate in view of the uneven distribution of ore-grains in this rock.

Summary of the Glen Lochsie samples

The four samples examined are all mafic medium-grade schists in which both biotite and chlorite are present, but which probably represent biotite-grade metamorphism. Lithologies are extremely variable with calcite occurring in one rock while another shows extreme calcium depletion. All four rocks contain pyrite and a minor amount of chalcopyrite, and pyrrhotite is evidently common in this stream-section. There is much evidence to suggest that the pyrite was present during the period of tectogenesis, and it may thus be inferred that the other sulphides were also present (though this is by no means established in any conclusive sense yet).

b. Brerachan Water Section

CZR 703 (pts 2150) - Biotite-hornblende-schist; strongly laminated medium to coarse-grained rock. Much of it is made up of a homogeneous assemblage of quartz + hornblende + biotite + chlorite + zircon + pyrite + chalcopyrite + pyrrhotite. Also present are quartzite laminae and epidote-rich coarse-grained bands in which the opaque assemblage is again pyrite + pyrrhotite + chalcopyrite. Tiny irregular grains of magnetite and ilmenite occur in the coarser-grained bands in accessory proportions. The form of the sulphides appears to be loosely related to the texture of the host silicates. Where the rock is medium-grained the sulphides are relatively small. The pyrite occurs as rectangular grains of the order of 0.01 mm wide by 0.03 mm long, and small groups of grains of comparable dimensions markedly drawn out in the plane of the schistosity. Pyrrhotite occurs as irregular blebs which sometimes have small cores of chalcopyrite, and are of approximately the same size as the adjacent quartz grains. Where the rock is coarse and rich in epidote, pyrite forms irregular grains and somewhat drawn out groups of grains slightly less flattened than those in the finer parts of the rock (typical dimensions are 0.8 mm + 1.0 mm though many larger grains are present). Pyrrhotite and chalcopyrite occur as irregular grains which convey an impression that the two sulphides formed simultaneously. Total sulphide content is estimated to be 8 to 10 per cent by volume, and that of chalcopyrite to be 0.2 per cent by volume of the whole rock.

The sympathetic relationship of the forms of the ore-grains to the texture of the rock as a whole gives the impression that they were present during the formation of the metamorphic fabric.

CZR 709 (pts 2151) - Banded calcareous schist; intensely contorted and strongly banded rock. The assemblages seen in the thin-section include quartz + biotite + epidote + zircon + sulphide, quartz + calcite + epidote, quartz + feldspar + biotite + hornblende + epidote + sulphide, and quartz + calcite + biotite + chlorite + epidote. It should be noted that two of these main assemblages contain carbonate and no sulphide, while the other two contain sulphide and no carbonate. Both the carbonate and the sulphide fractions appear to form integral parts of the metamorphic texture of the rock. Pyrite, which is the only sulphide present, occurs as rectangular crystals elongated in the direction of the schistosity (Fig. 29). Where sharp flexures of the schistosity occur it is sometimes found that the pyrite is arranged around the folding. It would seem, therefore, that the sulphides are not of post-tectonic origin.

CZR 711 (pts 2250) - Calcareous biotite-schist; the assemblage is quartz + calcite + biotite + hornblende + chlorite + epidote. In this rock it is clearly seen that the chlorite is of late (possibly post-tectonic) origin. The rock is coarse-grained and has a poorly developed schistosity. No sulphides are present.

CZR 717 (pts 2251) - Biotite-schist; homogeneous schist with well-developed schistosity. The mineral assemblage is quartz + albite + biotite + epidote + zircon + sulphides. Hornblende, chlorite and calcite are absent. The sulphide grains are present throughout the rock but show some preference for the quartzose laminae. Pyrite is the only sulphide present, forming an estimated 1.5 per cent of the rock by volume. It occurs as elongated grains and small groups of elongated grains concentrated along particular cleavage surfaces.

CZR 707 (pts 2243) - Quartz-amphibolite; the rock is made up of some 60 per cent by volume of green hornblende with lesser amounts of epidote, quartz, zircon, and sulphides. It is a coarse-grained, homogeneous rock with a weakly developed schistosity. The total sulphide content is of the order of 0.5 per cent by volume. Pyrite occurs as isolated slightly irregular grains showing little evidence of tectonic flattening. Chalcopyrite, the only other sulphide present, occurs as minute irregular grains which are disseminated thinly and unevenly through the rock and concentrated in the vicinity of the pyrite crystals.

Summary of the Brerachan Water samples

The rocks examined are four pelitic metasediments and one amphibolite, and all show medium (biotite) - grade metamorphism. Ore-contents are very low but persistent through many samples. The sulphide-assemblage is pyrite, pyrrhotite and chalcopyrite. Of these pyrite is by far the dominant member by volume, and frequently occurs as drawn out grains and small groups of grains which appear to form an integral part of the metamorphic fabric. The other sulphides are less persistent and occur as small irregular grains. Oxide minerals are virtually absent.

The samples described show evidence of an antipathetic relationship between the occurrence of ore-minerals and the presence of carbonate minerals. This is well seen in pts 2151 (CZR 709) which is a thinly banded rock consisting of alternating ore-free calcareous bands and calcite-free pyritiferous bands.

c. Auchtertyre section

CZR 609 (pts 2242) - Quartz-chlorite-schist; coarse grained quartzite carrying some 40 per cent by volume of chlorite. The chlorite occurs in an interlocking network of elongate lensoid patches which define a schistosity. No other silicates appear to be present. The sulphides are coarse, individual crystals being commonly of the order of 1 mm in diameter. Irregular clusters of pyrite drawn out along the schistosity form about 30 per cent by volume of the thin-section, but are probably less plentiful in the rock as a whole. Chalcopyrite is present as small irregular crystals grown within the matrix and on the margins of the pyrite. Sphalerite occurs as irregular patches up to 1.00 mm in width generally sited within the pressure-shadows of the larger groups of pyrite. Pyrrhotite (not positively identified) is a minor constituent occurring as small, irregular, porous grains, sometimes having inclusions of chalcopyrite. An additional opaque constituent is a grey, strongly bireflecting and strongly anistropic mineral provisionally identified as molybdenite. Also present is an accessory amount of magnetite.

This sample is far more diverse in its ore-mineral assemblage than any of the other samples examined. The presence of sphalerite and of possible molybdenite appears to be restricted in the pyrite zone to the Auchtertyre section.

d. Allt a' Bhorland Section

CZR 551 (pts 2281) - Calcareous chlorite-schist; a texturally homogenous rock consisting of about 50 per cent chlorite, 45 per cent quartz, significant amounts of calcite and muscovite, a minor amount of zircon, and a minor amount (about 2 per cent by volume) of sulphide. Pyrite, the main sulphide, is present as isolated grains up to 1 mm in diameter which are usually straight-sided and subhedral. The pyrites always have small rounded inclusions of chlorite, muscovite, and other silicates, and occasionally it is seen that straight-sided inclusion-free primary grains are mantled by irregular second generation overgrowths of pyrite which contain many tiny silicate inclusions. Chalcopyrite is the only other sulphide present. It occurs as minute irregular grains some of which were seen to have cores of pyrite. No spatial or textural relationship between the sulphides and the carbonate crystals in this rock was observed.

CZR 553 (pts 2249) - Epidote-bearing calcareous-quartzite; a strongly banded rock possessing a flat, planar schistosity. The principal lithologies are coarse-grained quartz + calcite + epidote rock, medium-grained quartz + calcite + epidote bands, very coarse conformable quartz + calcite veins, fine-grained almost monomineralic quartzite bands, and lenses of coarsely crystalline calcite. The total sulphide content is approximately 3 per cent by volume, and consists entirely of pyrite present as irregular isolated grains up to 0.6 mm in width, and as small developments of interstitial filigree veinlets.

CZR 555 10 m (pts 2144) - "Marble" (coarse calcite-rock); the thin-section is largely composed of coarsely-crystalline calcite. Quartz is also a major constituent occurring as large (up to 3 mm width) isolated strained crystals possibly of clastic origin, elongate patches of coarsely-crystalline polygonal quartz crystals, "trails" of small corroded crystals leading off from the coarse patches, and as irregular patches of medium-grained quartzite. Also present in minor amounts are flakes of biotite, muscovite and of chlorite, all of which are spatially associated with the quartzite fragments. The calcite is almost entirely clouded with minute opaque inclusions of probable goethite. The quartzose fragments appear to be relics of a quartzite band now almost completely corroded and replaced by calcite. The rock is an extreme development of a phenomenon frequently found in these rocks in which the calcareous fraction of the rock is present as crude coarsely-crystalline veins in which corroded relict quartz grains, much smaller than non-corroded grains in adjacent non-calcareous material, are found.

The opaque content is less than 0.1 per cent by volume, and consists entirely of small to minute irregular pyrite crystals.

CZR 555 15 m (pts 2282) - Quartzite; the assemblage is quartz, albite, biotite, chlorite, calcite and possible rutile. Average grain-size is of the order of 0.1 mm. The grains tend to be roughly diamond-shaped due to tectonic distortion. The rock is texturally homogenous except where crossed by bands of very coarsely-crystalline quartz containing flakes and patches of chlorite and a few sphene crystals. Associated with the coarse veins are thin, secondary veinlets of what may be pyrophyllite. Pyrite is present, mainly associated with the coarse veins; and chalcopyrite occurs in a trace amount. The pyrite crystals tend to be angular and discrete though some are irregular, having a sieve texture containing many relict quartz crystals. In the quartzite itself the only opaque constituent is a trace amount of pyrite present as minute crystals.

CZR 556 10 m (pts 2237) - Pyritiferous quartzite; the thin-section consists of some 60 per cent by volume of pyrite, and 40 per cent of quartzite. The quartzite consists of quartz, albite, chlorite, and muscovite. No cupriferous phase is present.

CZR 556 11 m (pts 2145) - Pyritiferous quartzite; medium-grained homogeneous quartzite consisting of quartz and minor amounts of albite and muscovite, and a trace of zircon. Pyrite, the only opaque mineral, forms about 20 per cent by volume. It occurs as large (up to 1 cm in width) irregular crystals which are either skeletal or have a sieve texture containing small quartz grains.

CZR 557 0 m (pts 2146) - Pyritiferous quartzite; quartz with minor amounts of albite, chlorite, muscovite and probable rutile. This rock has an average grain size of the order of 0.1 mm showing very little sign of tectonic distortion. The opaque content is about 20 per cent by volume, and consists entirely of sieve-textured pyrites.

CZR 557 10 m (pts 2147) - Chlorite-rich calc-quartzite; medium to fine-grained quartzite traversed by two sets of close-spaced veinlets consisting of chlorite with quartz, and of inclusion-rich carbonate. Some parts are especially chlorite-rich and take on a pronounced schistosity. The veinlets possess a preferred orientation which was governed by tectonic stresses. The only minor constituent is rutile. No sulphides are present.

CZR 558 (pts 2238) - Calc chlorite-quartz-schist; with intensely contorted schistosity. Patches of sparry calcite have developed by replacement, whereas patches of coarsely-crystalline quartz appear to pre-date the development of schistosity since this is deflected around them. The total transparent assemblage is quartz, chlorite, calcite, biotite, muscovite, zircon and/or rutile. Pyrite and a trace of chalcopyrite account for about 2 per cent of the rock. The sulphide occurs as angular grains which often have a rectangular form due to stress-controlled growth. The larger pyrite crystals occur in the coarsest quartz and calcite patches, and the smaller ones reside in the chlorite-rich material. However, there is no sign of distortion of the schistosity by the pyrite, or of the creation of pressure shadows about them.

CZR 561 (pts 2239) - Muscovite schist; 40 per cent muscovite, 8 per cent chlorite, 30 per cent quartz, 10 per cent calcite, 2 per cent sulphide. Banded rock in which quartz-rich and mica-rich assemblages alternate. The banding and its accompanying strongly-developed schistosity are much contorted by strain-slip cleavage. Patches of coarse calcite developed by replacement of the silicate assemblage. The sulphides are pyrite and chalcopyrite (about 0.1 per cent). Also present are zircon and rutile. The pyrite occurs as large, slightly rounded subhedra, or as small irregular crystals which tend to occur along particular bands rather than being disseminated evenly through the rock. Chalcopyrite occurs as tiny irregular patches associated with and generally marginal to pyrite crystals.

Summary of Allt a' Bhorland Section

The samples examined from this section represent pyritiferous chlorite-rich semipelites and quartzites. Calcite occurs in varying amounts, sometimes forming rock which are effectively marbles. Micas are generally subordinate to the chlorite. Sulphides can form more than 50 per cent by volume of individual samples.

However, they consist entirely of pyrite save for trace amounts of chalcopyrite.

e. Roromore Section

CZR 565 (pts 2240) - Calcareous hornblende-mica-schist; the assemblage of transparent minerals is quartz, albite, hornblende, biotite, muscovite, zircon, rutile, calcite and possible others. The texture is that of a muscovite-schist bearing hornblende-rich lenses and laminae. Biotite has developed by alteration of hornblende and by replacement of muscovite. Albite is part of the early texture and occurs as extremely stretched grains. Zircon and rutile occur as minor constituents of the primary fabric. Calcite occurs as isolated crystals and as sparry patches clearly grown by replacement of the earlier fabric. The total sulphide content is of the order of 2 per cent by volume. Pyrite accounts for almost all of this, being present as irregular grains elongate in the direction of the cleavage but sometimes rather skeletal or sieve-like.

A few pyrite crystals contain rounded inclusions of pyrrhotite and some seem to have marginal growths of magnetite (or ?sphalerite).

CZR 567 (pts 2283) - Micaceous calc-quartzite of variable grain-size. Detrital albite is common in this rock. Muscovite and green biotite are also common and sometimes mark the schistosity. Patches of late-formed chlorite are common. This rock is rich in what appears to be zoisite, and zircon is also present. Calcite occurs sporadically as coarse, irregular grains grown by replacement of quartz. The total opaque content is approximately 4 per cent by volume and consists entirely of pyrite.

CZR 568 (pts 2284) - Micaceous calc-quartzite; the early fabric is that of a banded quartzite of varying grain-size and varying mica-content. Both muscovite and biotite are plentiful, and a small amount of chlorite is present. Zoisite (or ?apatite) is plentiful, and zircon is a common accessory (surrounded by haloes when embedded in biotite). Calcite is plentiful and has the appearance of having grown by replacement. The total opaque content is of the order of 3 per cent by volume. Pyrite occurs as rather irregular grains mostly of the order of 0.5 mm width, but occasionally 3 mm across. Irregular grains of chalcopyrite occur but form no more than 0.1 per cent of the rock. Irregular crystals of what is probably magnetite are present.

CZR 570 (pts 2285) - Amphibolite; hornblende (about 60 per cent), with quartz and epidote and minor amounts of zircon and calcite. The hornblendes are shortened on their a-axes, and the lozenge-shaped crystals so formed define a crude schistosity. The calcite appears to have grown by replacement. No pyrite is present but a trace of chalcopyrite is found. A trace of hematite with limonite and goethite is associated with the sulphide.

Summary of the Roromore Section

Micaceous rocks and some amphibolites are seen in these samples. The metamorphic grade appears to be biotite-grade (cf the chlorite-grade rocks at Glen Lochay). Sulphide levels are low, and the only ore minerals are traces of chalcopyrite. One point of interest is the presence in certain rocks of abundant zoisite.

f. Allt Phubuill Section

CZR 572 (pts 2148) - Amphibolite; medium-grained schistose rock containing about 75 per cent green hornblende. Also present are significant amounts of quartz, biotite and epidote, and accessory amounts of probable zircon. The total opaque content is of the order of 1 per cent by volume and consists of pyrite with a trace of chalcopyrite. Pyrite occurs as discrete, subhedral crystals. The chalcopyrite occurs as later overgrowths of pyrite and as minute grains dissememinated through certain restricted areas of the rock.

CZR 573 (pts 2241) -Acid segregation; coarse-grained rock consisting of quartz, slightly sericitised orthoclase and albite, sheaves of chlorite, and a minor amount of muscovite. Also present are a minor amount of biotite, accessory zircon, veinlets of calcite, and ore-granules in the chlorite. The total opaque content is less than 0.5 per cent of the rock, and comprises isolated subhedral pyrite sometimes accompanied by irregular grains of chalcopyrite.

Summary of Allt Phubuill Section

Both rocks from the Allt Phubuill section appear to be of igneous origin, one an amphibolite and the other a granite. Ore levels are low, and chalcopyrite is present only in trace amounts.

Discussion

The problem posed by the different styles of sampling for geochemical purposes and mineralogical purposes is illustrated by the following observations. Information provided by Mr Michie showed that nine of the geochemical samples for which mineralogical equivalents had been collected possessed significantly high Cu levels, one of them (CZR 609) being also rich in Zn. Of the equivalent mineralogical samples two proved to be virtually devoid of sulphides (CZR 711, 180), and two contained minor pyrite but no chalcopyrite (CZR 717, 553). One contained major pyrite but no chalcopyrite (CZR 557) and this sample contained XRF-determined levels of 300 ppm Cu and 40 ppm Zn in contrast to 65 ppm Cu and 70 ppm Zu obtained from the equivalent geochemical sample. The remaining four samples gave 90 ppm Cu and 160 ppm Zn (CZR 522) for which no equivalent geochemical data were given; 4000 ppm Cu and 3800 ppm Zu (CZR 524) for which no equivalent geochemical data were given; 1100 ppm Cu and 440 ppm Zn (CZR 561) compared with 190 ppm Cu and 130 ppm Zn; and lastly 1.07 per cent Cu and 1250 ppm Zn (CZR 609) compared with 1400 ppm Cu and 4050 ppm Zn.

It is clear that the samples examined cannot be taken as being necessarily representative of the gross lithologies of the stream sections. Nonetheless it is apparent that most of the rocks are biotite-grade meta-sediments in which chlorite developed as a retrogressive constituent imposed upon the tectonic fabrics of the rocks. In the Glen Lochay section the rocks appear to be chlorite-grade schists. Amphibolites and other meta-igneous rocks form a minor proportion of most sections.

Chalcopyrite is the only common ore-mineral present, in view of which its persistence along many kilometres of strike is remarkable. It generally occurs in loose spatial association with pyrite, the dominant sulphide, and to a lesser extent in intimate association with pyrrhotite.

In many rocks the textural relationships and flattened forms of the pyrite crystals strongly suggest that they were in their present sites during tectogenesis. Evidence of pyrite mobility is very limited and none of the characteristics of subsequent hydrothermal (eg Hercynian) mineralisation are seen.

Textural relationships indicate that the chalcopyrite and pyrrhotite formed after the pyrite, and that the rare occurrences of sphalerite were similarly late in reaching stability. It is probable that the paragenetic sequence reflects the relative mobilities of the metals during metamorphism rather than late introduction of the constituents of these minerals.

APPENDIX VI

PETROGRAPHIC NOTES ON SPECIMENS COLLECTED FROM AN AREA OF HIGH CHARGEABILITY AT PUBIL, GLEN LYON

Introduction

In the Pubil area of Glen Lyon significant chargeability anomalies in the Sron Bheag schist are approximately parallel to the regional strike. Minor amounts of stratiform pyrite are not uncommon in the anomalous area but in addition several horizons have a distinctive leaden (but not necessarily graphitic) lustre. Thin sections prepared in the Edinburgh Office revealed an unusually high proportion of fine-grained opaque minerals. Five specimens collected from the area by HIU were subsequently examined by Mineralogy Unit to determine the nature of the opaque minerals and the origin of the leaden lustre. This was achieved by optical examination of polished thin sections. In addition cut surfaces of each specimen were scanned by XRF for base metals including manganese.

Results

CX 304 - Finely laminated quartz-biotite -muscovite-schist containing accessory sphene and apatite. Finely disseminated pyrrhotite is common in certain bands. Carbonaceous granules are also abundant.

CX 306 - Finely laminated quartz-biotite-muscovite-schist with accessory sphene. Both pyrrhotite and pyrite are present as disseminated grains, and a trace of chalcopyrite was located as minute inclusions in pyrrhotite crystals. Carbonaceous granules are abundant.

CX 308 - Garnet-mica-schist with accessory sphene and possible epidote. The garnets have been made over in this specimen to sericitic pseudomorphs. The disseminated opaque grains include pyrrhotite, pyrite and probable ilmenite crystals. Carbonaceous granules are abundant.

CX 309 - Calcareous muscovite-schist with accessory apatite and biotite. Pyrrhotite and probable ilmenite occur disseminated through the rock. Carbonaceous granules are abundant. XRF located a trace of molybdenum in this rock and it is therefore likely that either molybdenite is present in a very minor amount or the Mo occurs as a trace constituent of the carbonaceous granules.

CX 310 - Garnet-mica-schist containing a minor amount of green secondary epidote. Disseminated grains of hematite are abundant, but no sulphides were located. Carbonaceous granules are generally abundant and form corona-like rims within the margins of the garnets.

Discussion

Fe and Mn were found to be present in conspicuous amounts in CX 308 and CX 310. In the other three specimens total Fe is low and Mn occurs in only trace amounts. Apart from these elements and the trace of Mo in CX 309 no significant base-metal concentrations were reported.

All five specimens were found to contain an abundance of "carbonaceous granules". These are opaque granules whose reflectivity is exceedingly low. Their sizes vary from microcrystalline dust-like granules to irregular grains of the order of 1 mm in width. Some of the larger grains show minute points of strong anisotropism, but they are generally quite isotropic. It is considered that they are granules of amorphous or cryptocrystalline carbonaceous matter which sometimes contain microcrystalline crystals of graphite. It seems reasonable to attribute the high chargeability and the "leaden lustre" to the abundance of these granules.

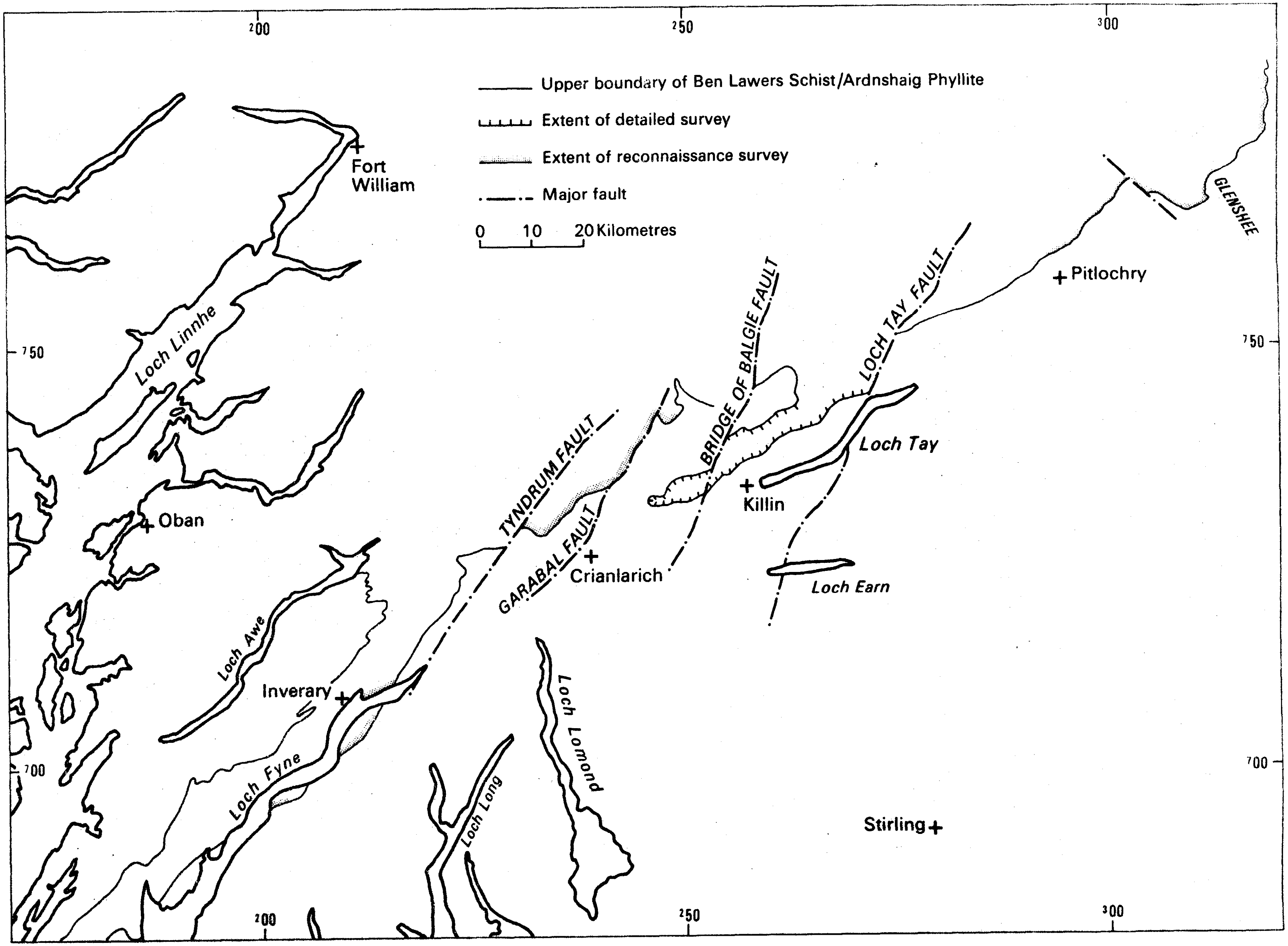


Fig 1 Location of geological survey

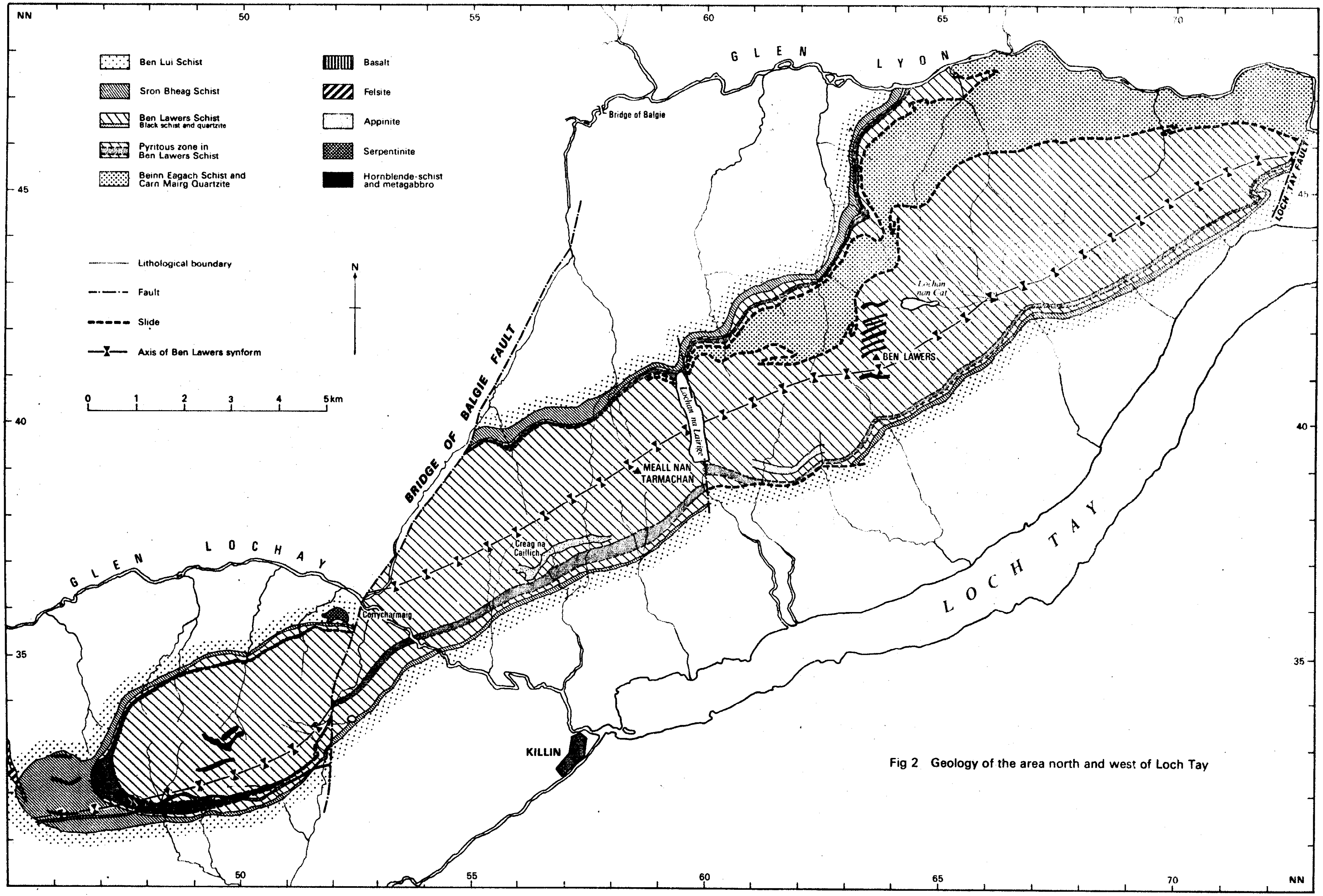


Fig 2 Geology of the area north and west of Loch Tay

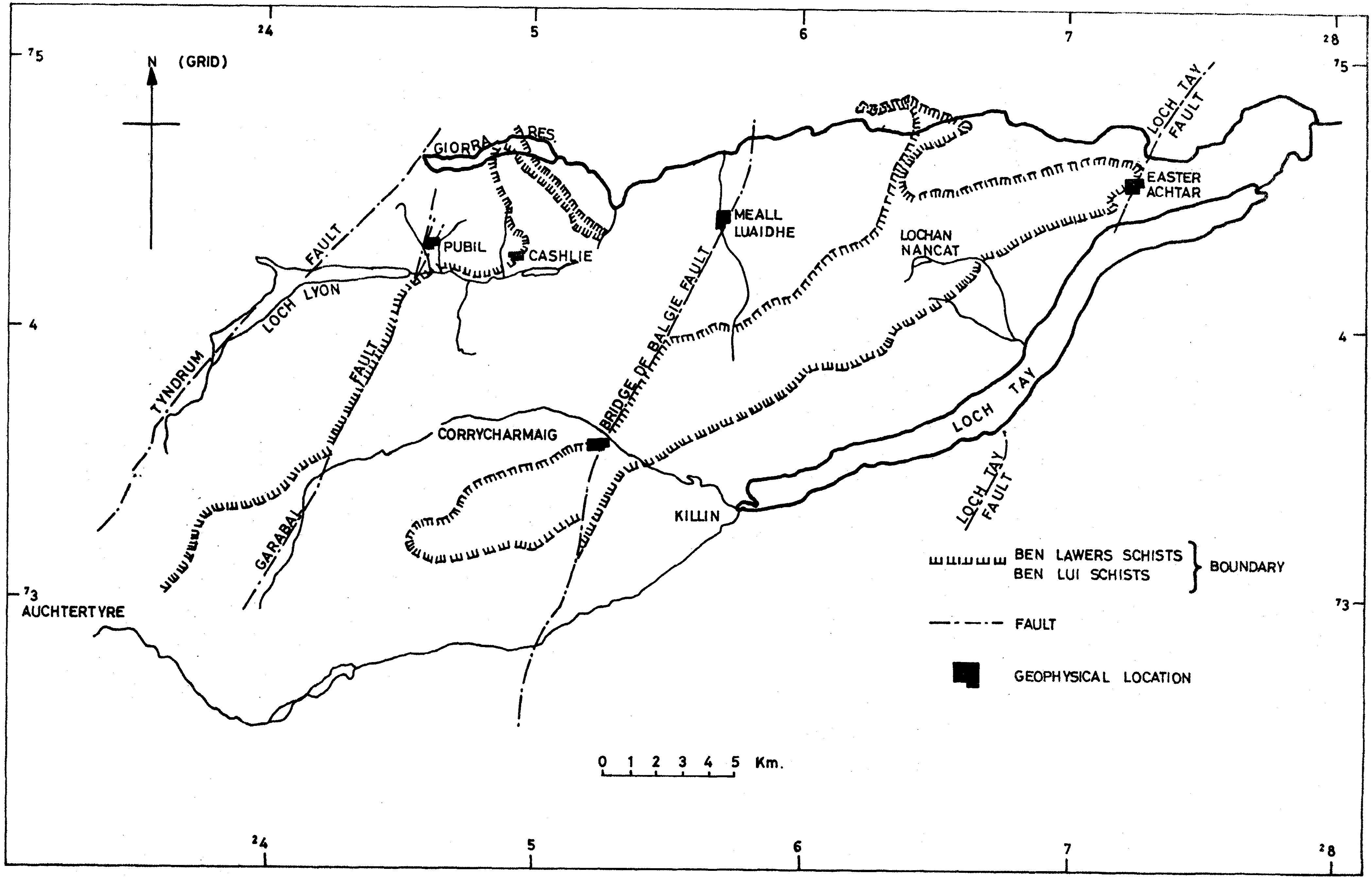
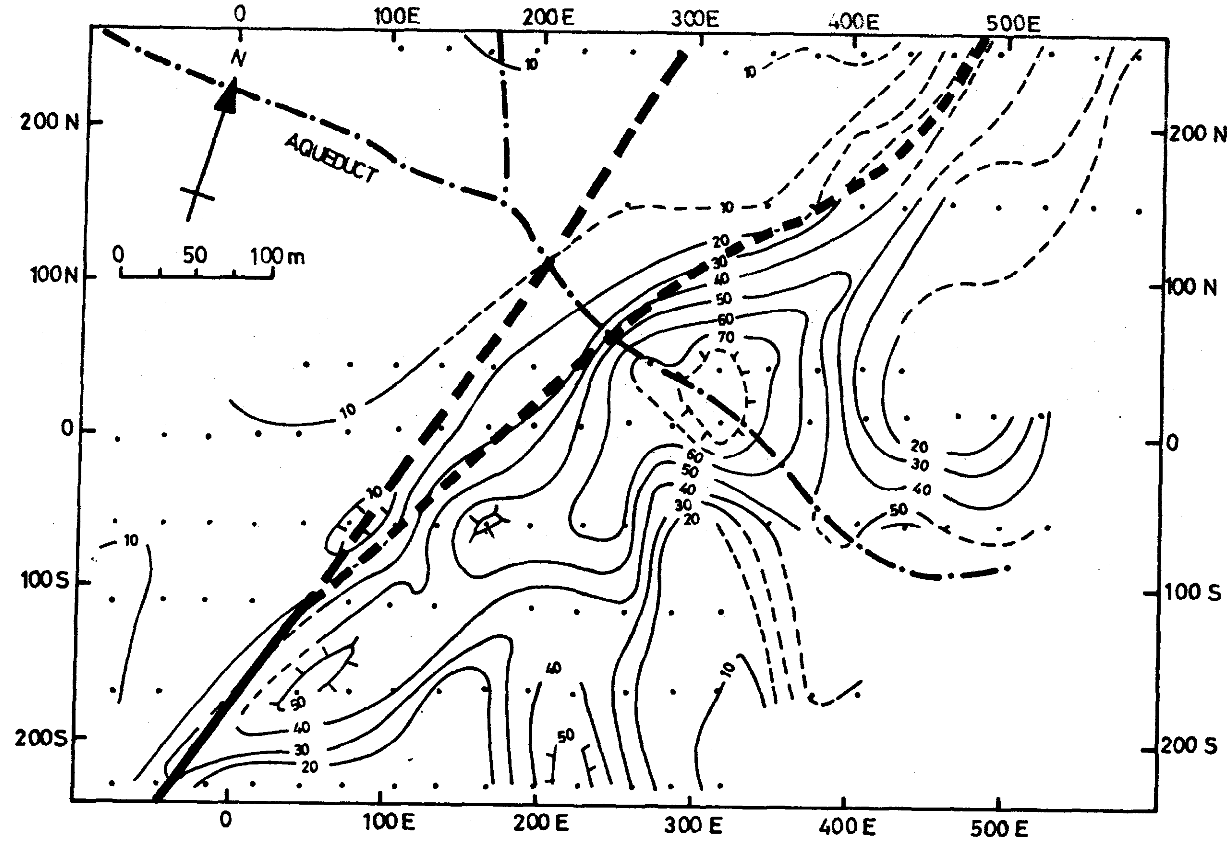


Fig 3 LOCATION OF GEOPHYSICAL SURVEYS



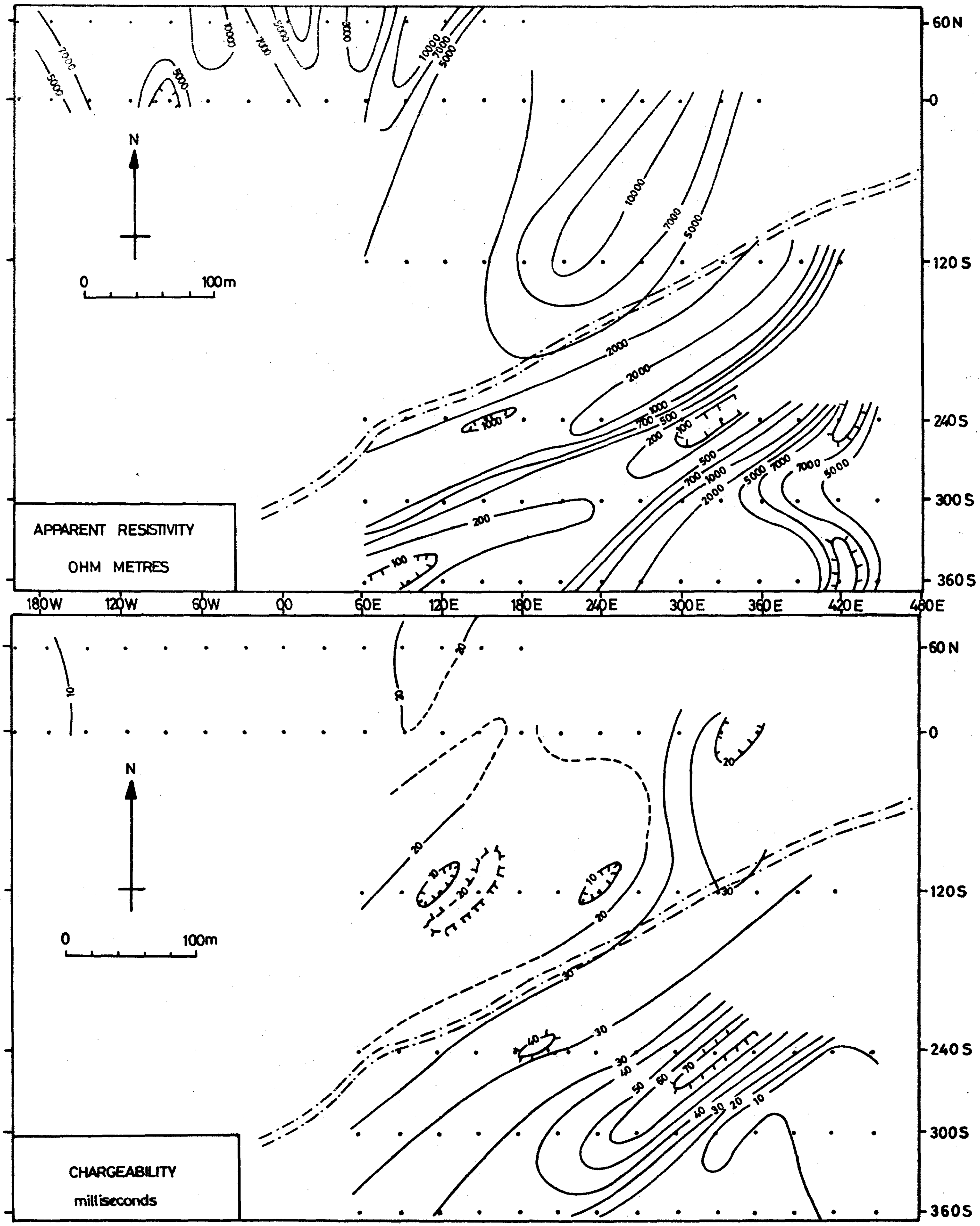
• = PLOTTING POINT FOR DIPOLE-DIPOLE ARRAY AT N = 2 (ie. DIPOLE CENTRE TO CENTRE SEPARATION = 60m)

FAULT (LINE BROKEN WHERE UNCERTAIN)

POSITION OF FAULT PREFERRED FROM GEOPHYSICAL SURVEY

HYDROELECTRIC TUNNEL / AQUEDUCT

FIG. 4. PUBIL: CHARGEABILITY CONTOURS



• = PLOTTING POINT FOR DIPOLE-DIPOLE ARRAY AT N=3 (ie DIPOLE CENTRE TO CENTRE SEPARATION = 90m)

LIMESTONE BAND

FIG. 5. CASHLIE: CONTOUR MAPS OF APPARENT RESISTIVITY & CHARGEABILITY

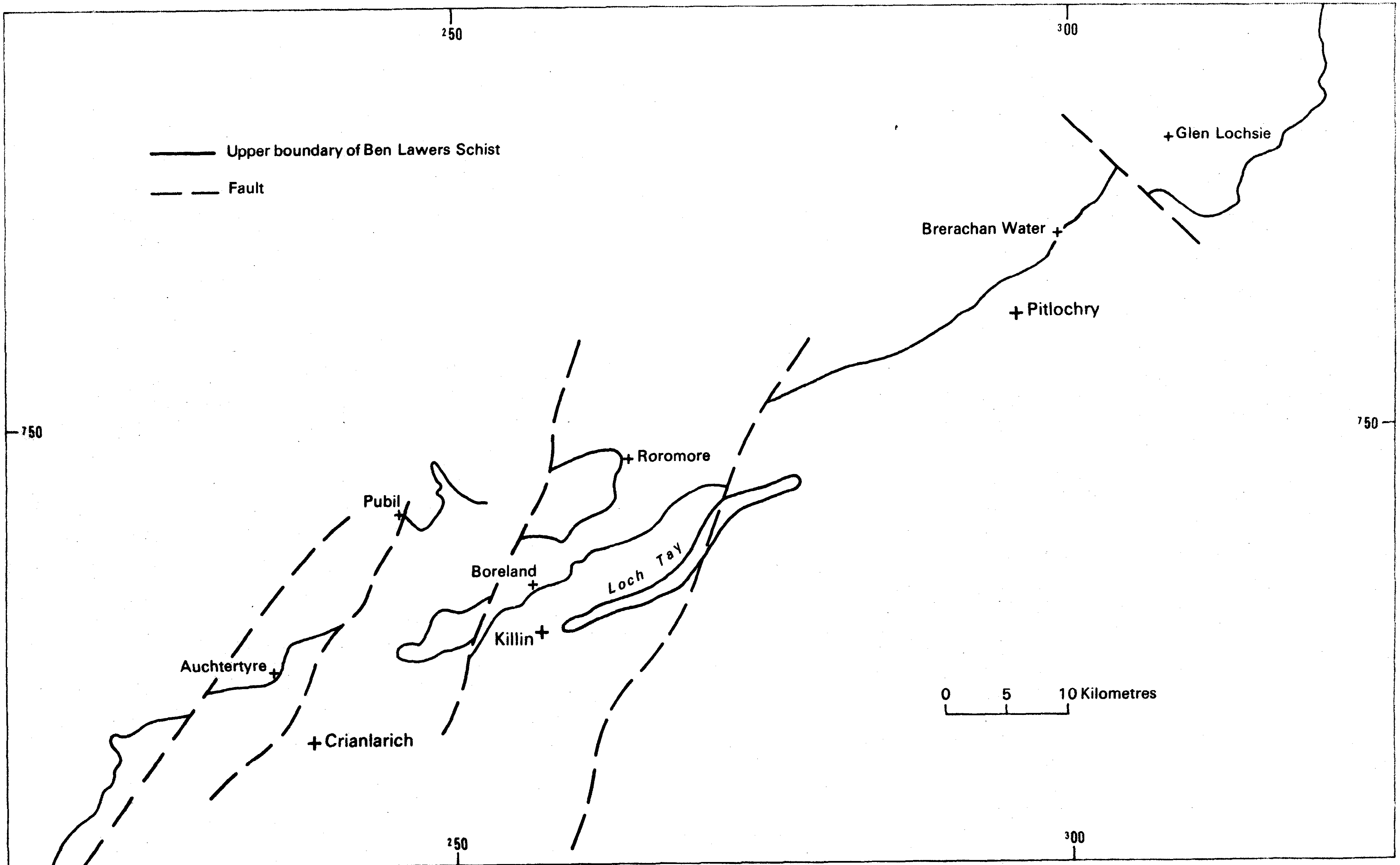
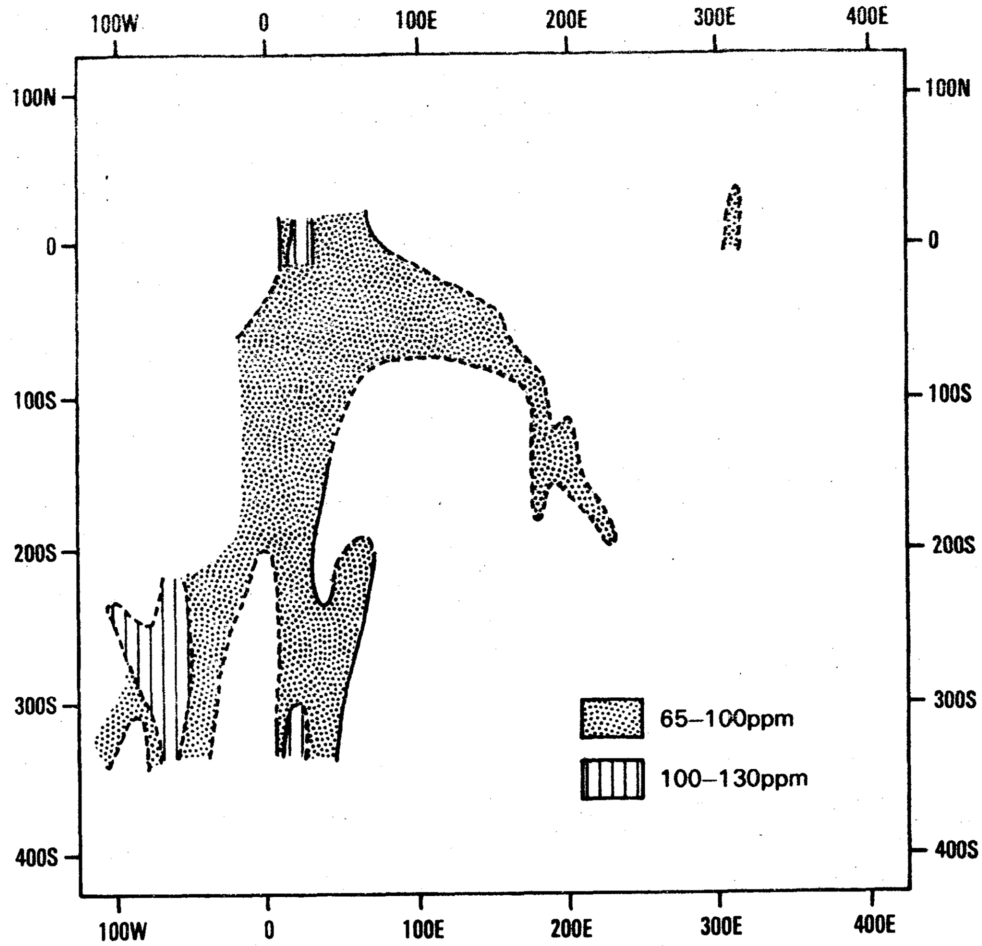
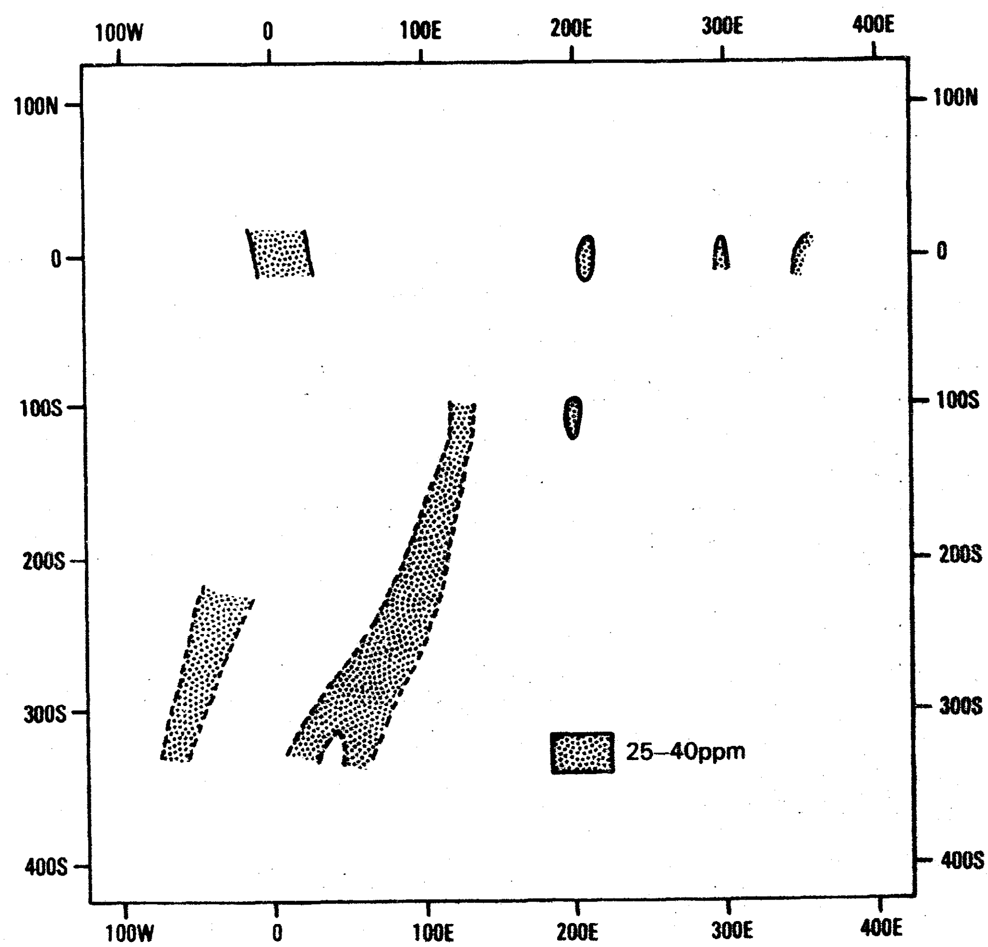


Fig 6 Location of rock sampled sections

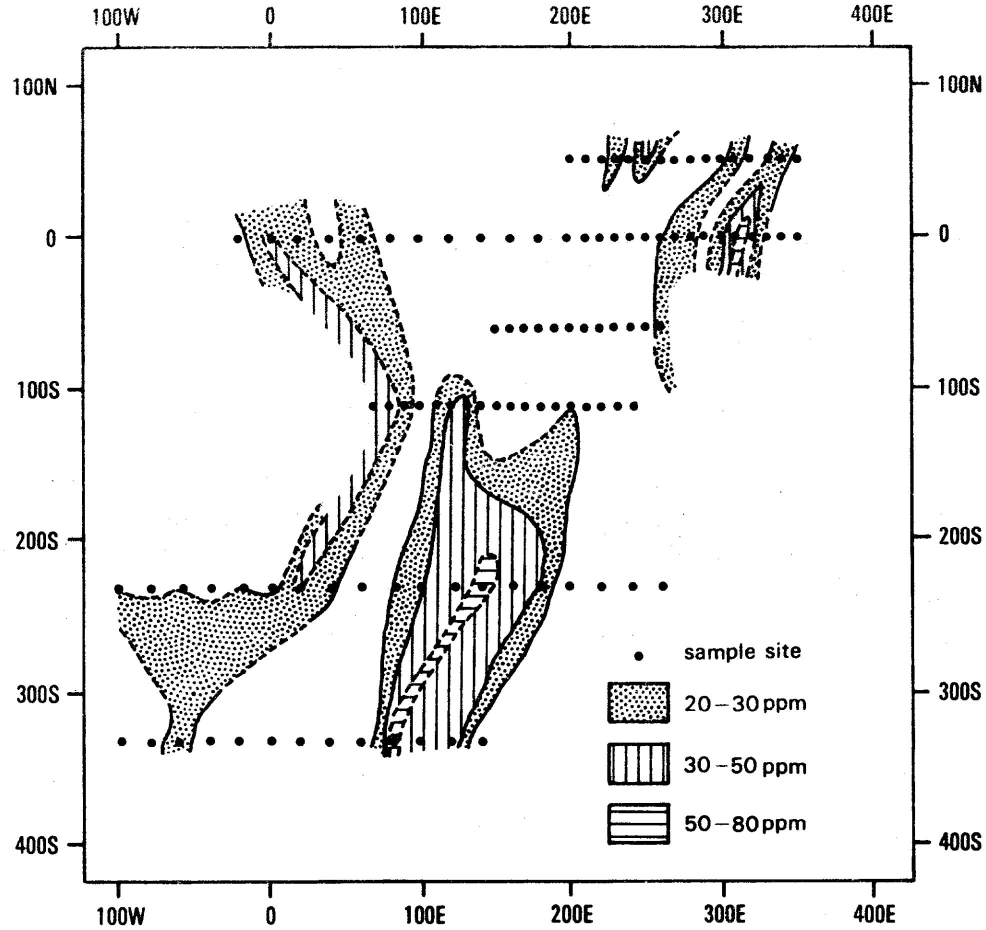


Pubil: Contoured map of zinc in soils

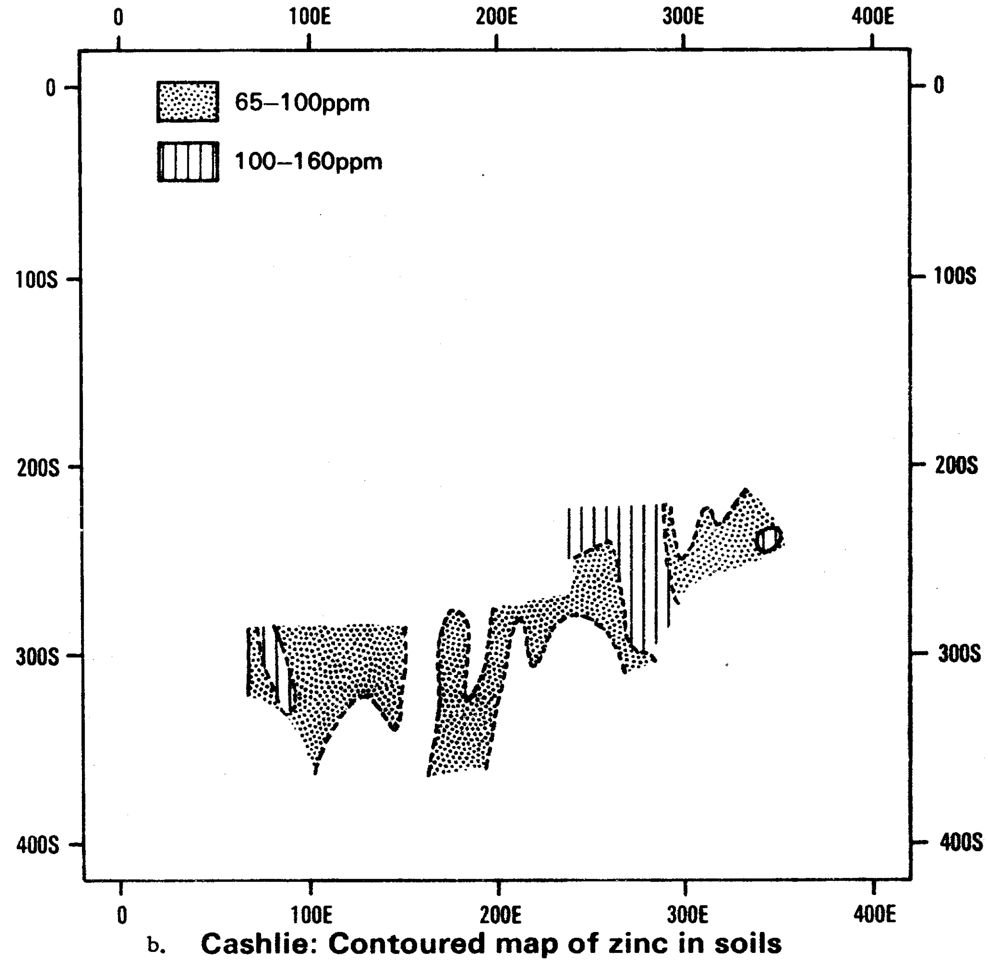


Pubil: Contoured map of lead in soils

Fig 7

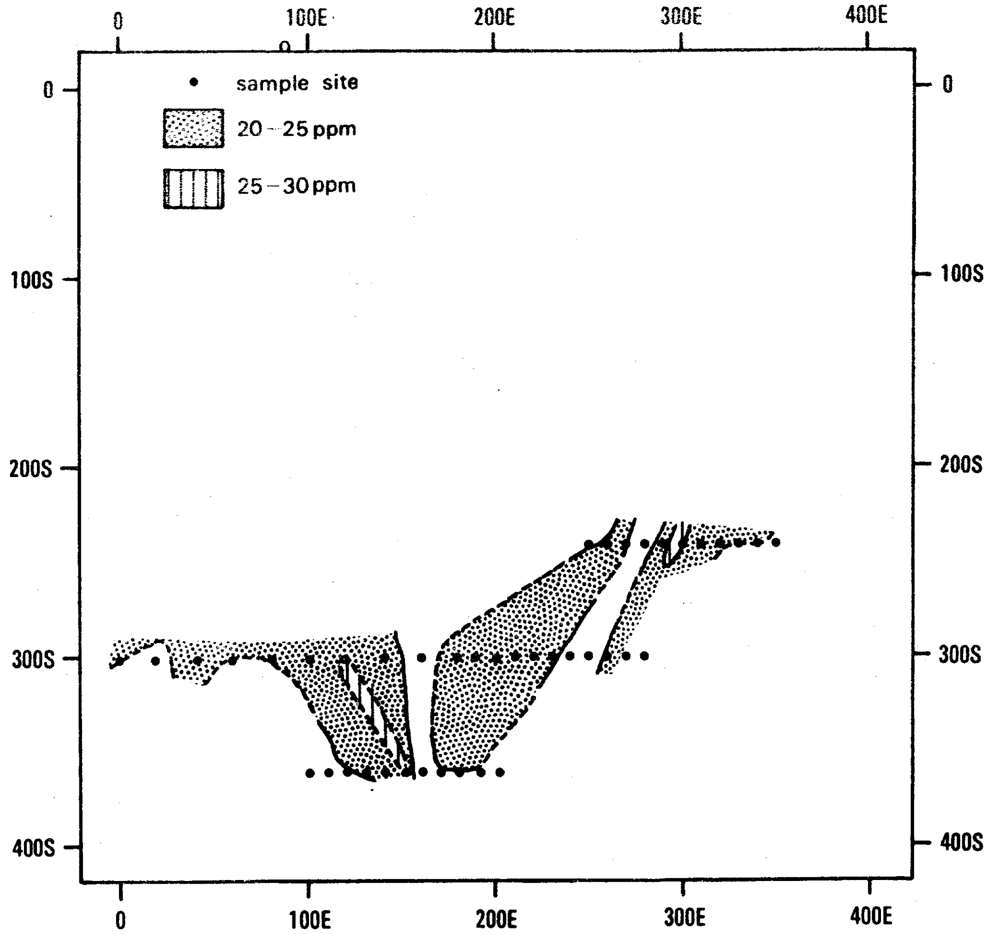


a. **Pubil: Contoured map of copper in soils**

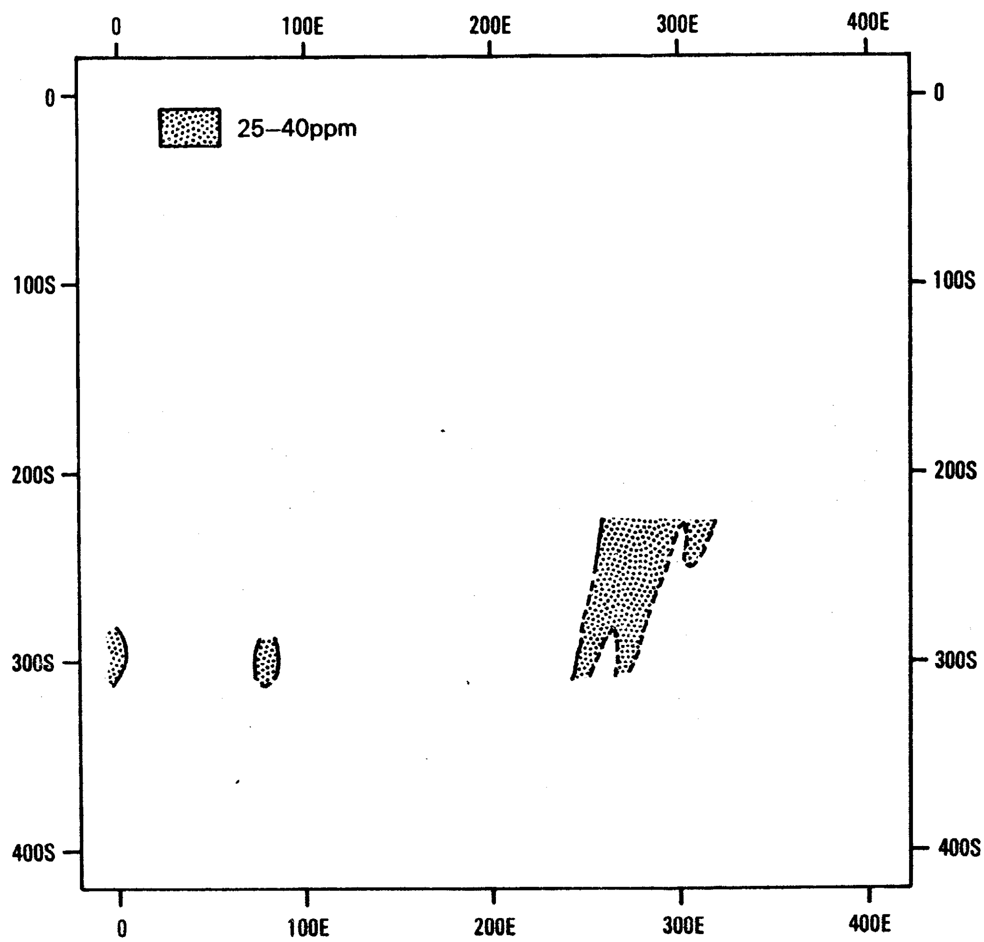


b. **Cashlie: Contoured map of zinc in soils**

Fig 8



Cashlie: Contoured map of copper in soils



Cashlie: Contoured map of lead in soils

Fig 9

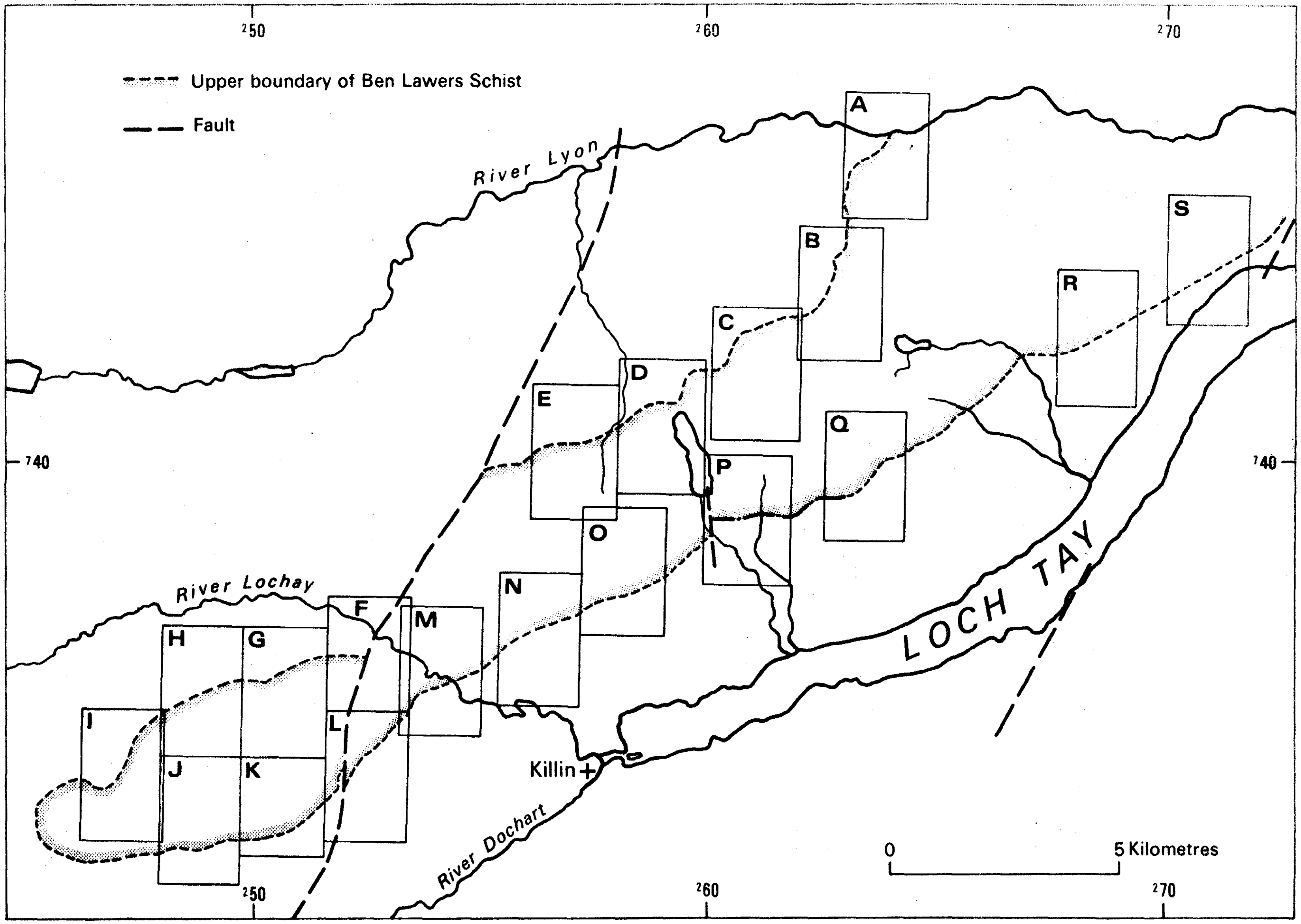


Fig. 10 Insets, showing location of 1:10 560 Geological Maps (Figs 10A–10S)

Dolerite, lamprophyre and porphyrite

Felsite

Appinite

Serpentinite

Metamorphosed basic rocks

MV	Metavolcanic
HS	hornblende-schist
MG	Metagabbro
GHS	Garnet-hornblende-schist

Loch Tay Limestone (Lst)

Ben Lui Schist

Sron Bheag Schist
Lst

Black schist
Ben Lawers Schist
Pyrite zone

Ben Eagach Black Schist

Carn Mairg Quartzite

(diss) py	(disseminated) Pyrite
cpy	Chalcopyrite
pyrr	Pyrrhotite

Fault

Slide

Formational boundary

Boundary of pyrite zone (conjectural)

bedding:
- Inclined, dip in degrees
- Generalised dip and strike

foliation:
- Inclined, dip in degrees
- Generalised dip and strike

0 1 2 3 4 5 Kilometres

Key to Figs.10, 10A–S.

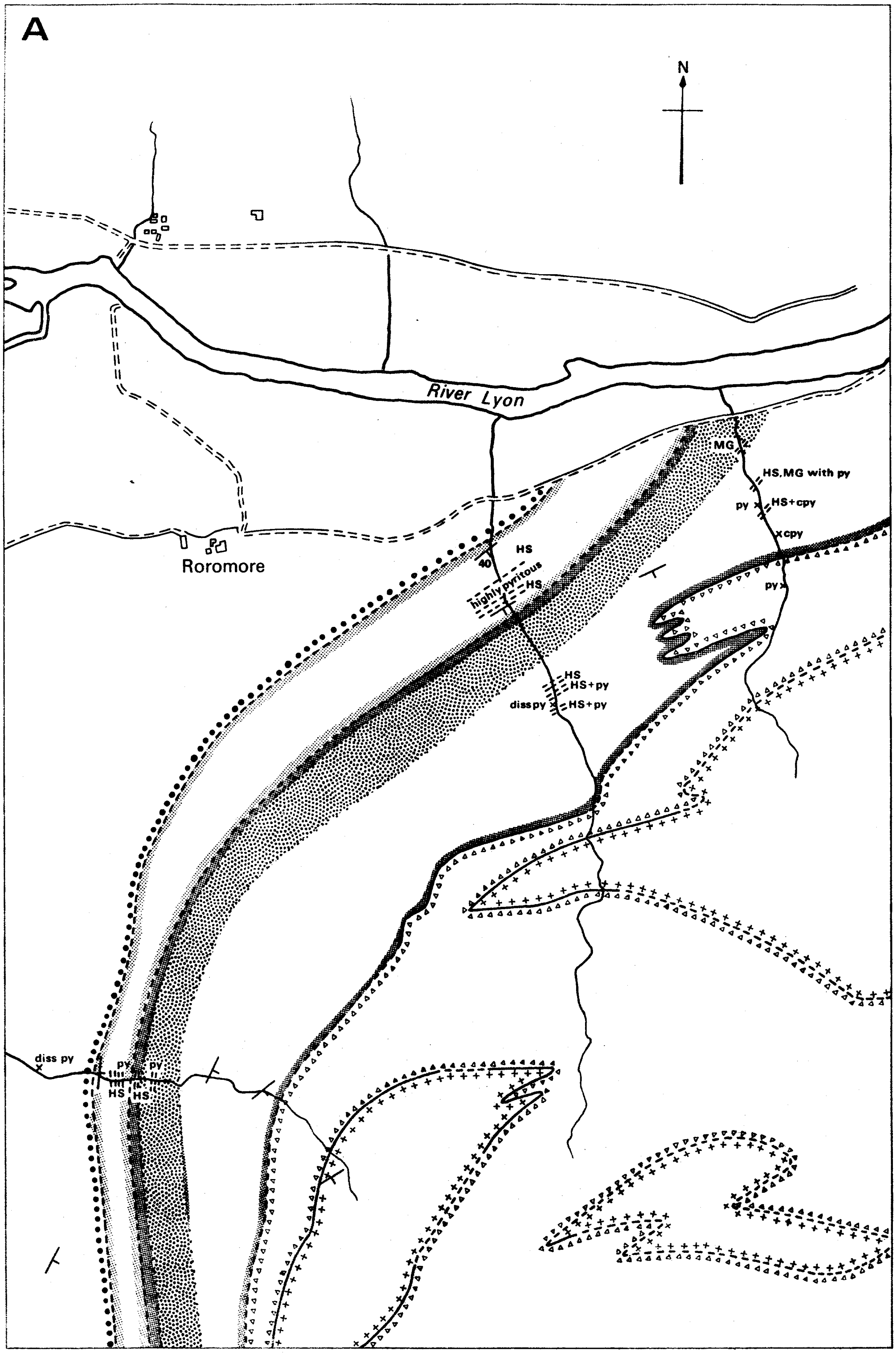

A
N
River Lyon
Roromore
MG
HS,MG with py
py
HS+cpy
xcpy
py
HS
40
highly pyritous
HS
HS
HS+py
diss py
HS+py
diss py
py
py
HS
HS

Fig.10 A

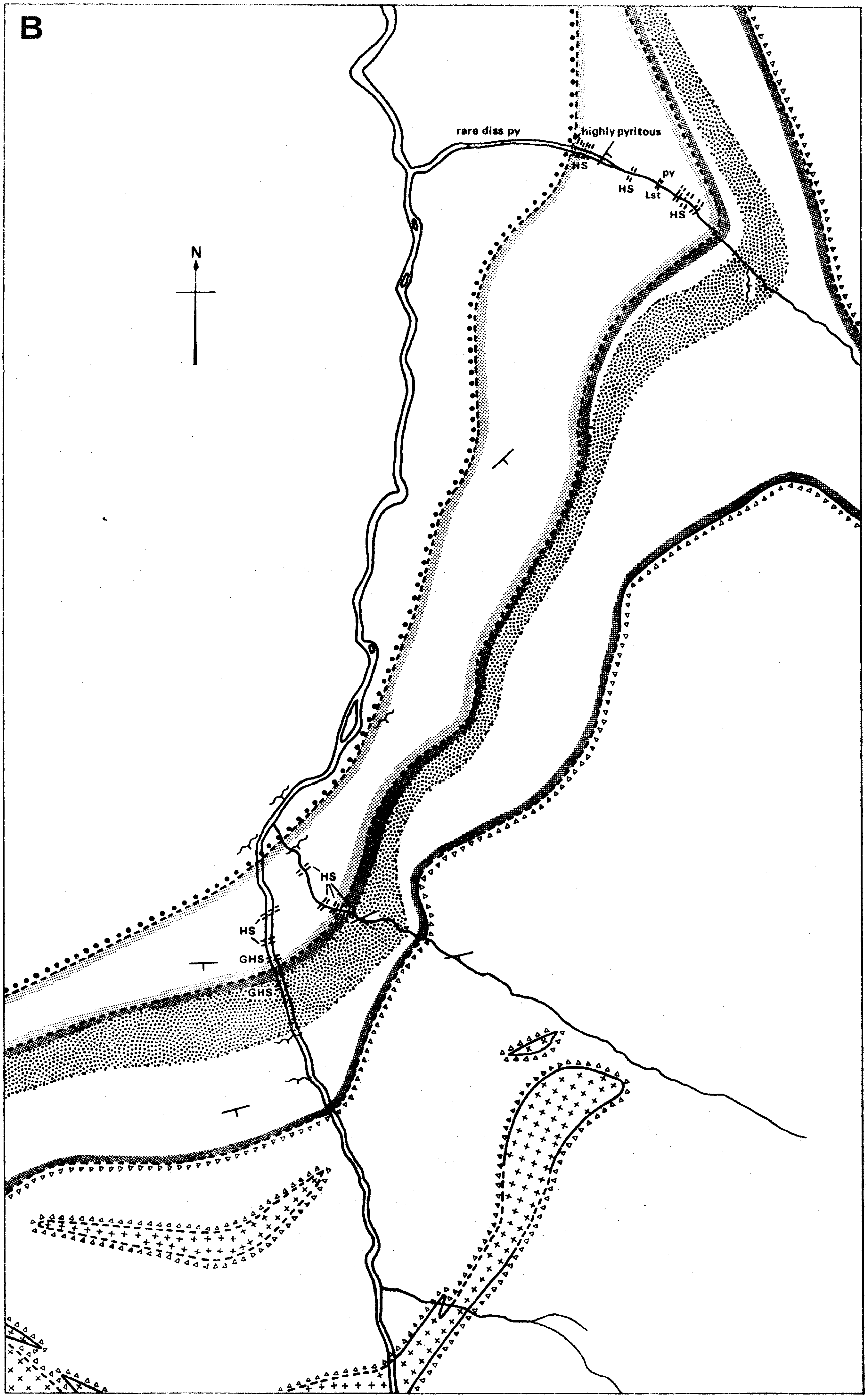


Fig.10 B

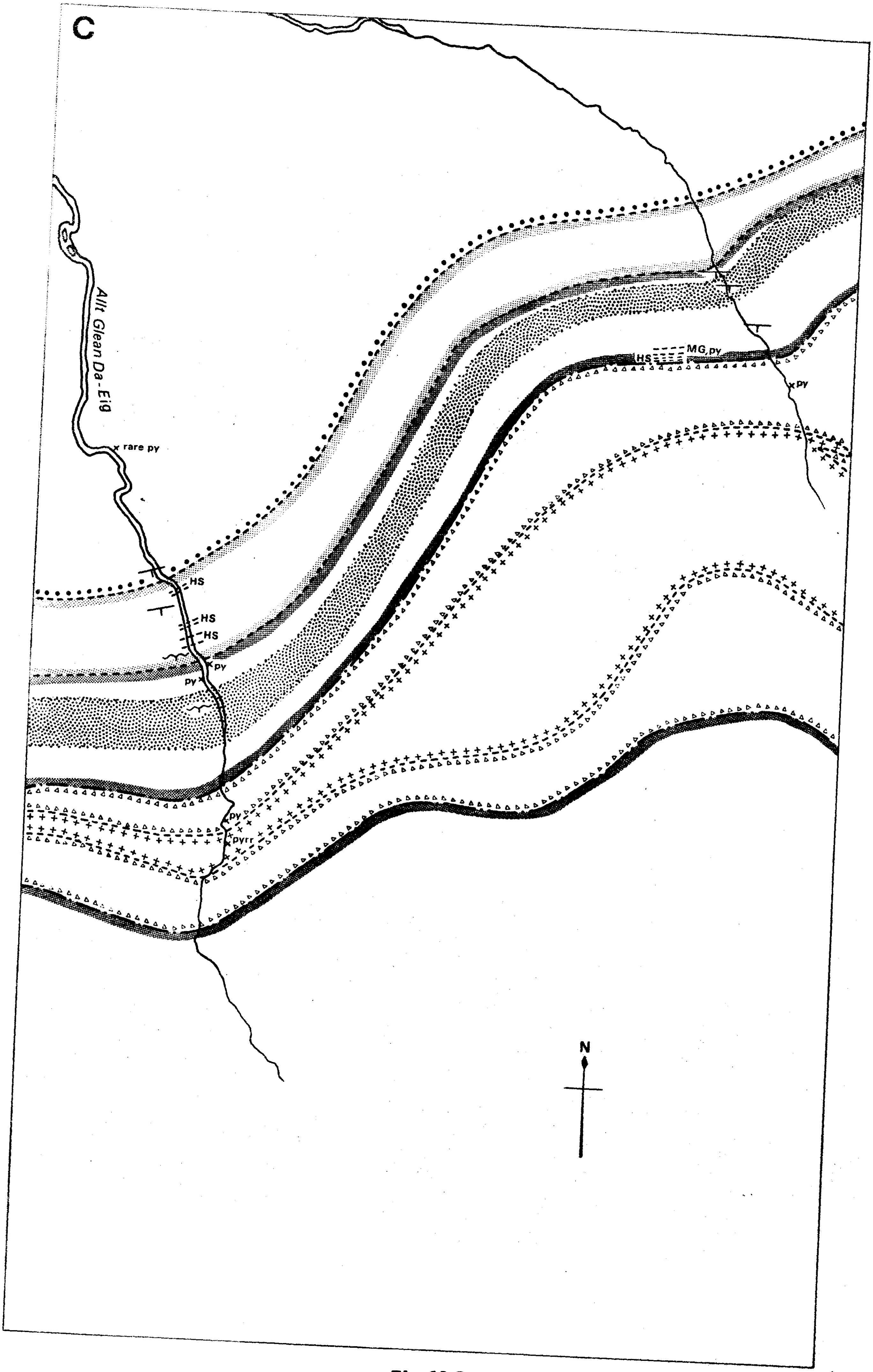


Fig. 10 C

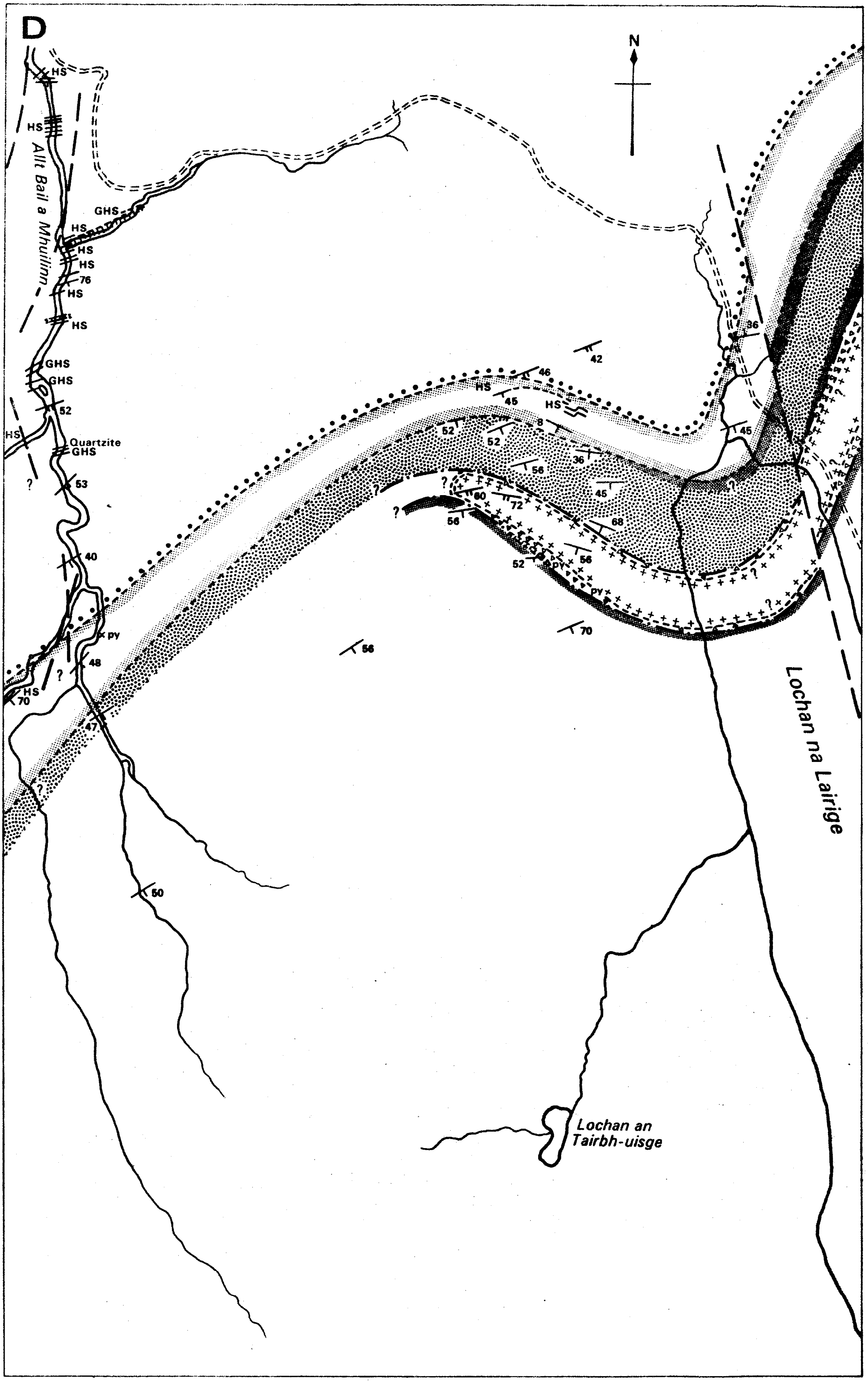

D
N
Allt Bail a Mhuilinn
HS
GHS
76
52
Quartzite
53
40
py
48
70
47
50
42
46
45
36
56
60
72
58
68
8
Lochan na Lairige
Lochan an Tairbh-uisge

Fig.10D

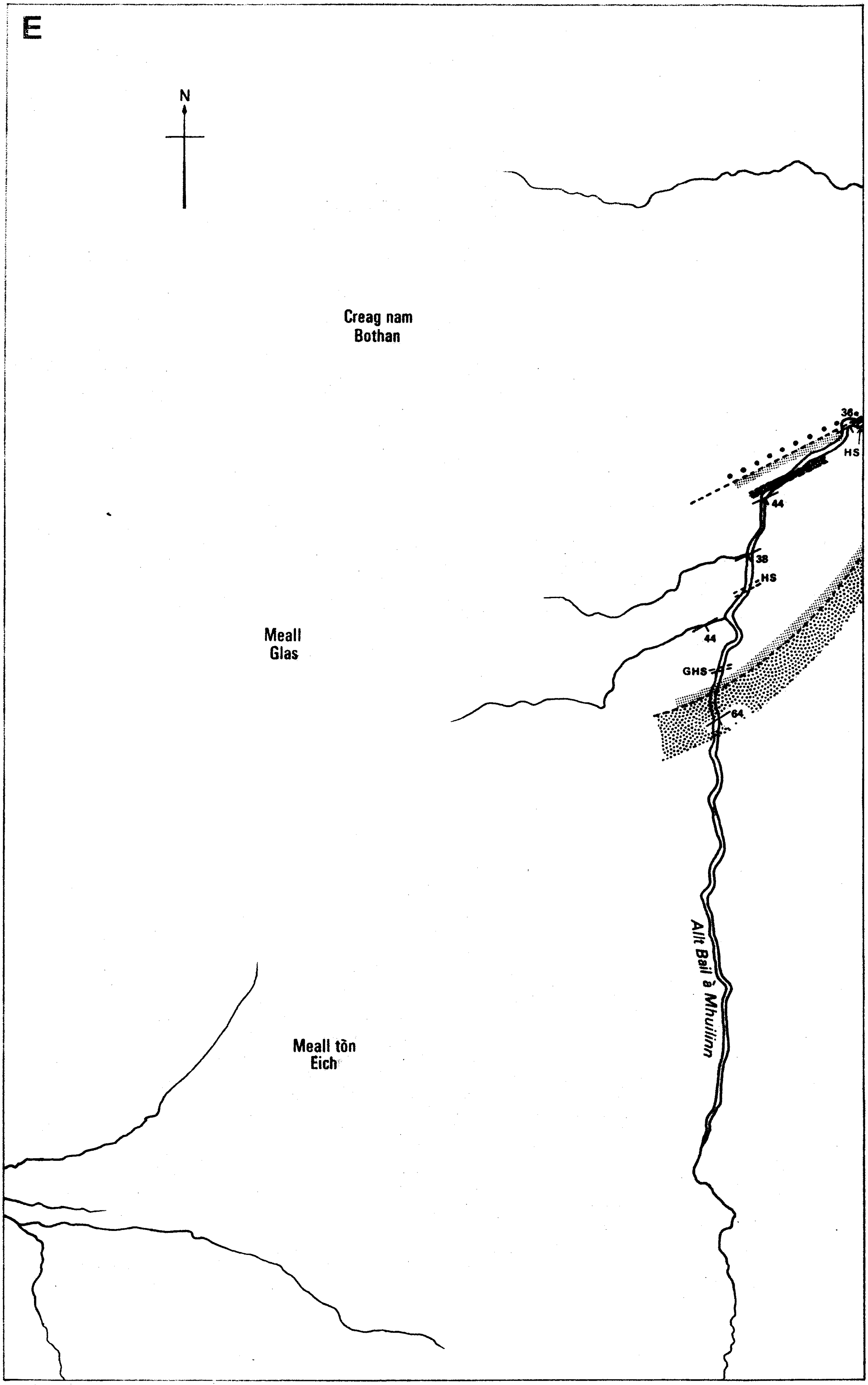

E
N
Creag nam
Bothan
36
HS
44
38
HS
44
GHS
64
Meall
Glas
Allt Bail' a' Mhuilinn
Meall tõn
Eich

Fig.10 E

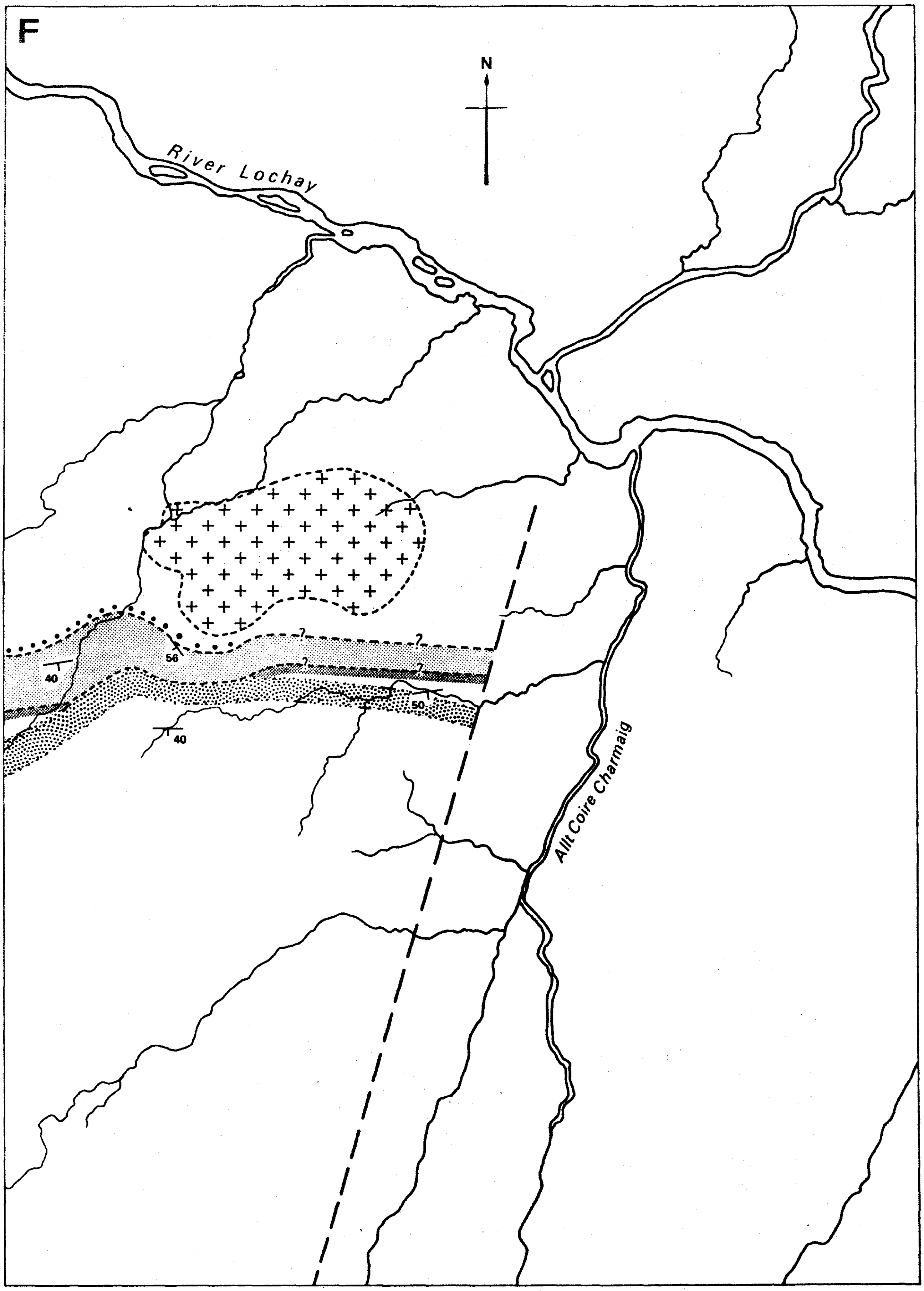


Fig.10 F

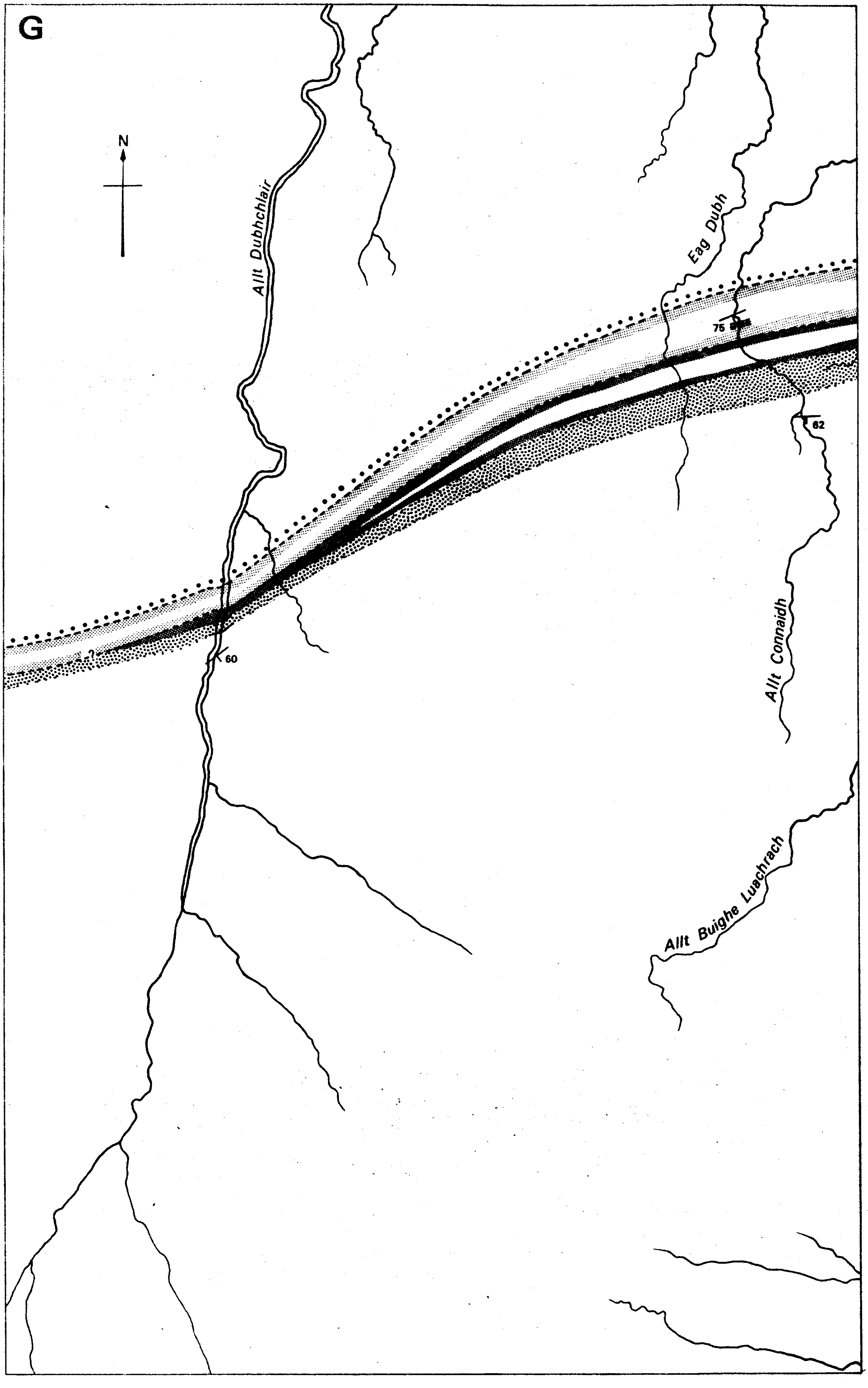

G
N
Allt Dubhchlair
Eag Dubh
75
62
60
Allt Connaidh
Allt Buighe Luachrach

Fig. 10 G

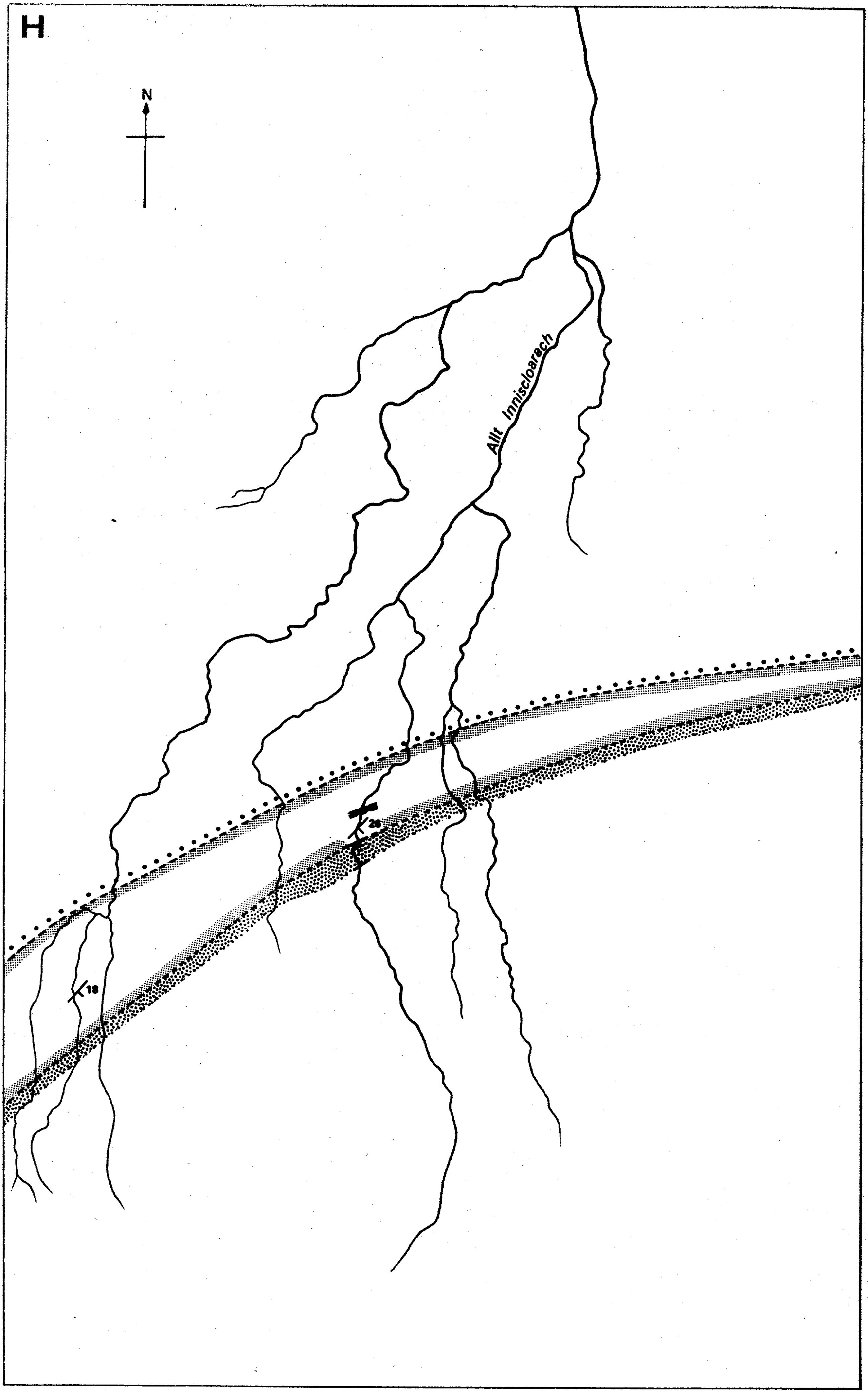


Fig. 10 H

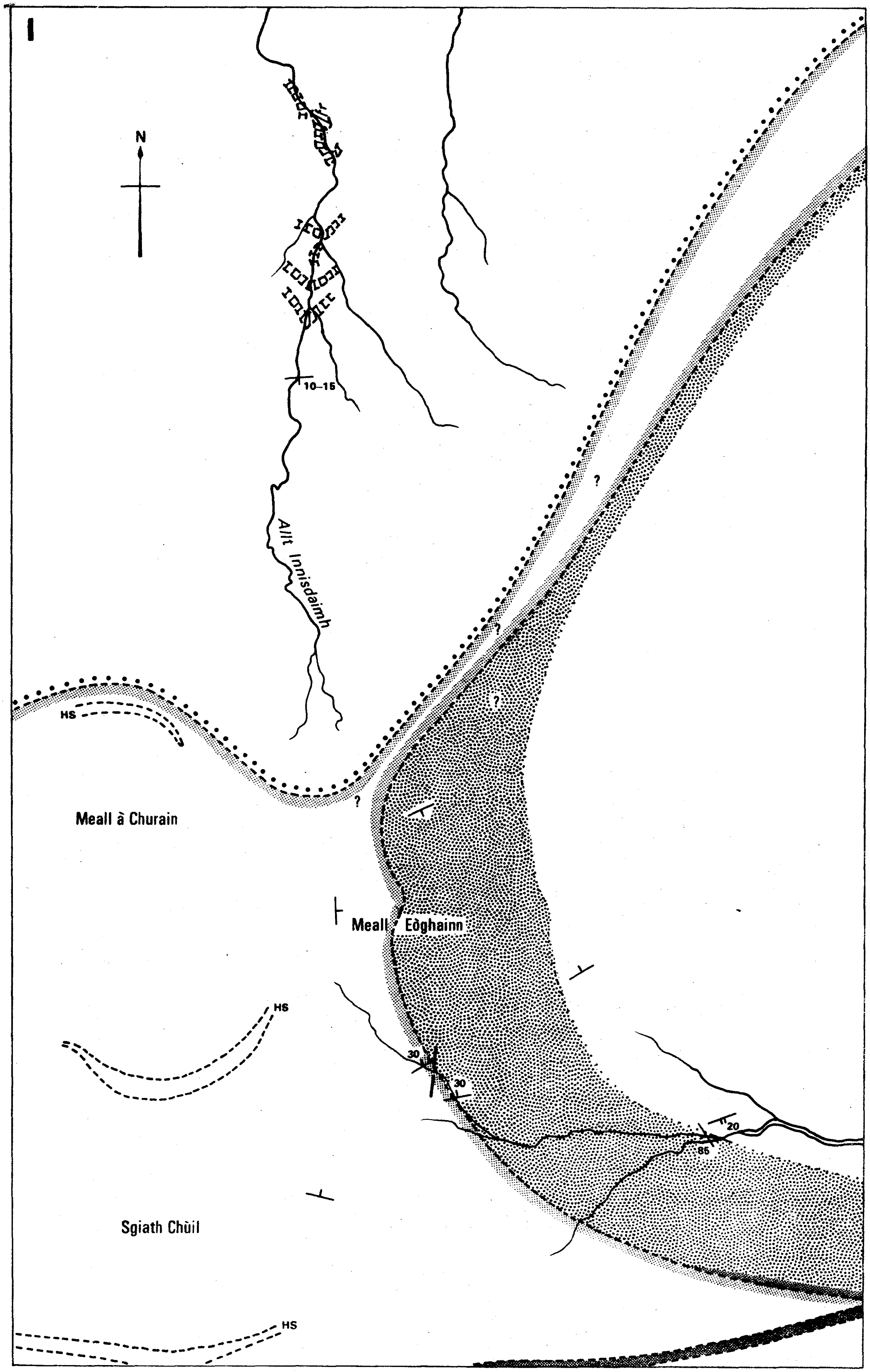
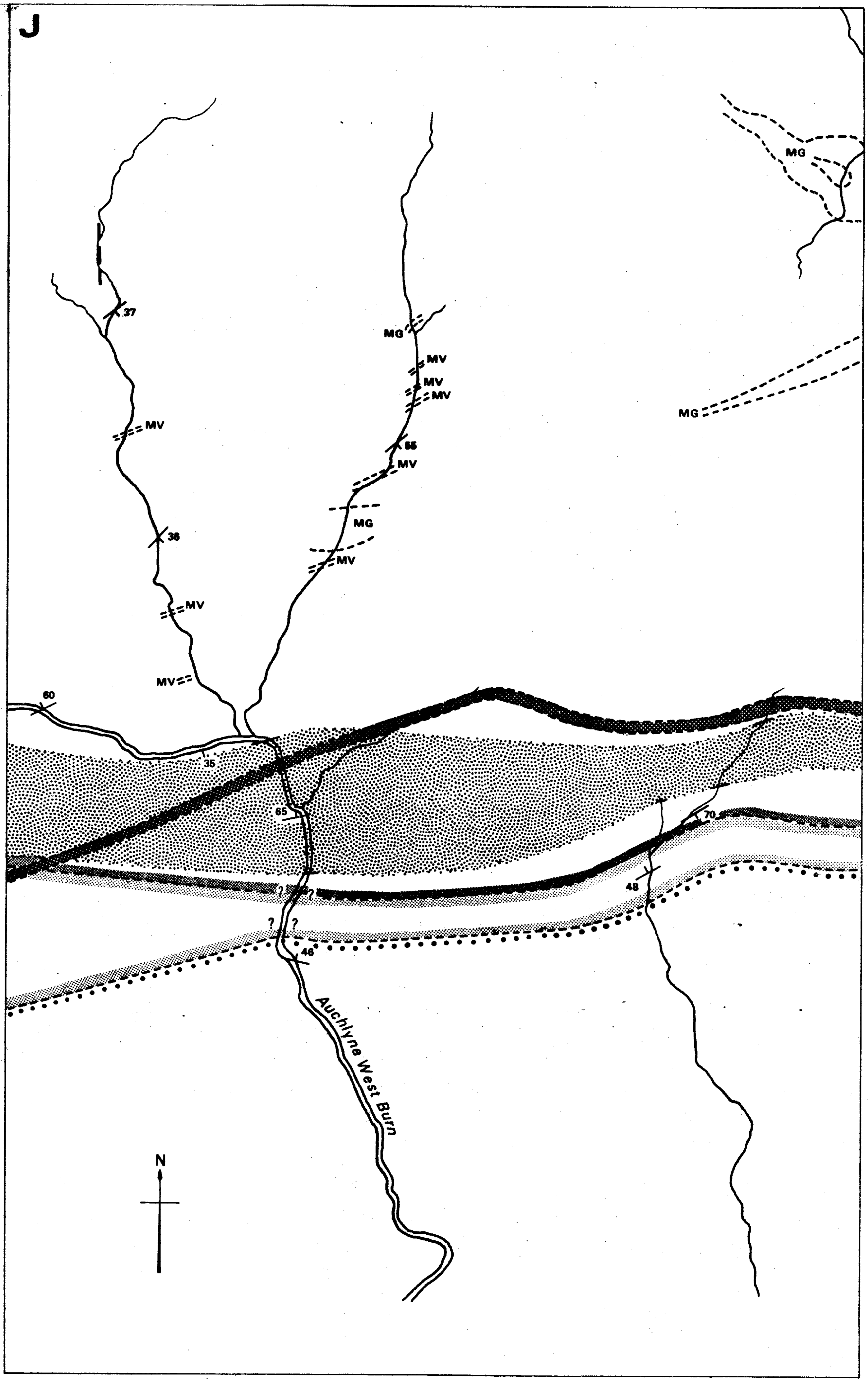

N
10–15
Allt Innisdaimh
HS
Meall à Churain
Meall Eòghainn
30
30
20
85
Sgiath Chùil
HS
HS
?
?
?
?

Fig.10 I



J
60
37
MG
MV
MV
MV
MV
MV
55
MV
MG
36
MV
MV
MV
MG
MG
35
65
70
48
?
?
?
?
46
Auchlyne West Burn
N

Fig. 10J

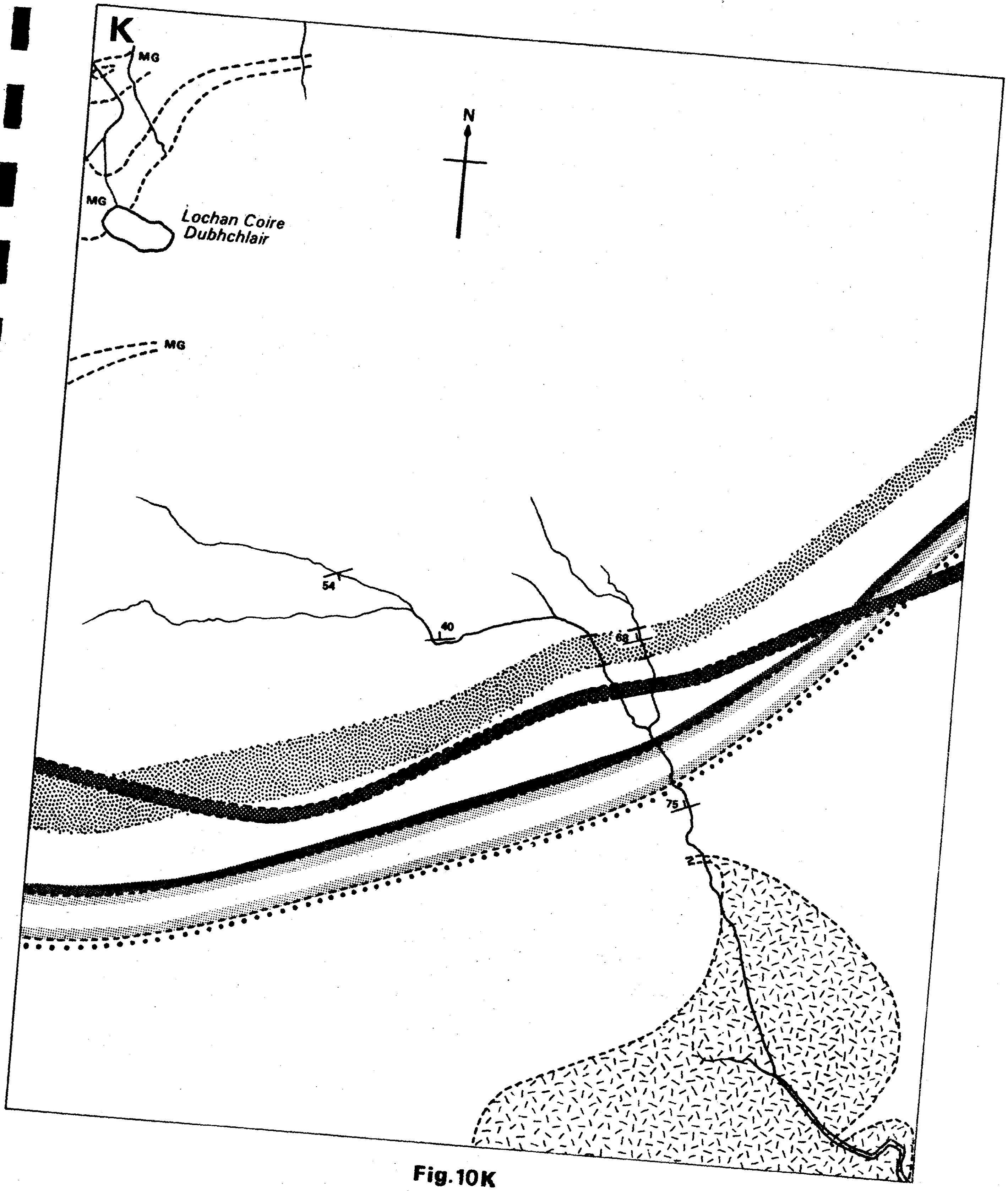


Fig.10K

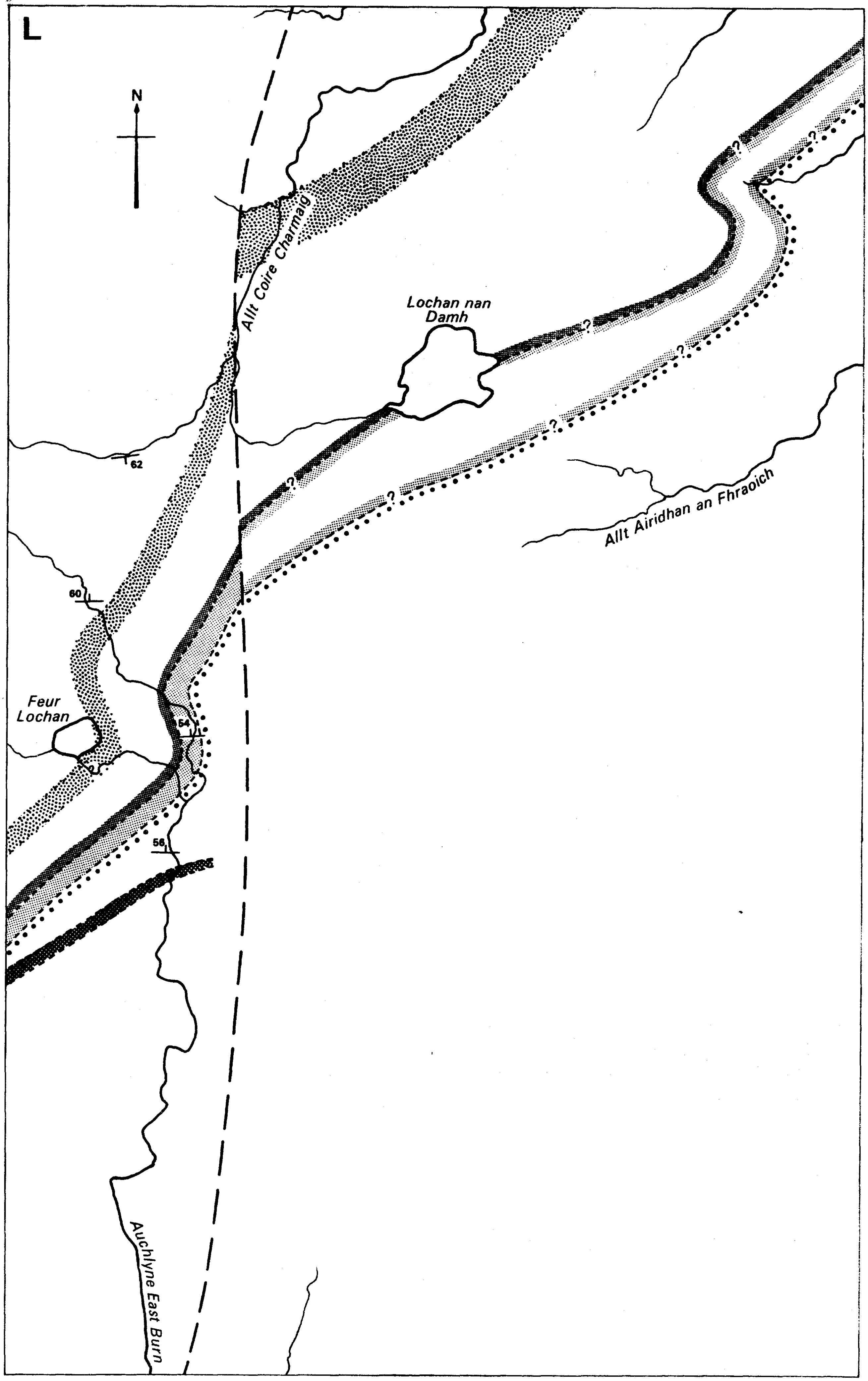

L
N
Allt Coire Charmaig
Lochan nan Damh
62
60
Feur Lochan
54
56
Allt Airidhan an Fhraoich
Auchlyne East Burn

Fig. 10 L

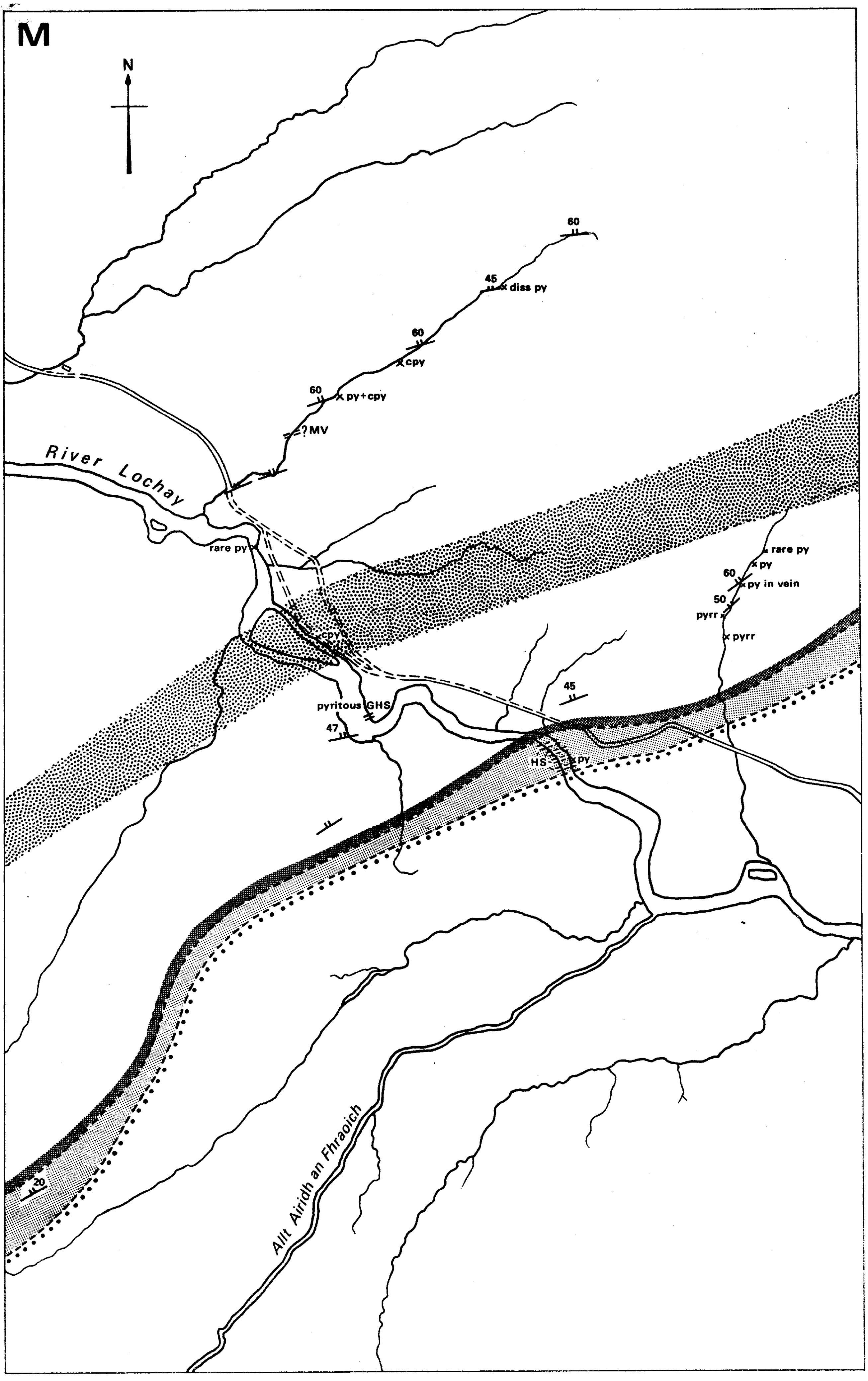

M
N
60
45
diss py
60
cpy
60
py+cpy
?MV
River Lochay
rare py
cpy
pyritous GHS
47
45
HS
py
rare py
py
60
py in vein
50
pyrr
pyrr
20
Allt Airidh an Fhraoich

Fig.10 M

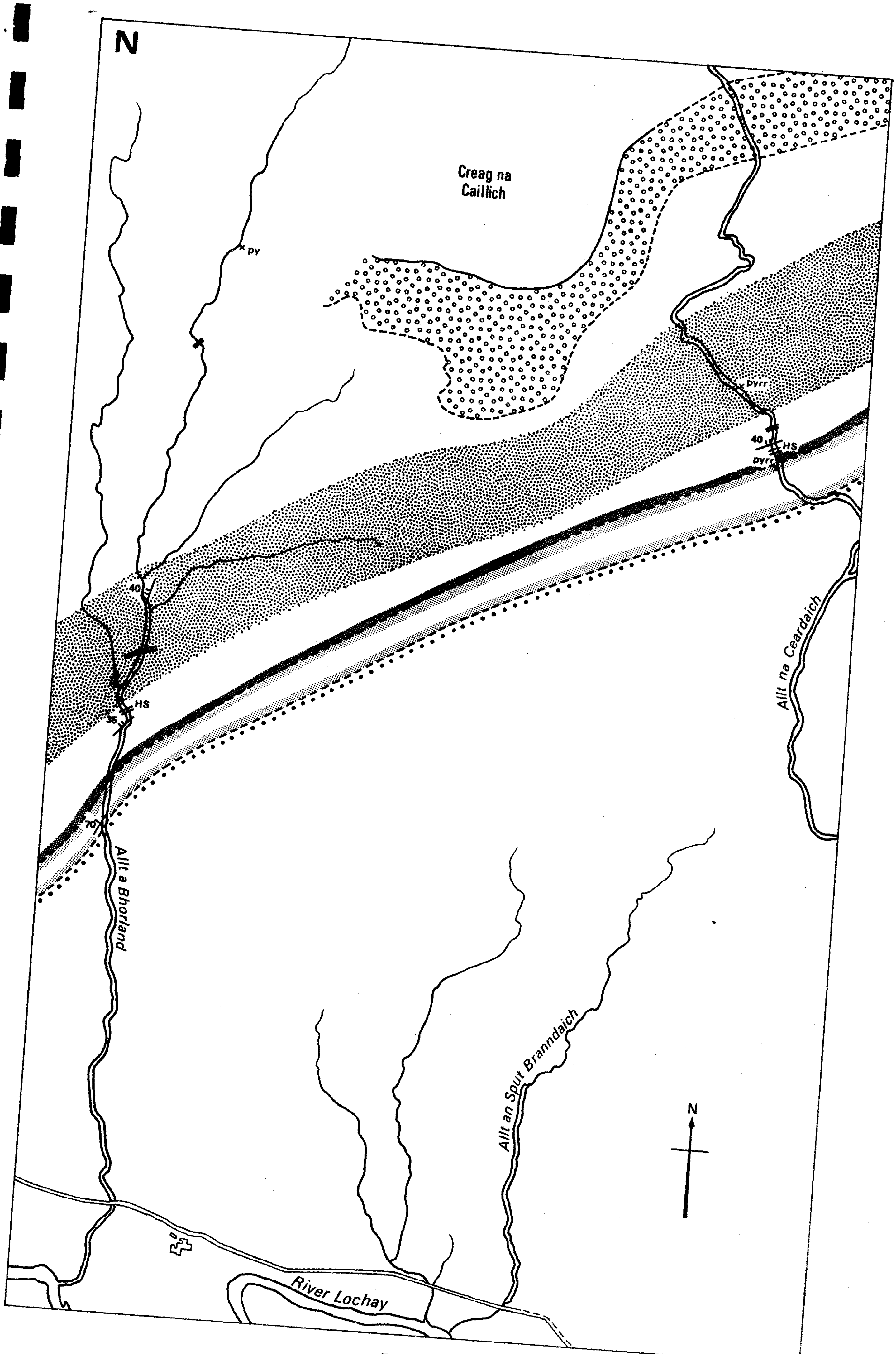

N
Creag na Caillich
py
pyrr
40
HS
pyrr
40
HS
35
70
Allt a Bhorland
Allt na Ceardaich
Allt an Sput Branndaich
N
River Lochay

Fig.10 N

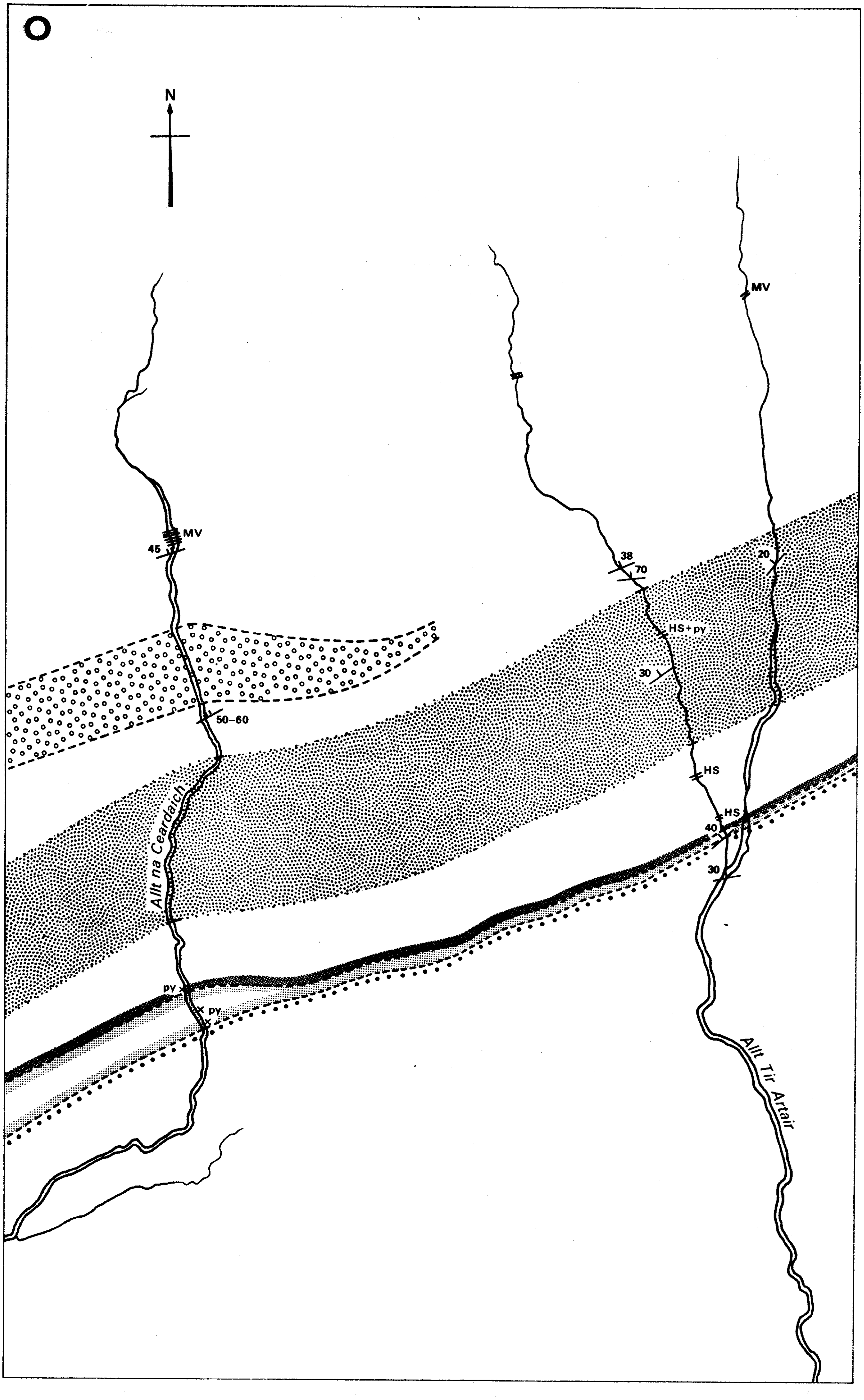

O
N
MV
45
50–60
Allt na Ceardaich
py
py
38
70
HS+py
30
HS
HS
40
30
MV
20
Allt Tir Artair

Fig.10 O

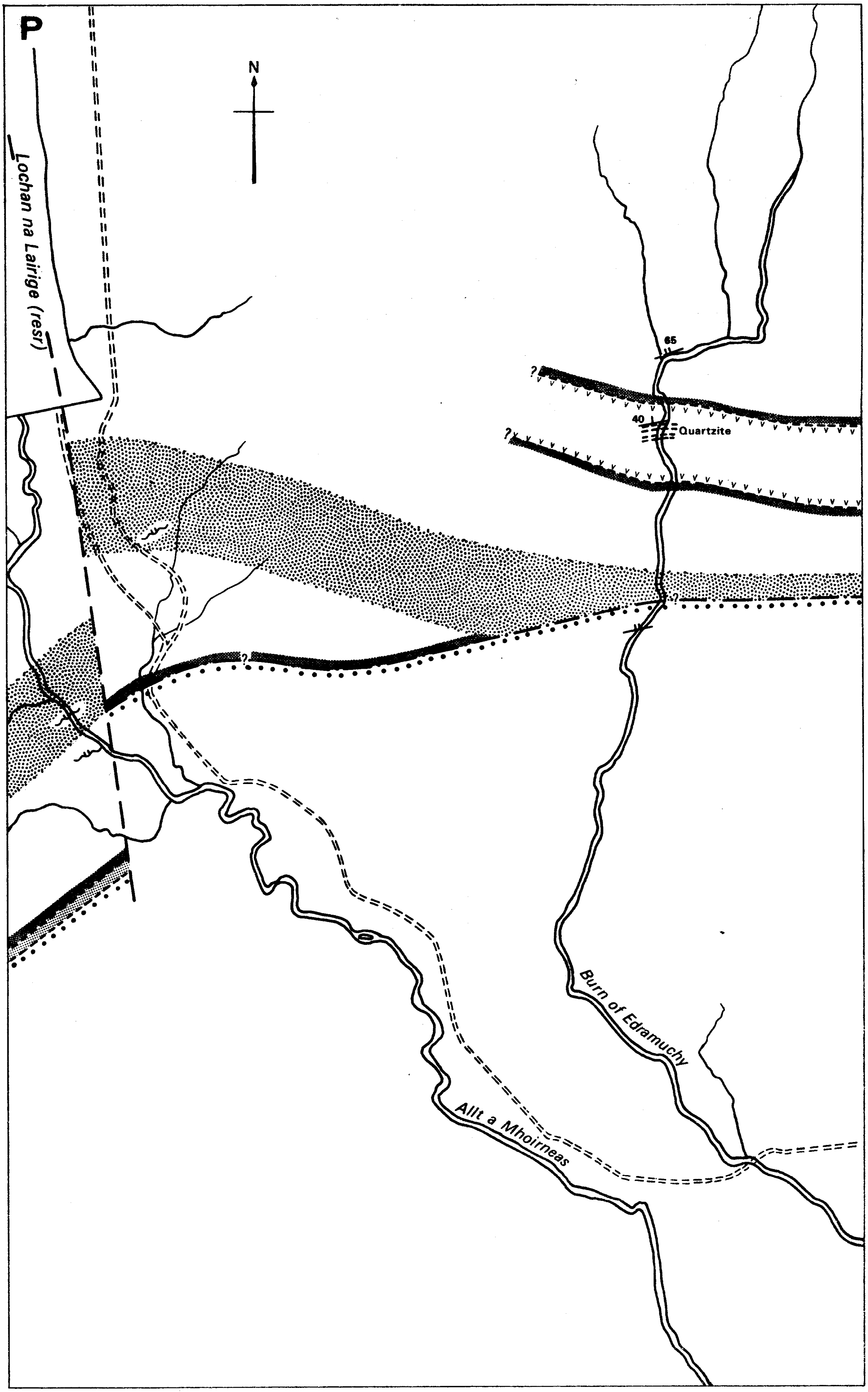

P
N
Lochan na Lairige (resr)
65
40
Quartzite
?
Burn of Edramuchy
Allt a Mhoirneas

Fig.10 P

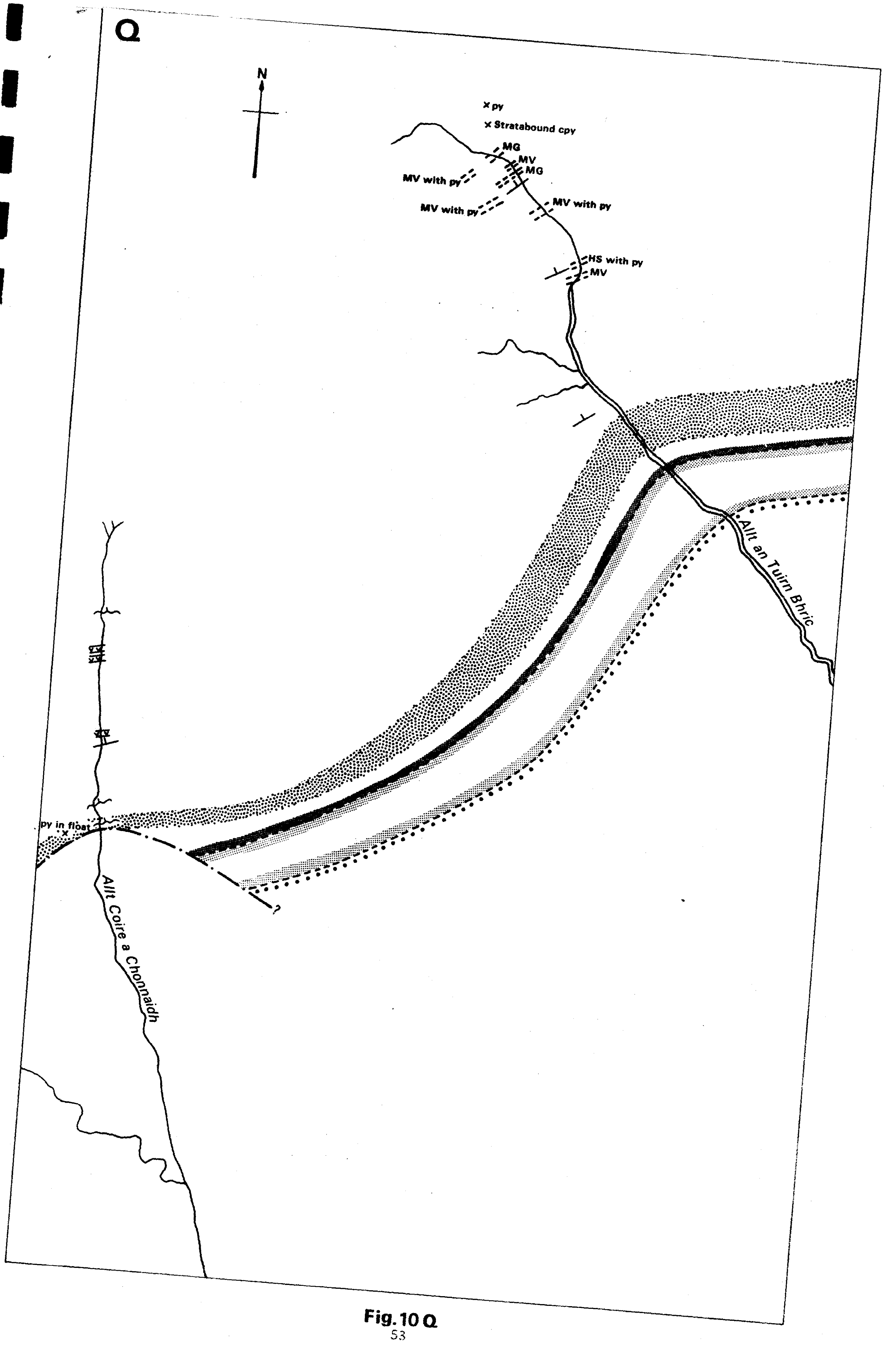

Q
N
× py
× Stratabound cpy
MG
MV
MG
MV with py
MV with py
MV with py
HS with py
MV
Allt an Tuirn Bhric
py in float
Allt Coire a Chonnaidh

Fig. 10 Q

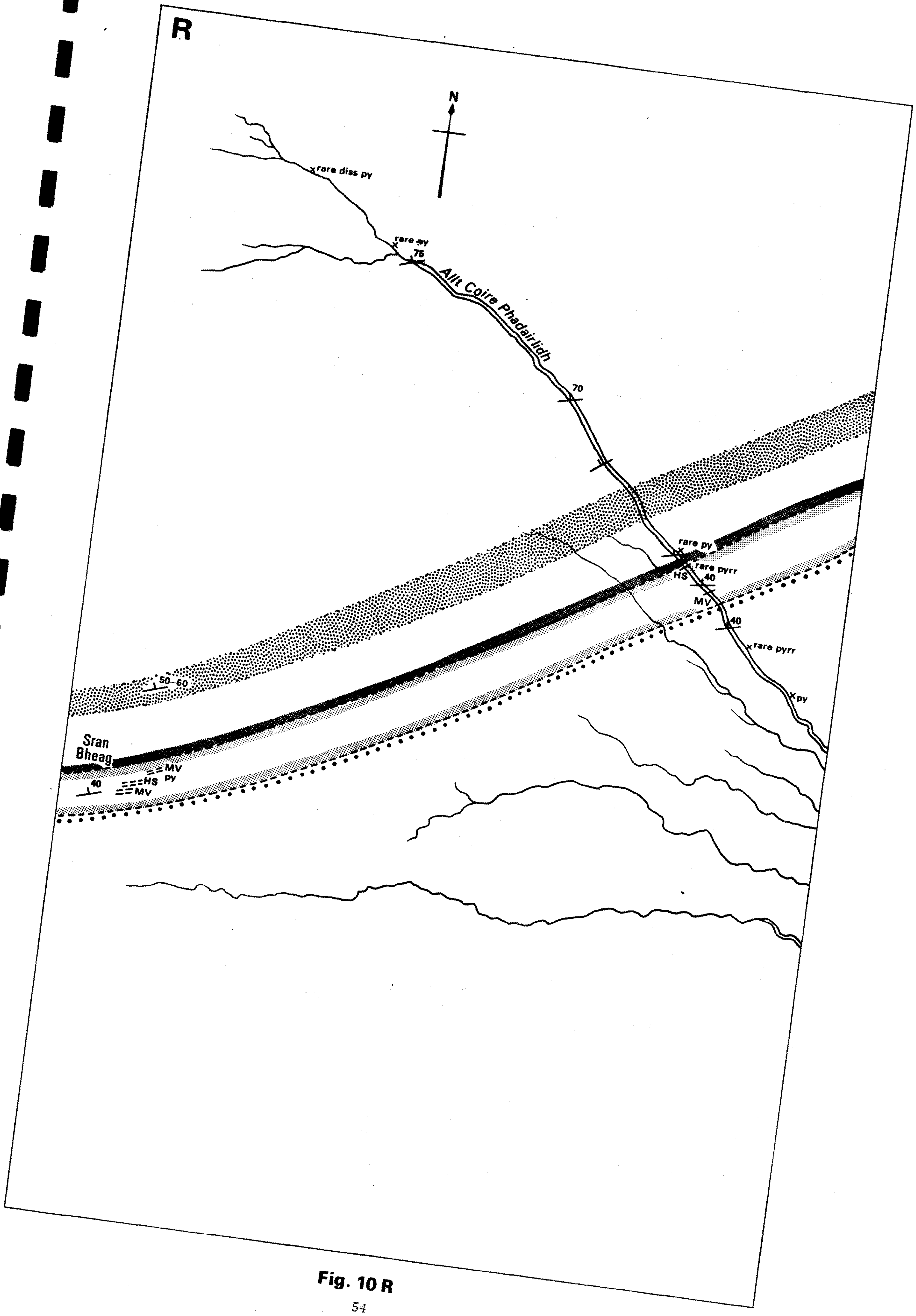

R
N
rare diss py
rare py
75
Allt Coire Phadairlidh
70
rare py
rare pyrr
HS
40
MV
40
rare pyrr
py
50–60
Sran
Bheag
MV
HS
py
MV
40

Fig. 10 R

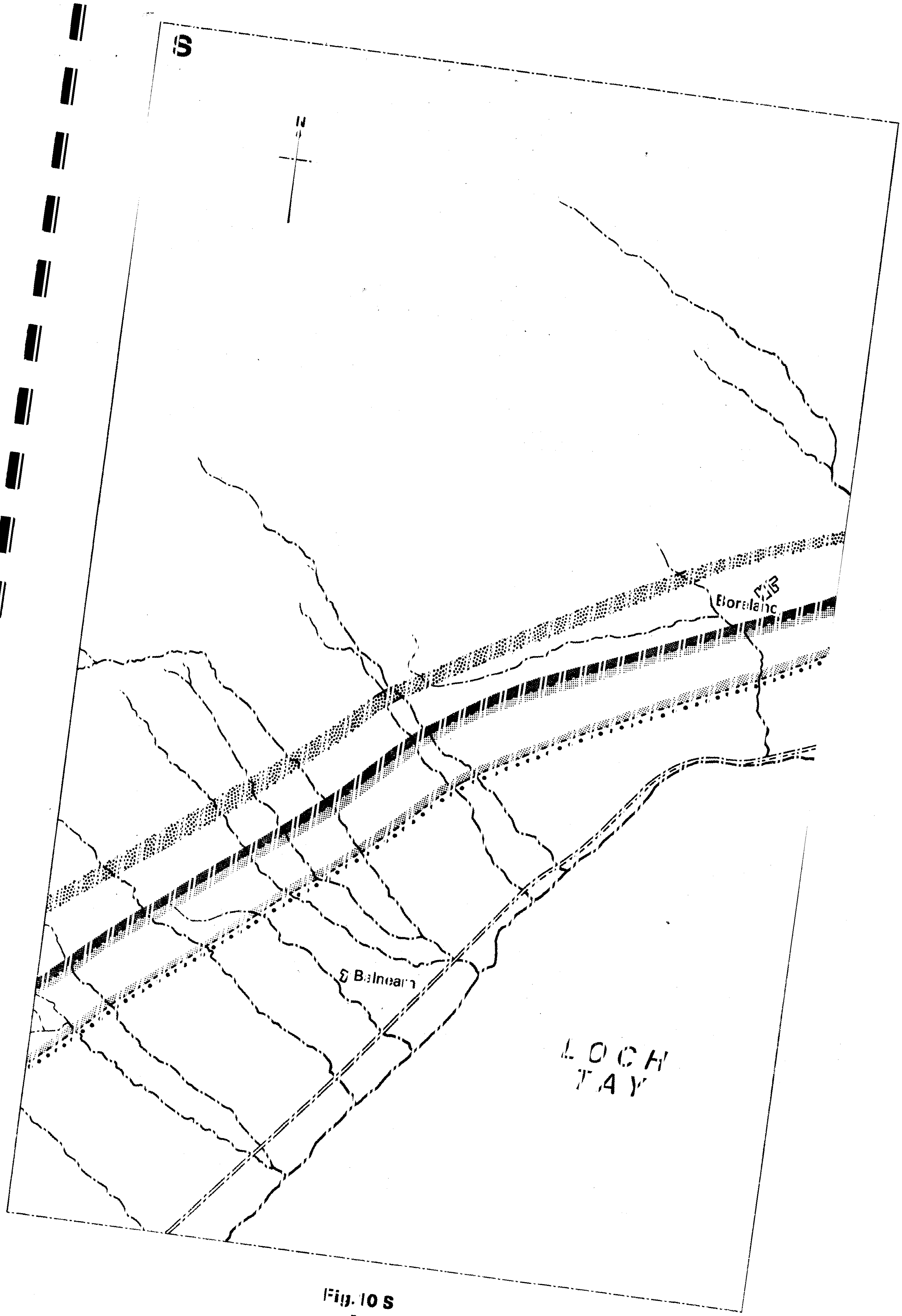


Fig. 10 S

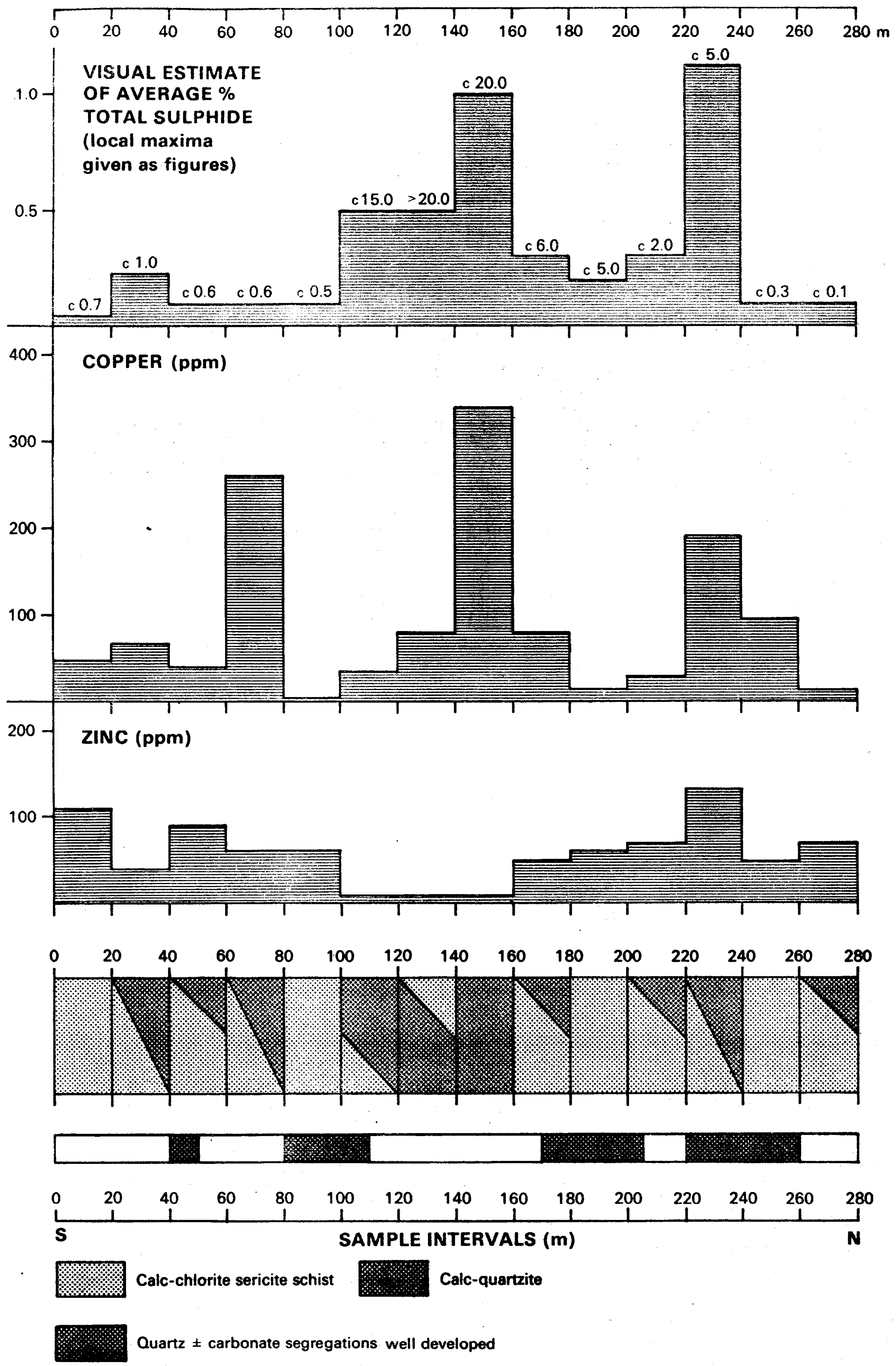


Fig. 11 Distribution of metal values and sulphide contents in the Allt a'Bhorland Section, Glen Lochay '0' at NGR NN 25553600

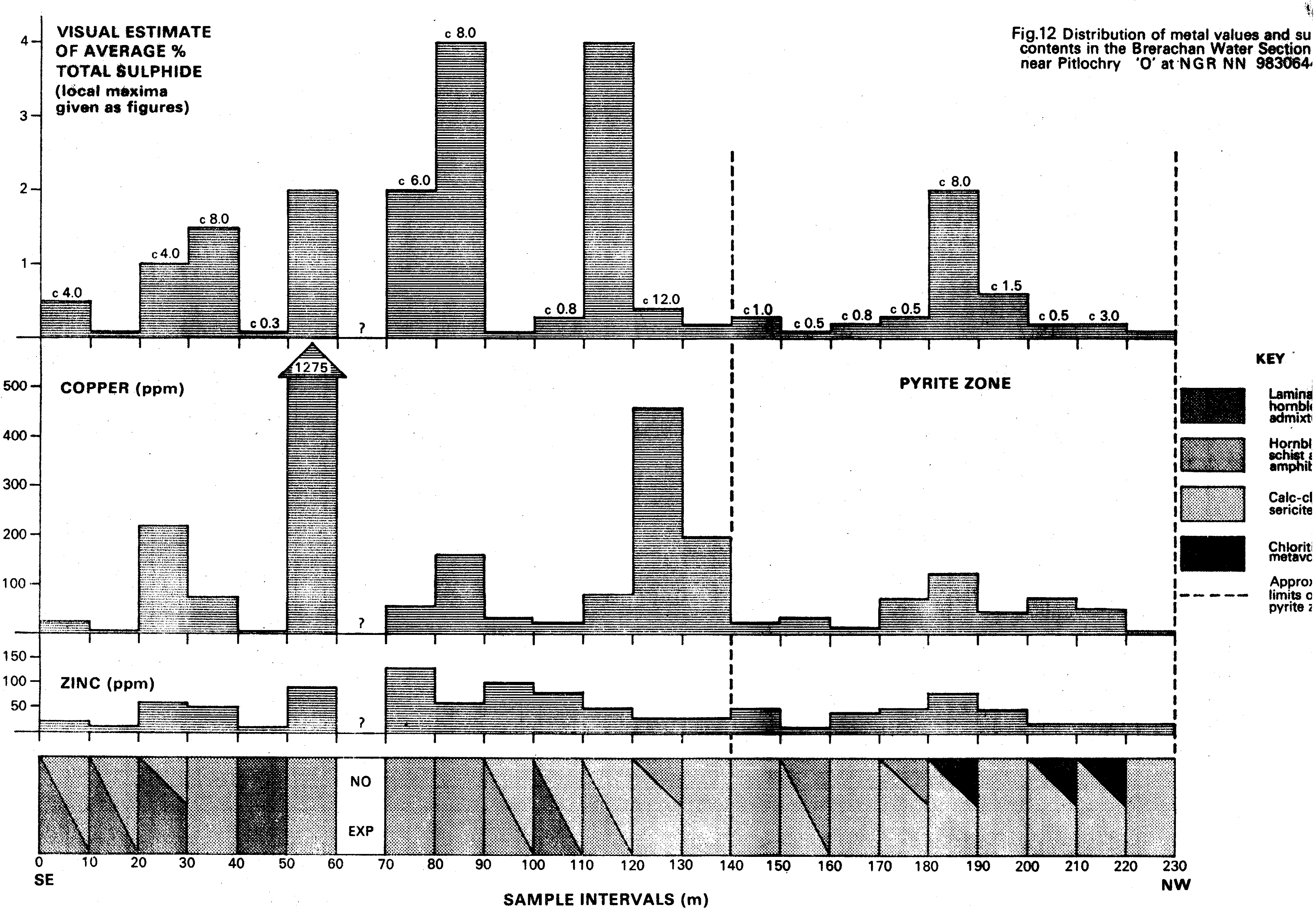
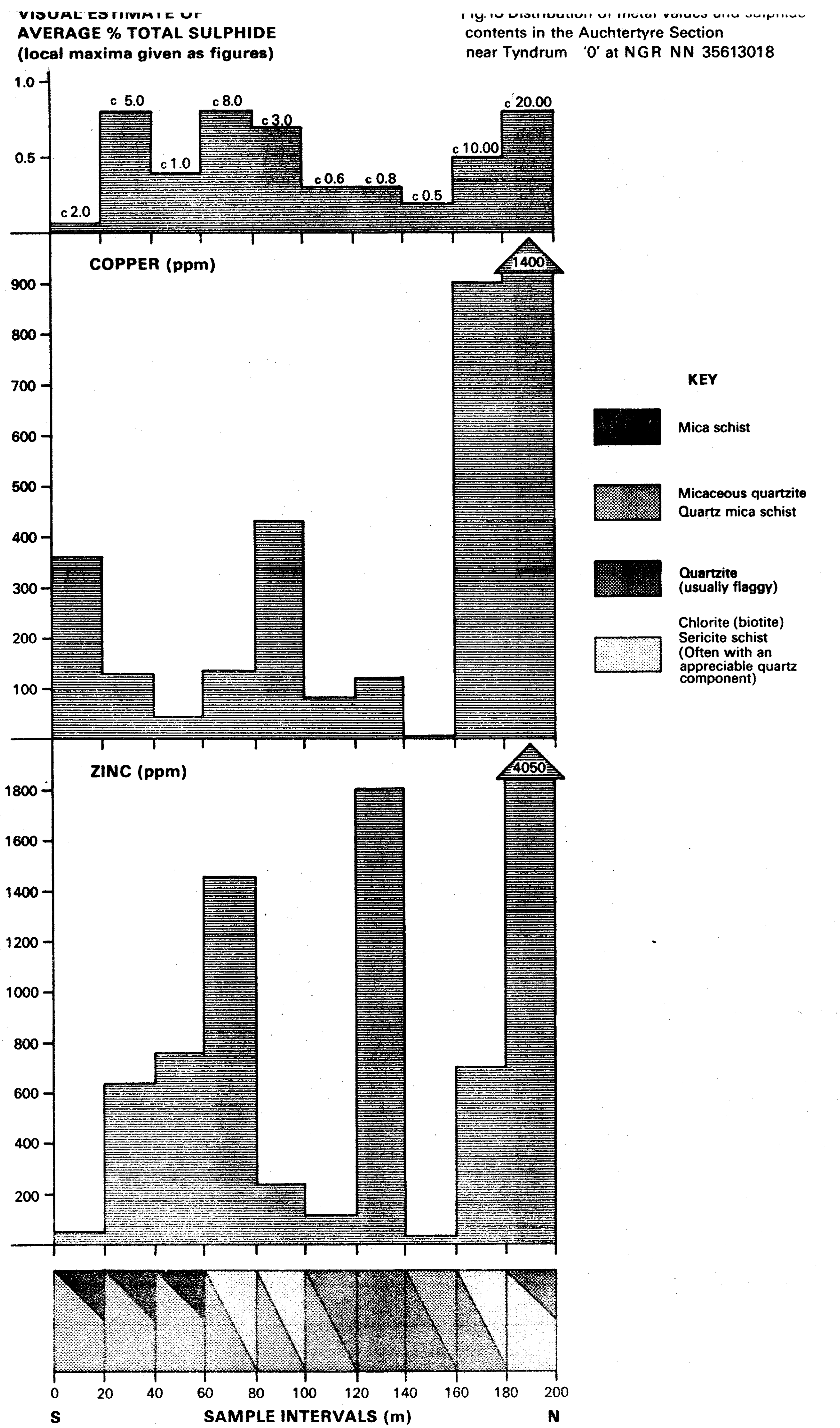
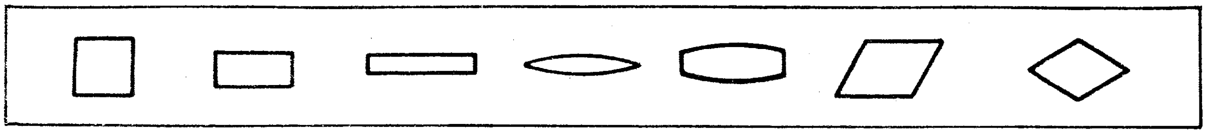


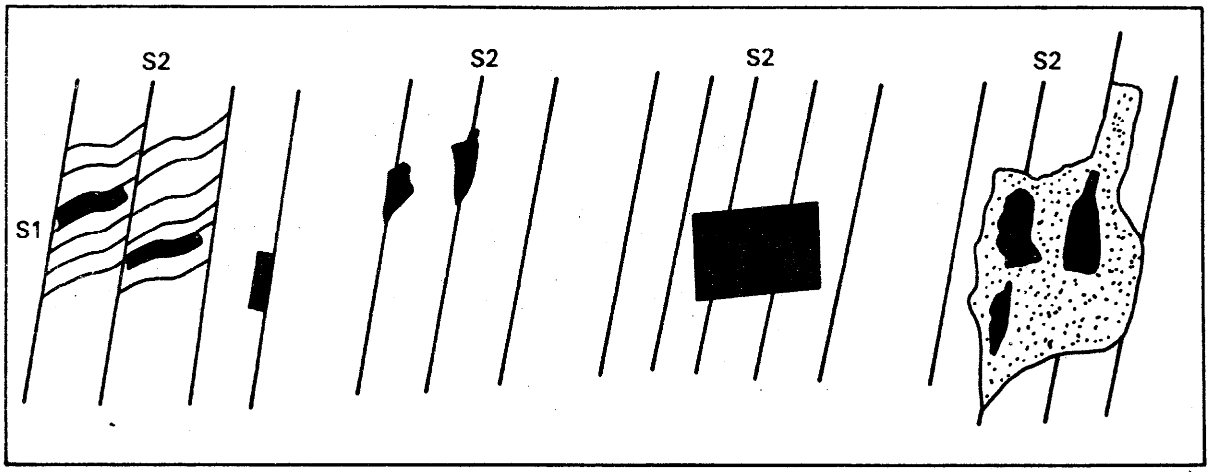
Fig.12 Distribution of metal values and su contents in the Brerachan Water Section near Pitlochry 'O' at NGR NN 983064

Fig.1[illegible] Distribution of metal values and sulphide contents in the Auchtertyre Section near Tyndrum '0' at NGR NN 35613018



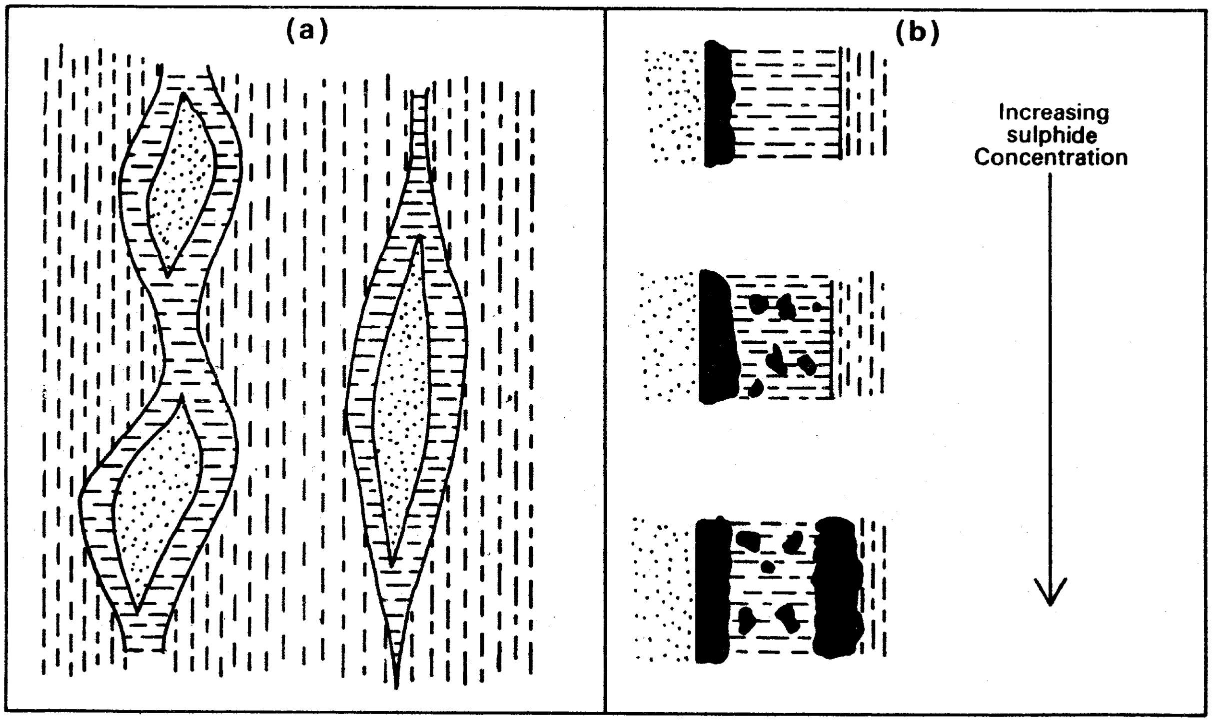


Cross-sections of pyrite crystals showing variations in form



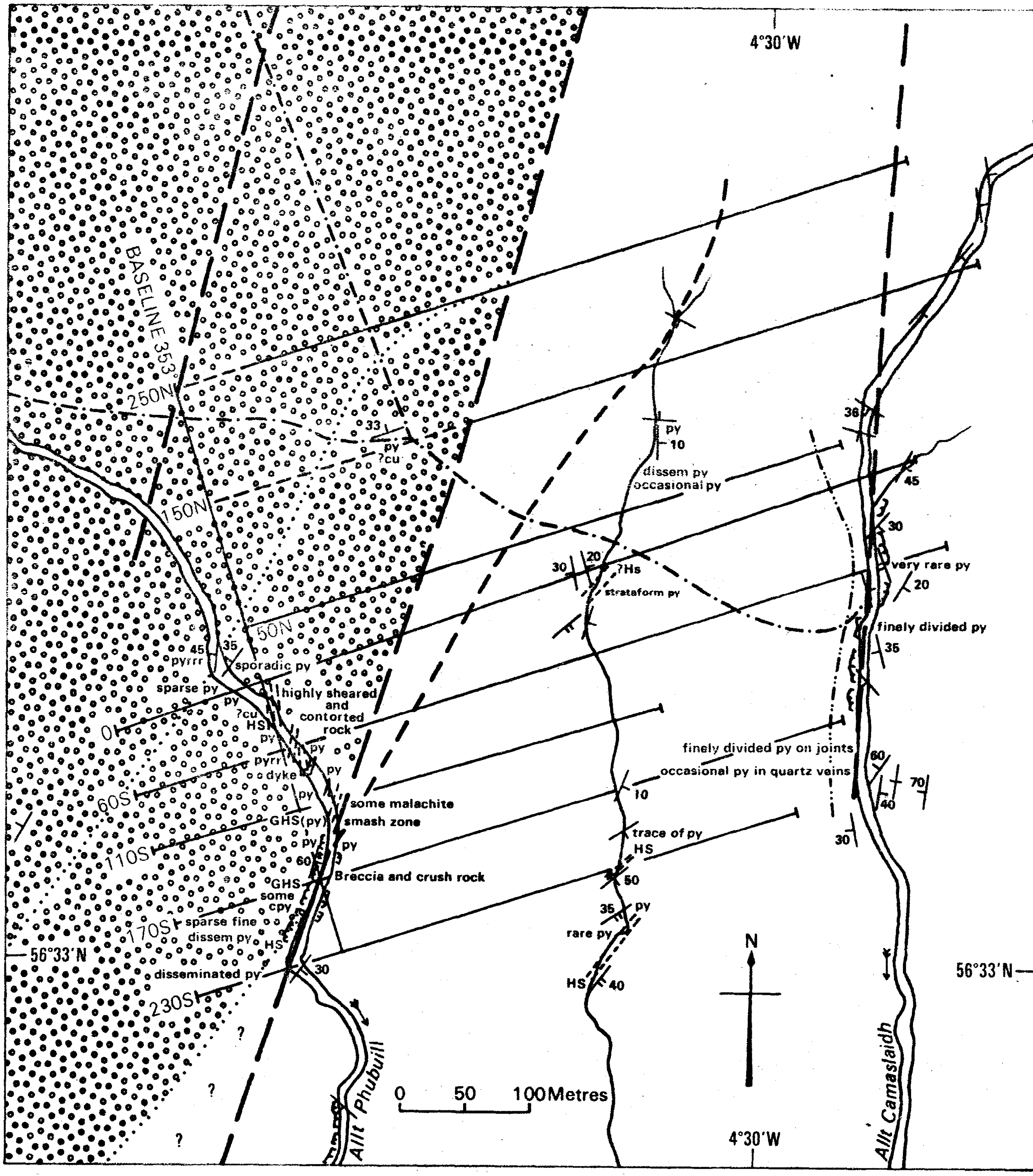
S1 Bedding/schistosity S2 Strain-slip cleavage Pyrite Quartz

Fig. 14 Habits of pyrite in schists with strain-slip cleavage



Schist Carbonate Quartz Sulphide

Fig. 15 Cross-sections of quartz-carbonate segregations showing (a) distribution of mineral phases and (b) the pattern of sulphide development at margins



Ben Lawers Schist

Sron Bheag Schist

HS Hornblende-schist bands (meta-Igneus)

GHS Garnetiferous hornblende-schist

Fault, broken where uncertain

Position of fault prefered from geophysical survey

Approximate limit of pyritous zone

30 Inclined bedding, with dip in degrees

Vertical bedding

40 Inclined foliation, with dip in degrees

Geophysical traverse

Hydro-electric tunnel

Grounded metal fence

py pyrite

pyrr pyrrhotite

cpy chalcopyrite

Fig. 16 **Pubil: Geology and location of geophysical traverses**

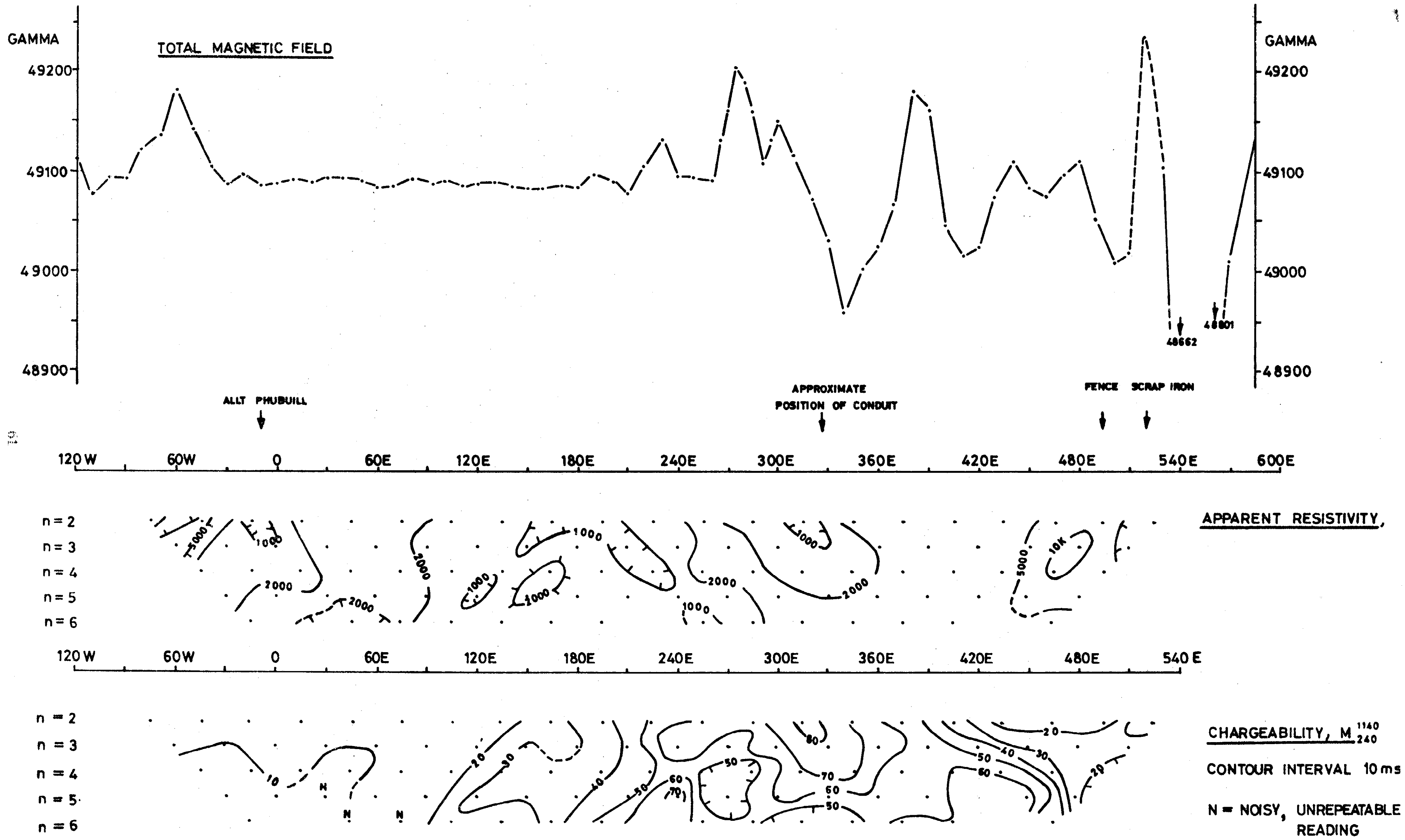


Fig. 17 PUBIL: GEOPHYSICAL RESULTS FOR TRAVERSE O

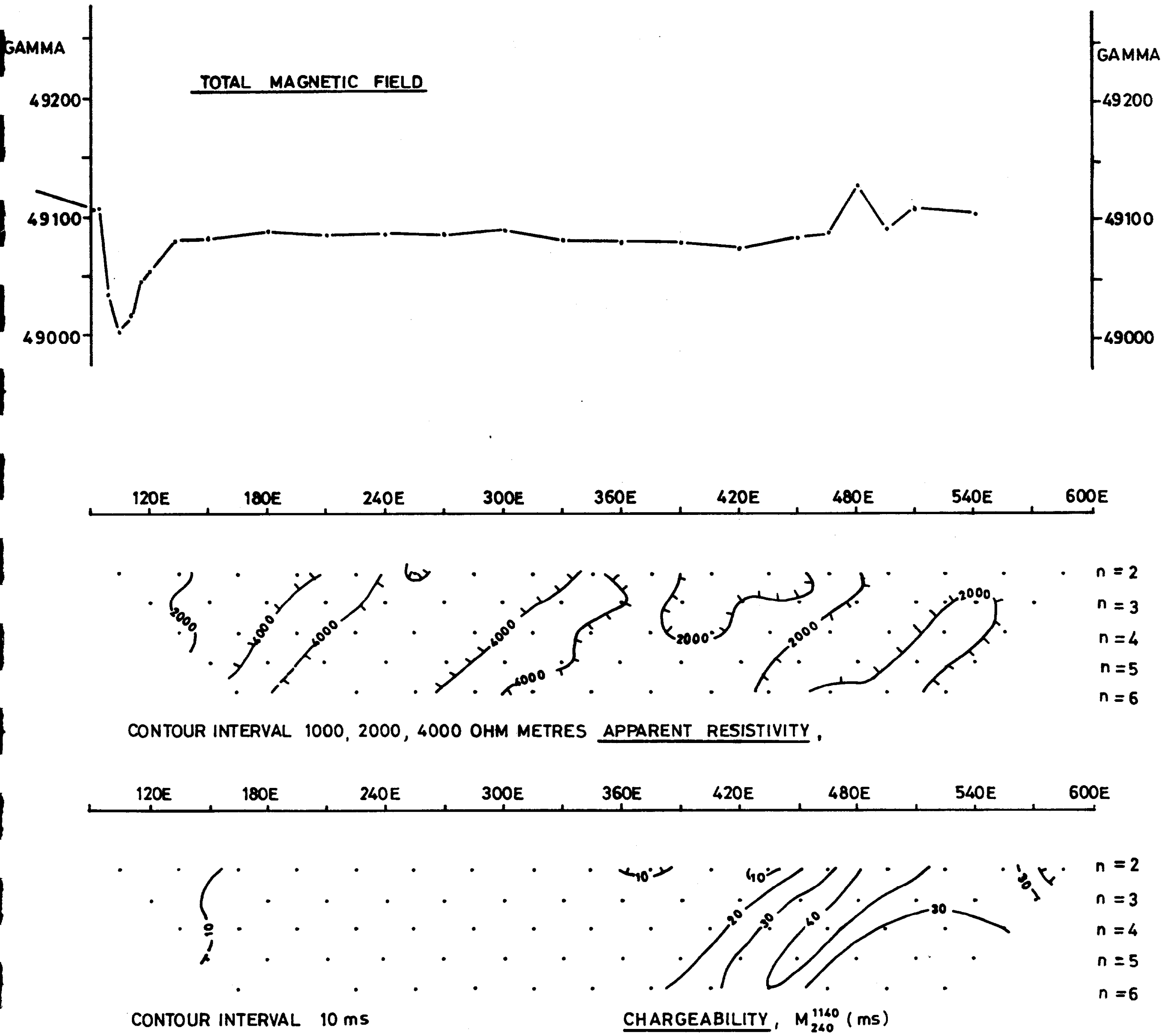


Fig. 18 PUBIL: GEOPHYSICAL RESULTS FOR TRAVERSE 250N

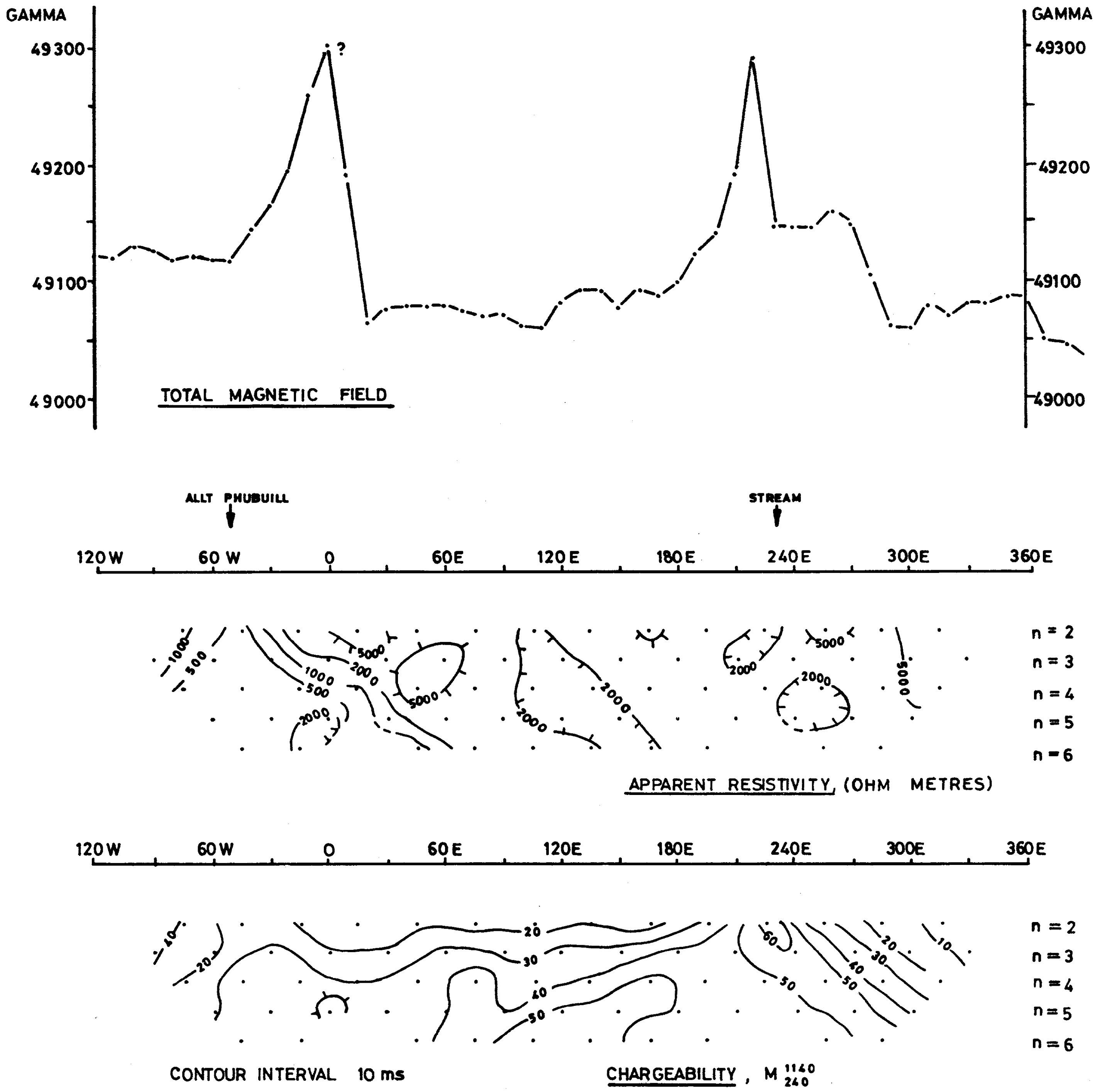


Fig. 19 PUBIL: GEOPHYSICAL RESULTS FOR TRAVERSE 230S

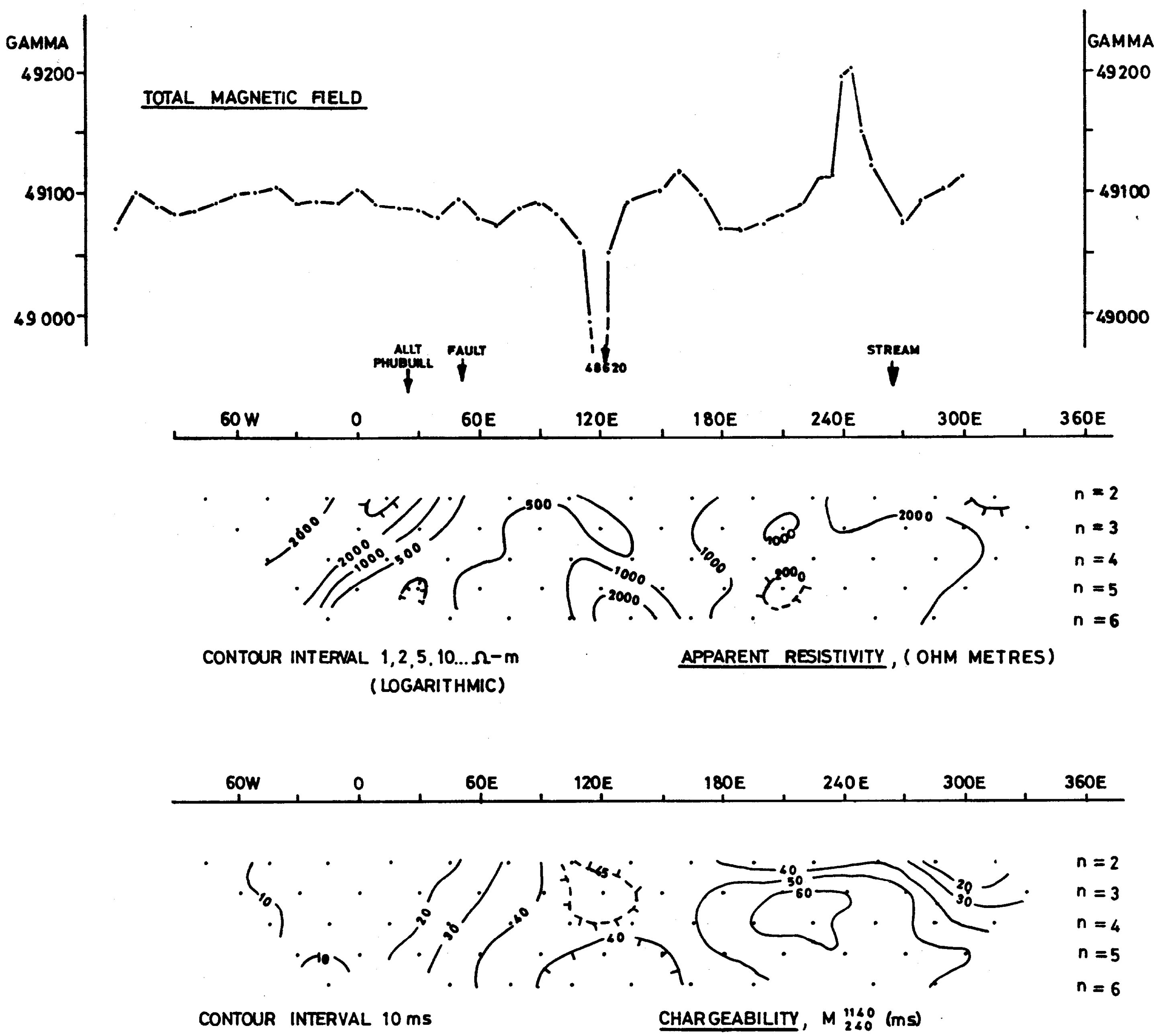


Fig. 20 PUBIL: GEOPHYSICAL RESULTS FOR TRAVERSE 110S

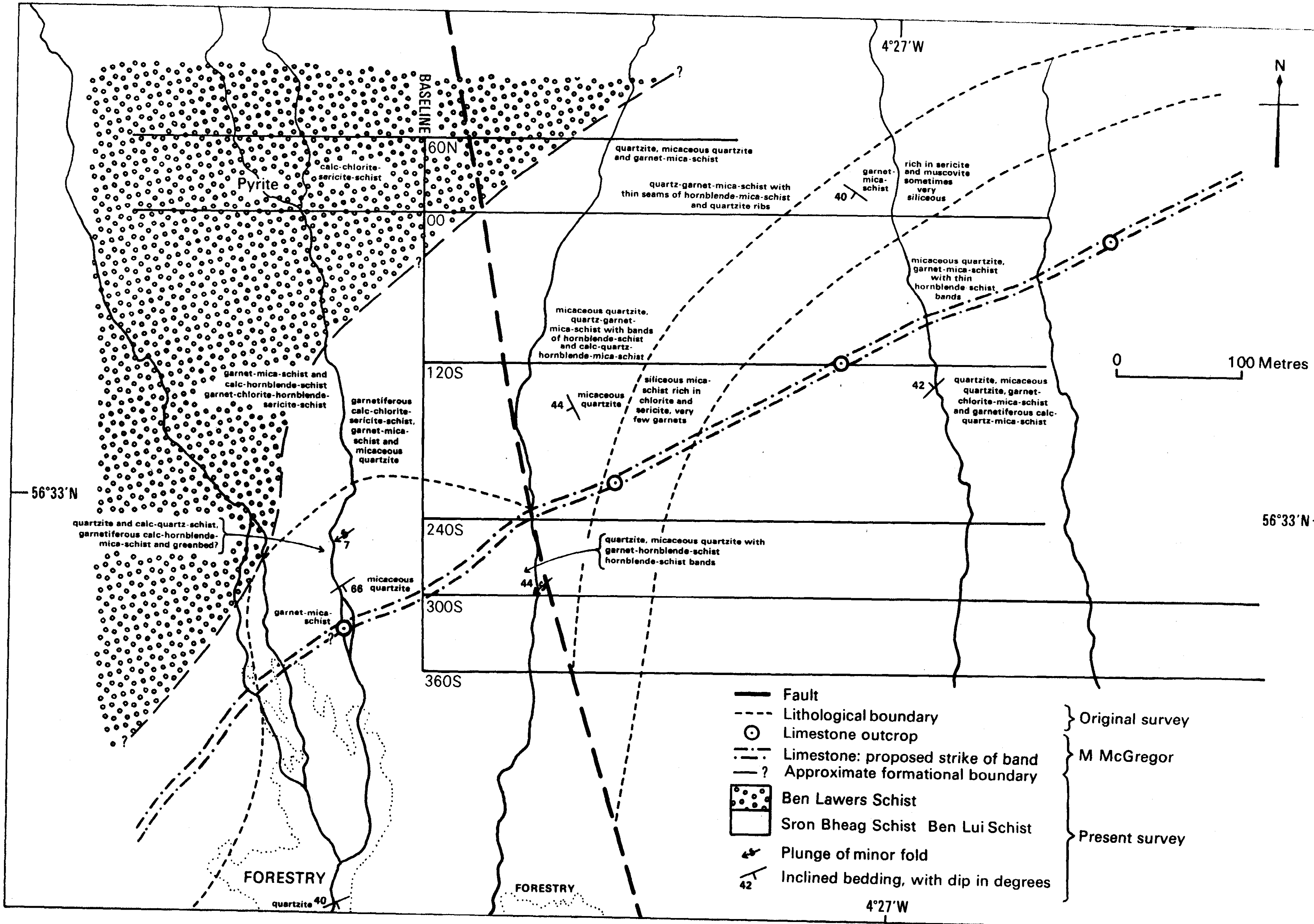


Fig. 21 Geological map showing past and present interpretations and location of geophysical traverses

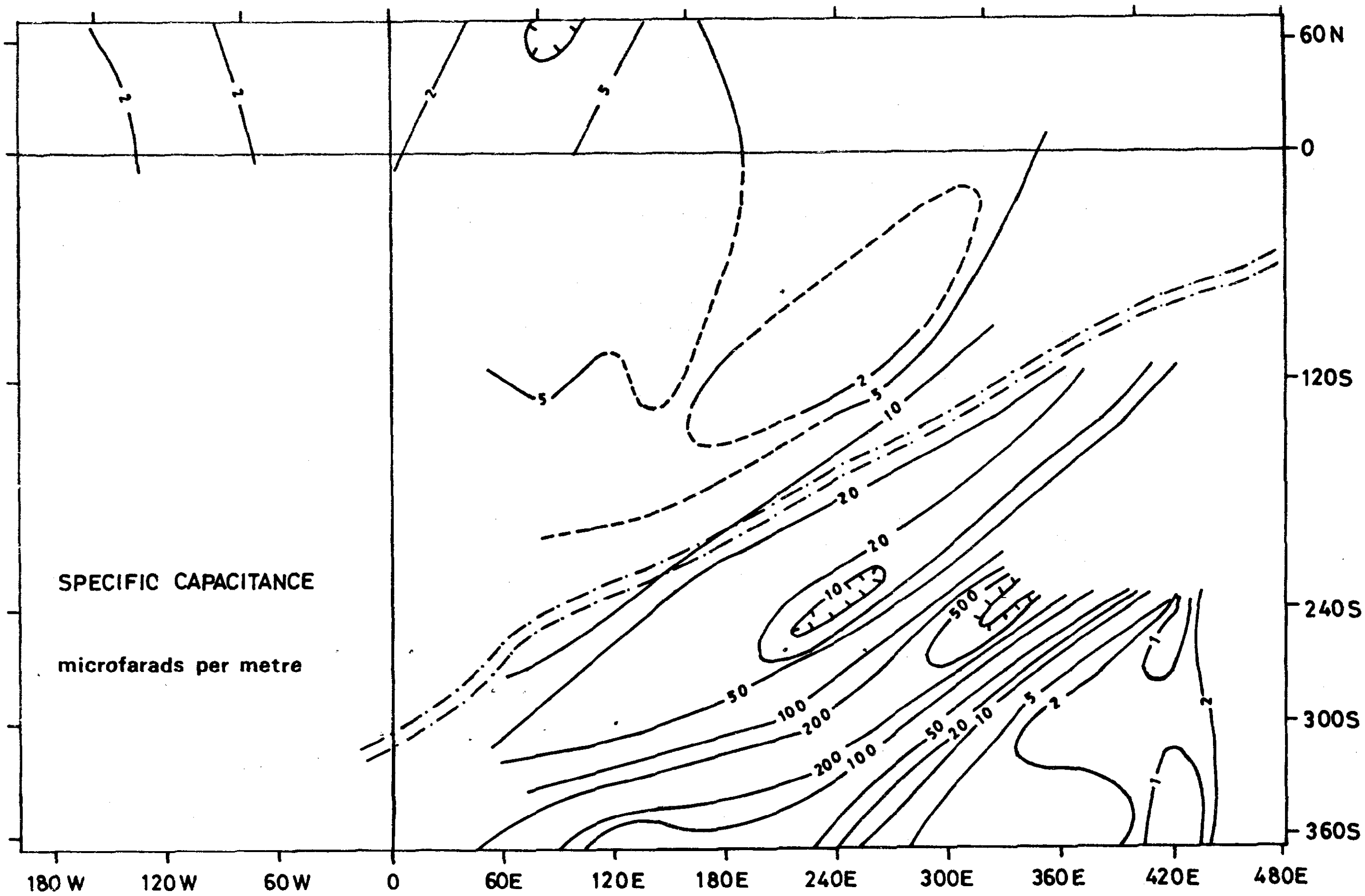


Fig. 22a CASHLIE: CONTOUR MAP OF SPECIFIC CAPACITANCE

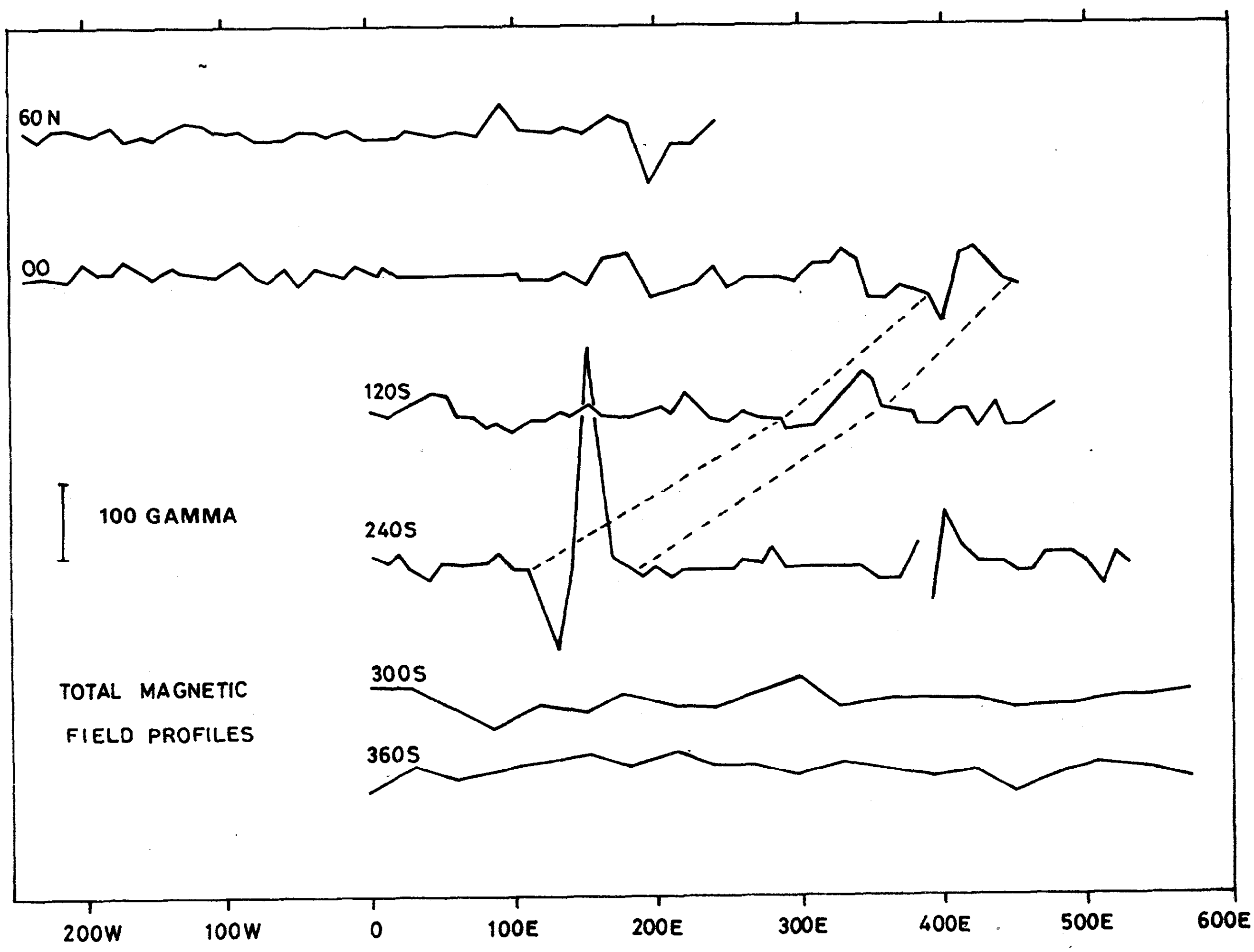


Fig. 22b CASHLIE TOTAL MAGNETIC FIELD PROFILES

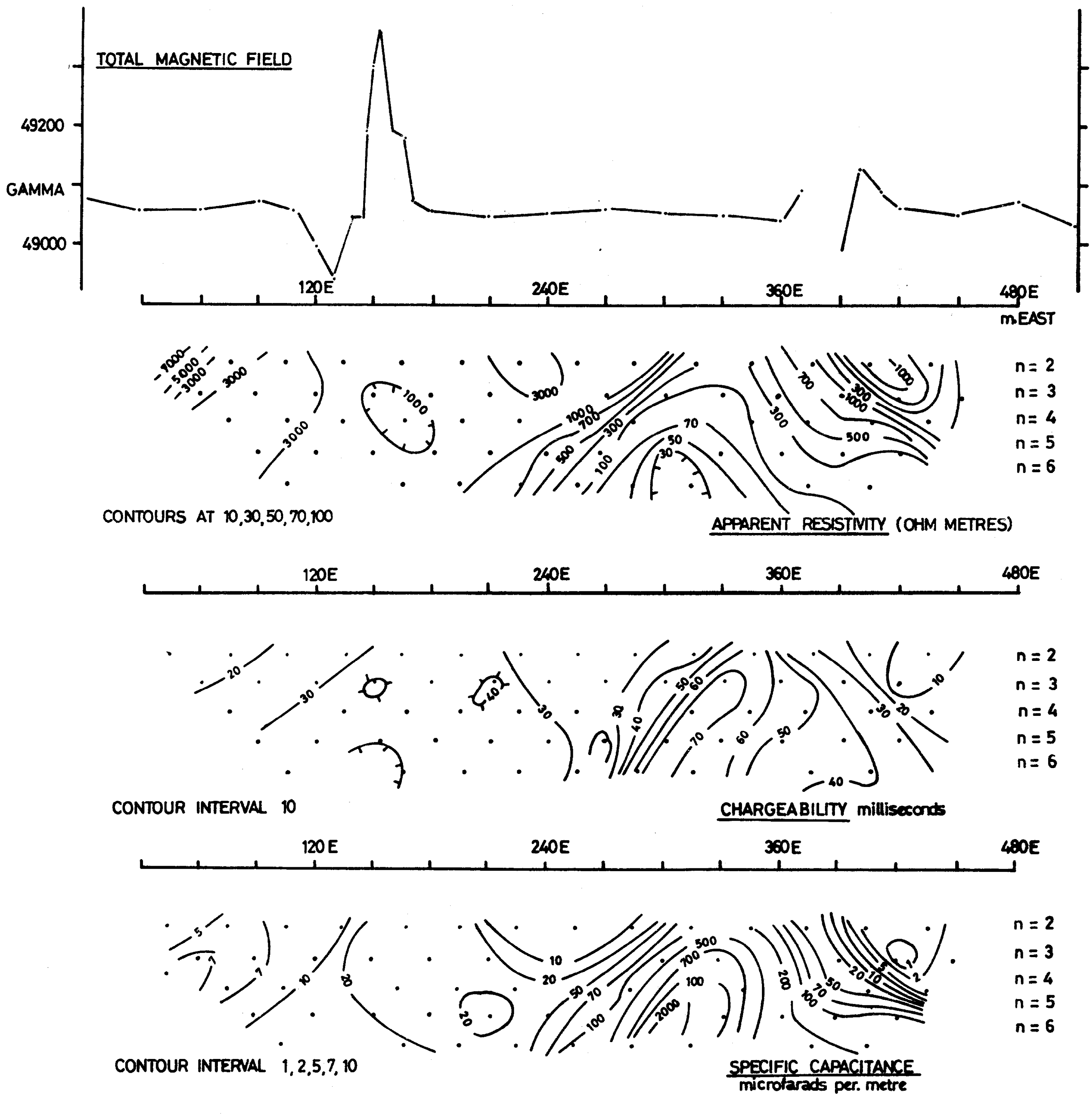


FIG. 23. CASHLIE: GEOPHYSICAL RESULTS FOR TRAVERSE 240S

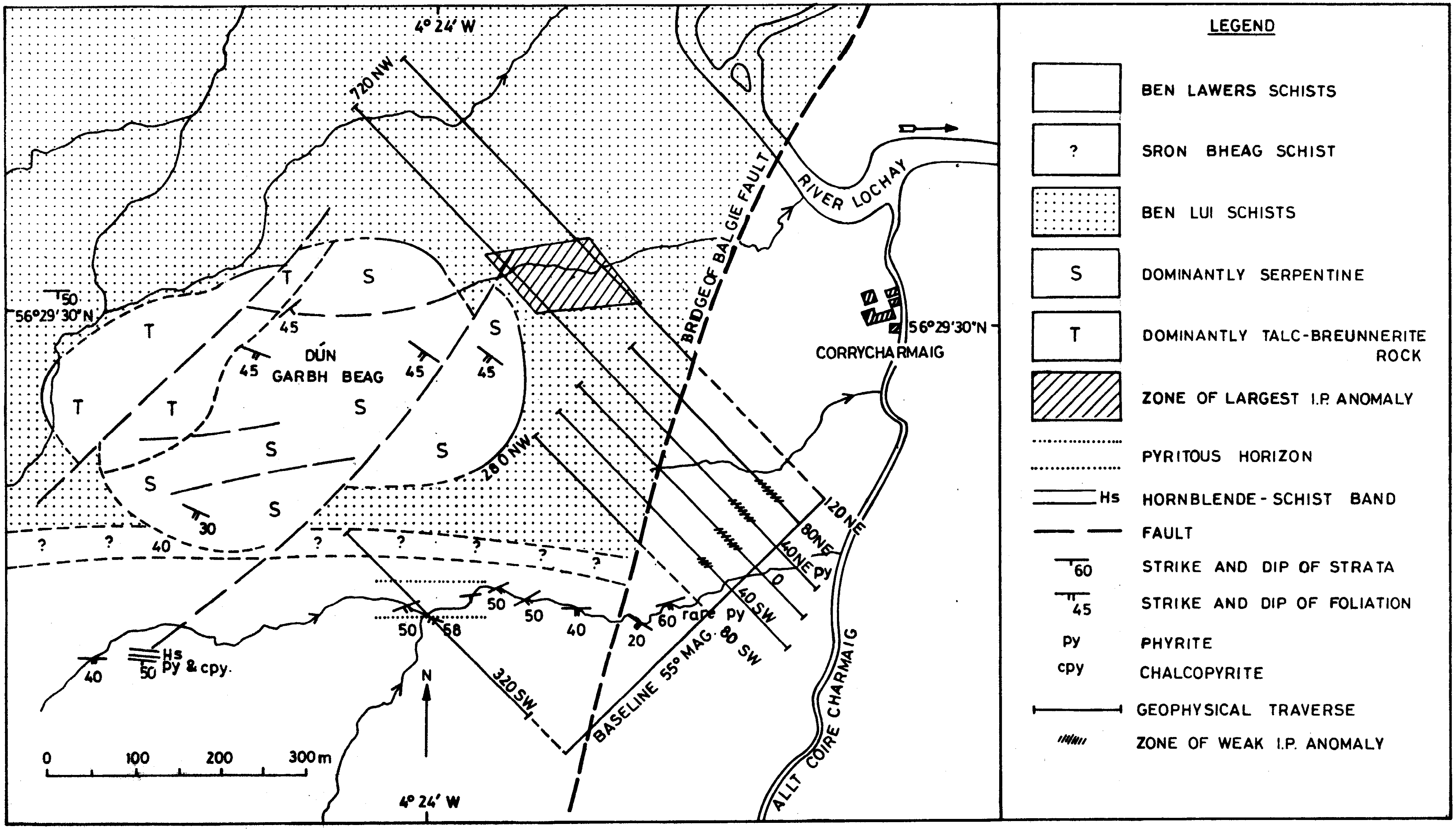


Fig. 24 CORRYCHARMAIG: GEOLOGY AND LOCATION OF GEOPHYSICAL TRAVERSES

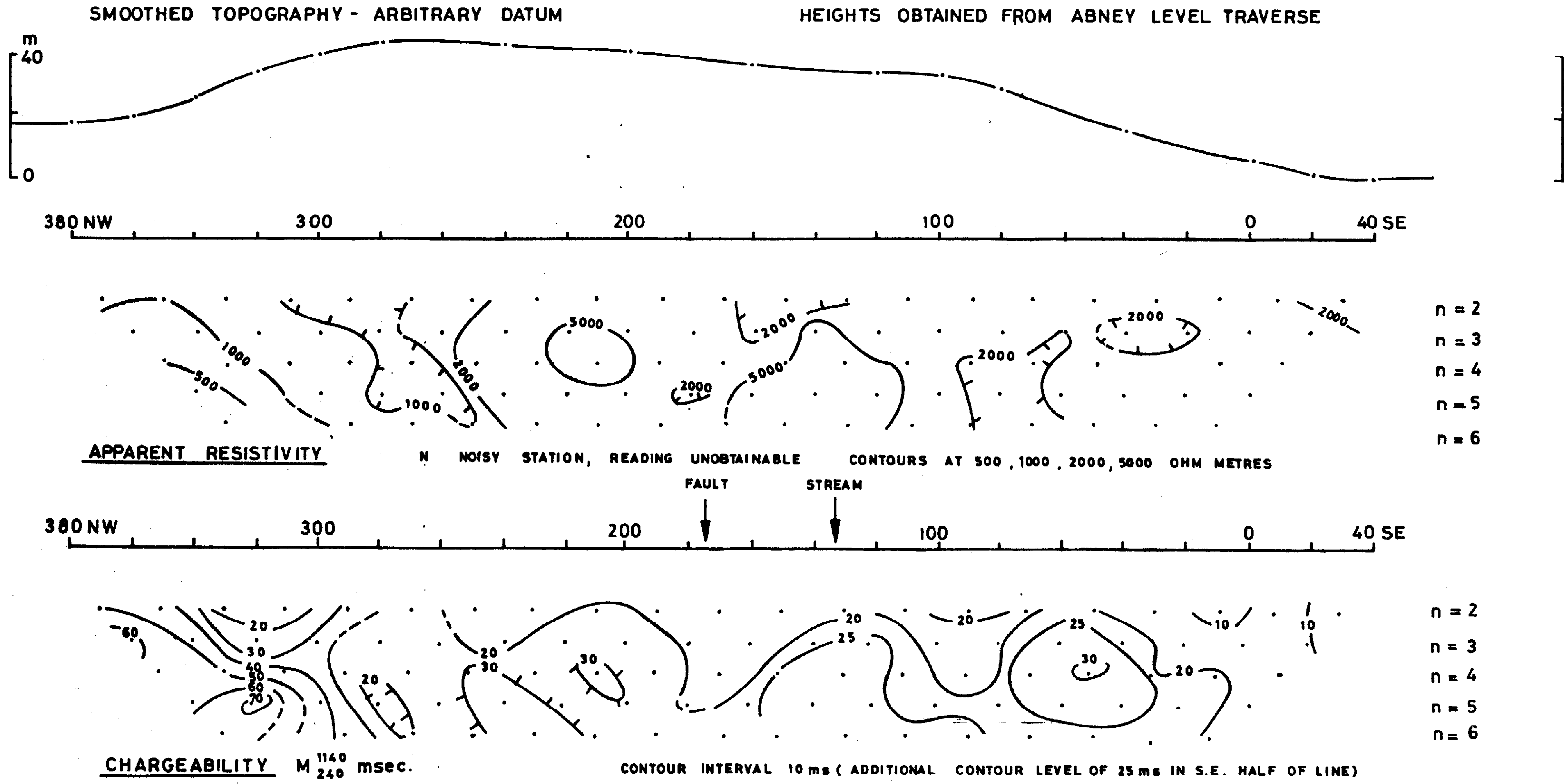


Fig. 25 CORRYCHARMAIG: GEOPHYSICAL RESULTS FOR TRAVERSE 40NE (DIPOLE LENGTH 20m)

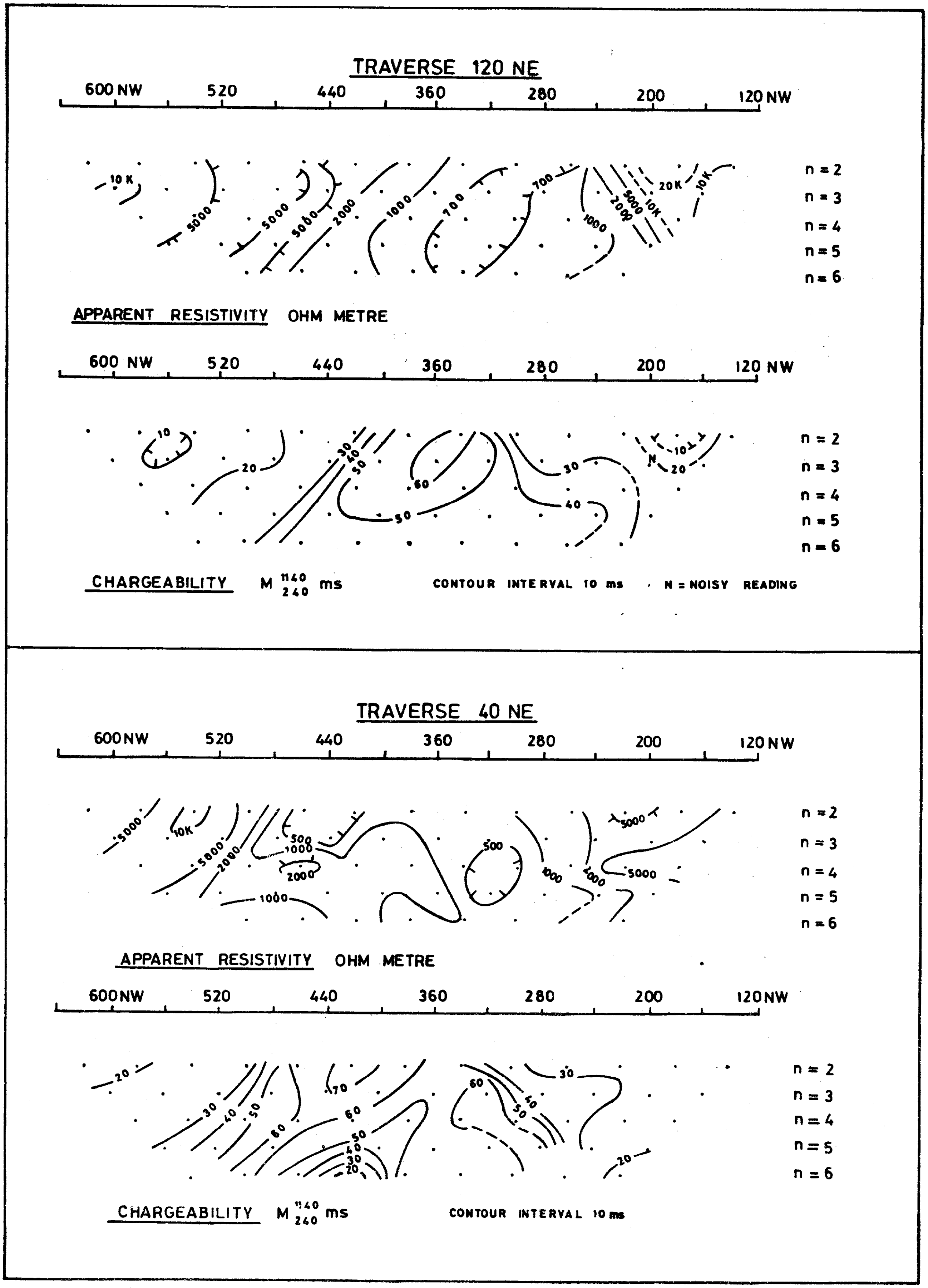


Fig. 26 CORRYCHARMAIG GEOPHYSICAL RESULTS
FOR TRAVERSES 120NE AND 40NE (DIPOLE LENGTH 40m)

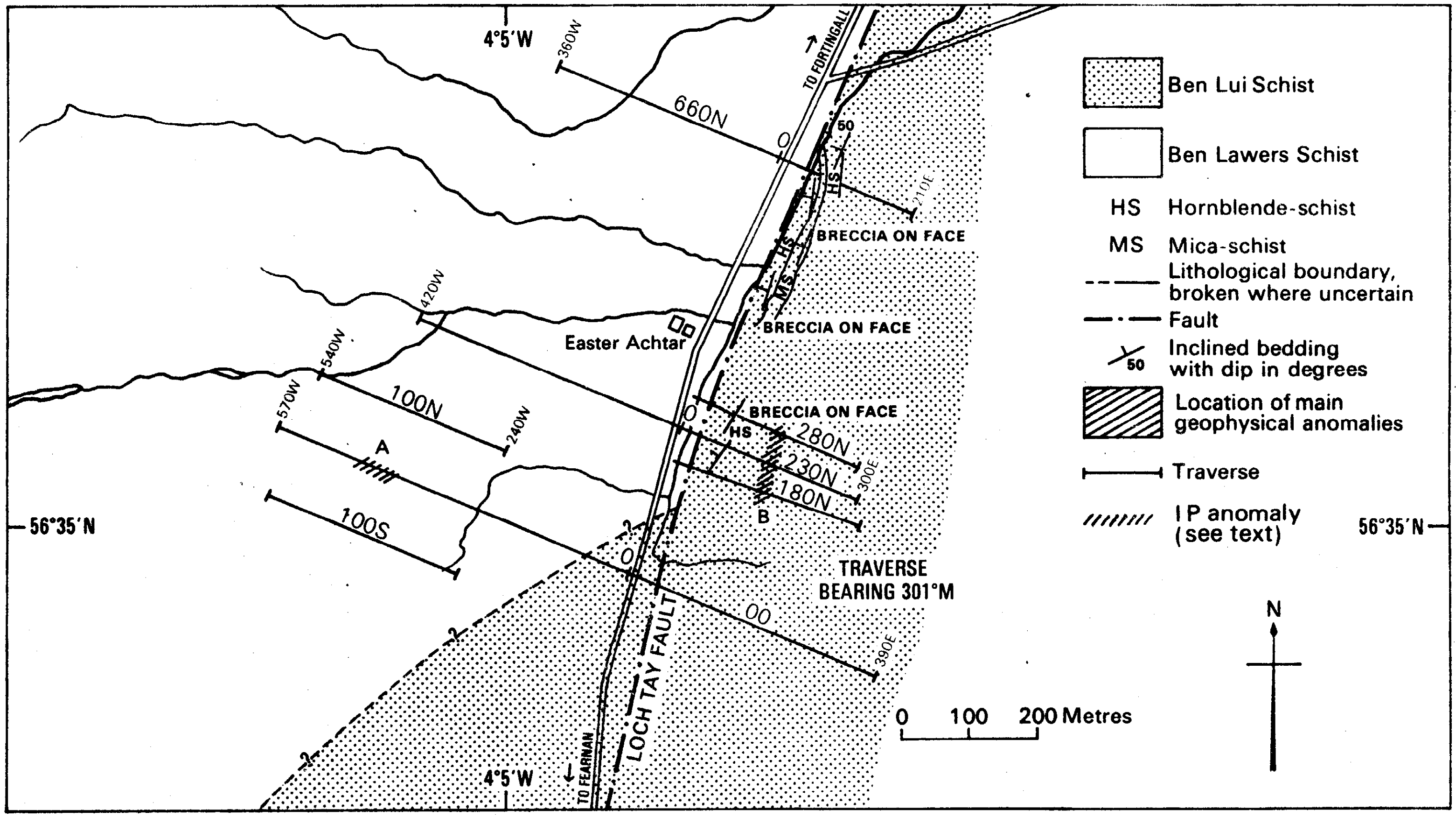
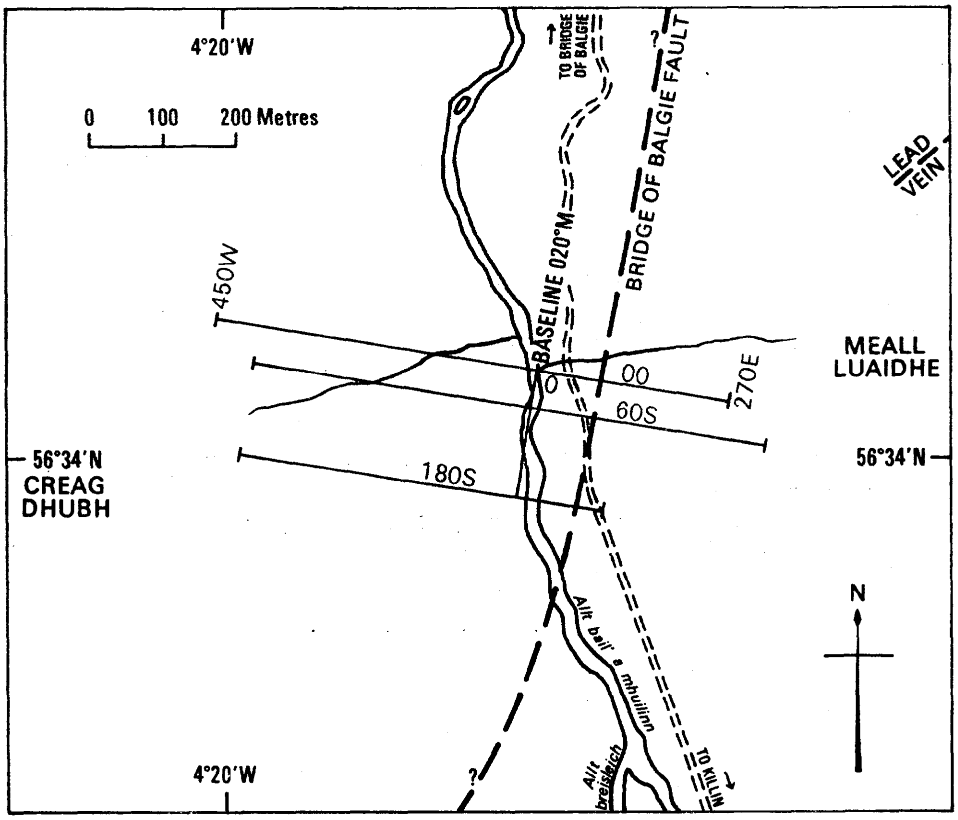
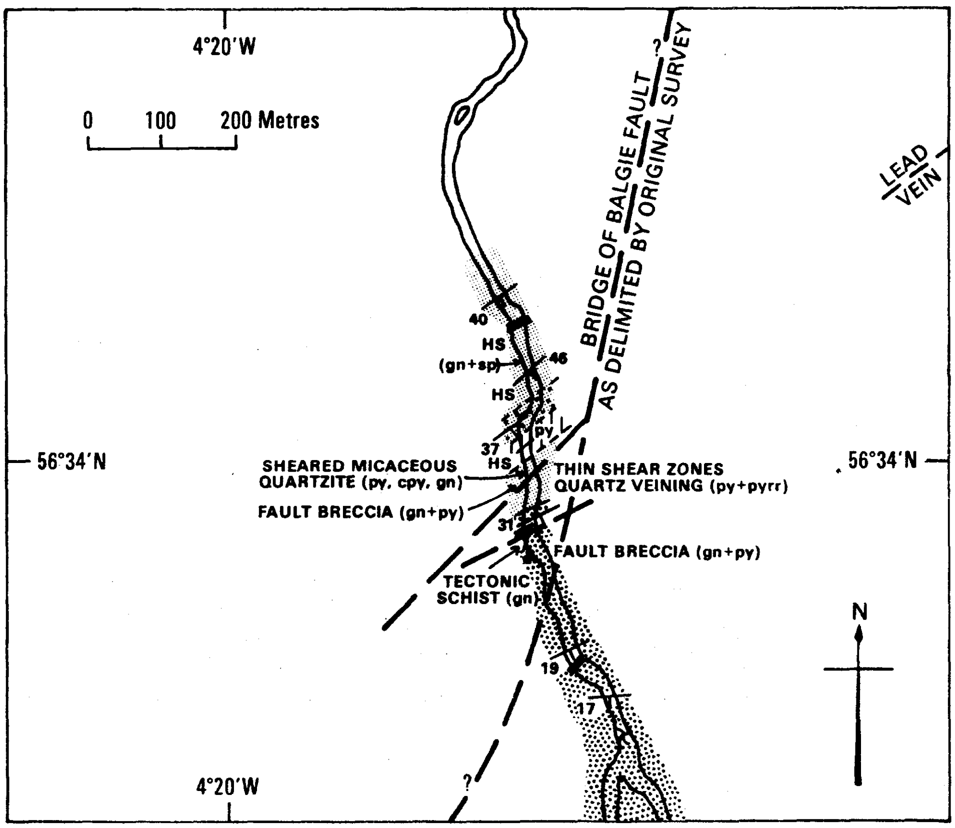


Fig. 27 Easter Achtar: general geology and location of geophysical traverses



Meall Luaidhe: location of geophysical traverses



- Grit (thick bedded)
- Quartzite/Quartz-schist
- Siliceous garnet-mica-schist
- Calc chlorite-mica-schist
- Basic dykes

- — – Fault
- - - - - Lithological boundary
- 17 Inclined bedding with dip in degrees
- Subhorizontal undulating strata
- HS hornblende-schist/amphibolite
- py pyrite
- cpy chalcopyrite
- gn galena
- sp sphalerite
- pyrr pyrrhotite

Fig. 28 Meall Luaidhe: location of geophysical traverses and geology.

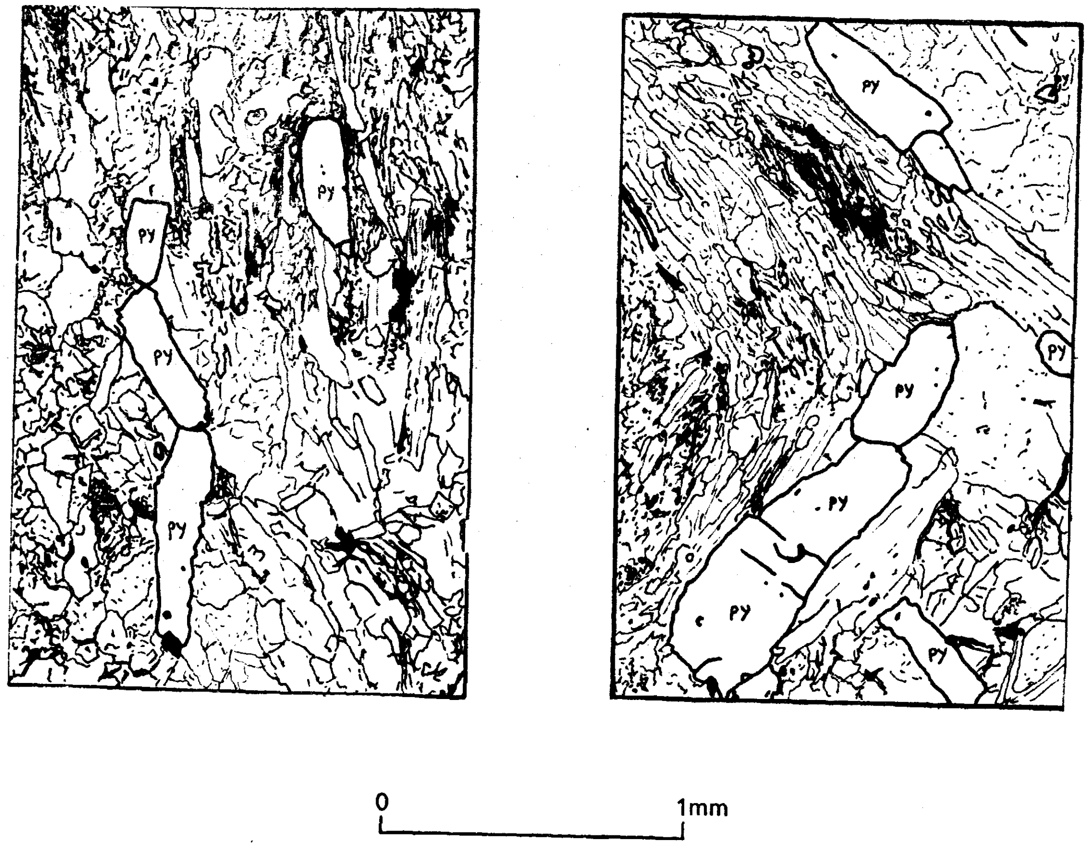


Fig. 29 Line drawings of drawn out pyrites forming an integral part of the tectonic fabric in CZR 709. From photomicrographs taken with an incident light source.

Table I. Sulphide and metal concentrations in the Allt a Bhorland rock-sampled section, Glen Lochay. Traverse upstream from a point 40 m below confluence following westernmost tributary.

'0' at NGR NN 2555 3600

Sample No. CZR	Sample interval (m) min. max.	% Exposure	Av. % Sulphide	Max. % Sulphide	ppm Cu	Zn	Ag	Pb	Au	ROCK DESCRIPTION
550	0-20	100	c <0.1	c0.7	47	110	1	30	nd	Calc-chlorite-sericite-schist
551	20-40	100	c0.2	c1.0	65	40	1	20	nd	Calc-chlorite-sericite-schist with calc-quartzite ribs (PTS 2281 Calc-chlorite-schist)
552	40-60	100	c0.1	c0.6	40	90	1	30	nd	Calc-chlorite-sericite-schist
553	60-80	90	c0.1	c0.6	260	60	1	20	nd	Calc-chlorite-sericite-schist: more calcareous and less schistose. Chalcopyrite present. (PTS 2249 Epidote-bearing calc-quartzite)
554	80-100	60	c0.1	c0.5	5	60	0	20	nd	Calc-chlorite-sericite-schist with quartz segregations. Fairly fissile
555	100-120	90	c0.5	c15.0	35	10	1	10	0.02	Calc-quartzite and calc bands dominant over calc-chlorite-sericite-schist [PTS 2144 (10 m) Marble (or coarse calcite rock)] [PTS 2282 (15 m) Quartzite]
556	120-140	100	c0.5	20.0	80	10	0	20	nd	Calc-chlorite-sericite schist with calc-quartzite ribs overlain by a thick sequence of calc-quartzite which forms 60% of the section [PTS 2237 (10 m) Pyritous quartzite] [PTS 2145 (11 m) Pyritous quartzite]

Table I. Allt a Bhorland Section

557	140-160	100	c1.0	c20.0	340	10	0	10	0.026	Predominantly calc-quartzite with thin calc-chlorite-sericite-schist bands. The calc-quartzite is generally richer in pyrite. [PTS 2146 (0 m) Pyritous quartzite] [PTS 2147 (10 m) Chlorite-rich calc-quartzite]
558	160-180	100	c0.3	c6.0	80	50	1	20	nd	Predominantly chlorite-sericite schist; some calc-chlorite-schist and calc-quartzite lenses. Quartz-carbonate segregations (PTS 2238 Calc-schist)
559	180-200	100	c0.2	c5.0	15	60	1	20	nd	Calc-chlorite-sericite-schist with quartz-carbonate segregations
560	200-220	75	c0.3	c2.0	30	70	0	20	nd	Calc-chlorite-sericite-schist with thin discontinuous calc ribs and rare quartz segregations. Chalcopyrite identified
561	220-240	80	c1.2	c5.0	190	130	1	10	<0.02	Calc-chlorite-sericite-schist with discontinuous calc-quartzite ribs and quartz segregation lenses and veins. Chalcopyrite and malachite present (PTS 2239 Calc-sericite-schist)
562	240-260	50	c0.1	c0.3	95	50	1	90	nd	Calc-chlorite-sericite-schist with quartz segregation lenses and veins
563	260-280	60	c0.1	c0.1	15	70	1	20	nd	Very platy chlorite-schist with thin calc stripes passing upstream into more typical calc-chlorite-sericite-schist and calc-schist

Table II . Sulphide and metal concentrations in the Brerachan Water rock-sampled section, nr. Moulin, Pitlochry. Traverse upstream from the lower point where the stream assumes a NW-SE direction.

'0' at NGR NN 9830 6447

Sample No. CZR	Sample interval (m) min. max.	% Exposure	Av. % Sulphide	Max. % Sulphide	ppm					ROCK DESCRIPTION
					Cu	Zn	Ag	Pb	Au	
700	0-10	100	c0.5	c4.0	25	20	0	10	<0.02	Massive hornblende-schist/amphibolite and laminated hornblende-schist with thin quartzose ± carbonate bands
701	10-20	20	c0.1	-	0	10	0	10	nd	Laminated hornblende-schist with tightly folded quartz-carbonate bands. Some amphibolite
702	20-30	50	c1.0	c4.0	220	60	1	20	nd	Chlorite schist and laminated hornblende-schist with calc bands and fairly thick hornblende-schist bands
703	30-40	60	c1.5	c8.0	75	50	1	20	nd	Hornblende-schist/amphibolite. Concordant quartz-carbonate veinlet. (PTS 2150 (32 m) Biotite-hornblende-schist)
704	40-50	10	c0.1	c0.3	0	10	0	10	nd	Platy calc-chlorite-hornblende-schist
705	50-60	10	c2.0	-	1270	90	1	20	nd	Amphibolite
706	70-80	10	c2.0	c6.0	55	130	1	20	nd	Amphibolite
707	80-90	30	c4.0	c8.0	160	60	1	20	0.02	Amphibolite (PTS 2243 Quartz-amphibolite)
708	90-100	15	c0.1	-	35	100	0	20	nd	Quartz-chlorite-biotite-schist with stripes of amphibolite

Table II. Brerachan Water Section (cont.)

709	100-110	20	c0.3	c0.8	25	80	1	20	nd	Calc-chlorite-schist with some laminated quartzose-hornblendic rock. (PTS 2151 (112 m) Banded calc-schist)
710	110-120	35	c4.0	-	80	50	1	20	nd	Banded calc-quartz-chlorite-schist with minor amphibolite
711	120-130	40	c0.4	c12.0	460	30	1	20	0.02	Calc-chlorite-schist with numerous calc bands. Locally some hornblende-schist. (PTS 2250 Calc-biotite-schist with hornblende and chlorite)
712	130-140	60	c0.2	-	200	30	0	10	nd	Calc-chlorite-schist : increasingly siliceous and more massive, less chlorite and hornblende. Fairly coarse pyrite in segregations
713	140-150	10	c0.3	c1.0	25	50	0	10	nd	Calc-chlorite-sericite-schist
714	150-160	20	c0.1	c0.5	35	10	0	10	nd	Calc-chlorite-sericite-schist and hornblende-schist
715	160-170	20	c0.2	c0.8	15	40	1	20	nd	Calc-chlorite-sericite-schist
716	170-180	60	c0.3	c0.5	75	50	1	20	nd	Calc-chlorite-sericite-schist with minor hornblende-schist
717	180-190	40	c2.0	c8.0	125	80	1	20	<0.02	Calc-chlorite-sericite-schist with minor metavolcanic horizons
718	190-200	80	c0.6	c1.5	50	50	0	20	nd	Calc-chlorite-sericite-schist
719	200-210	60	c0.2	c0.5	75	20	0	10	nd	Calc-chlorite-sericite-schist with minor metavolcanic horizons
720	210-220	90	c0.2	c3.0	55	20	0	10	<0.02	Calc-chlorite-sericite-schist with minor metavolcanic horizons
721	220-230	50	c0.1	-	10	20	0	10	nd	Calc-chlorite-sericite-schist

Table III. Sulphide and metal concentrations in the Auchtertyre rock-sampled section, nr. Auchtertyre Farm, Strath Fillan. Traverse upstream from a point 70 m below confluence following Allt a Ghaol Ghlinne.

'0' at NGR NN 3561 3018

Sample No. CZR	Sample interval (m) min. max.	% Exposure	Av. % Sulphide	Max. % Sulphide	ppm Cu	ppm Zn	ppm Ag	ppm Pb	ppm Au	ROCK DESCRIPTION
600	0-20	100	c 0.1	c2.0	360	60	0	20	nd	Micaceous quartzite with bands of mica-schist. Increasing chlorite-schist component. 0-10 m no sulphide seen. Chalcopyrite identified
601	20-40	100	c0.8	c5.0	130	640	0	10	<0.02	Micaceous quartzite with bands of mica-schist. Chlorite-biotite-muscovite-schist with quartzite ribs, and a band of hornblende-schist
602	40-60	100	c0.4	c1.0	45	760	0	160	nd	Micaceous-quartzite with bands of mica-schist
603	60-80	100	c0.8	c8.0	135	1450	0	10	<0.02	Micaceous-quartzite with chlorite-sericite-quartz-schist
604	80-100	90	c0.7	c3.0	430	240	0	20	nd	Micaceous-quartzite with chlorite-sericite-quartz-schist. Chalcopyrite identified
605	100-120	70	c0.3	c0.6	80	120	0	20	nd	Thin flaggy quartz-mica-schist and quartzite
606	120-140	100	c0.3	c0.8	120	1800	0	20	nd	Flaggy quartzite
607	140-160	100	c0.2	c0.5	5	40	0	20	nd	Thin flaggy quartzite and quartz-mica-schist
608	160-180	100	c0.5	c10.0	900	700	1	10	nd	Flaggy quartzite with chlorite-sericite-schist in thin bands and partings containing some garnets. 80% of the section contains 0.1% sulphide. A number of sulphide rich bands contain chalcopyrite
609	180-200	100	c0.8	c20.0	1400	4050	1	20	0.042	Chlorite-biotite-sericite-schist with flaggy quartzite horizons. Two sulphide-rich bands with chalcopyrite mainly associated with small quartz segregations (PTS 2242 Quartz-chlorite-schist)

Table IV. Sulphide and metal concentrations in the Allt Phubuill rock-sampled section, Pulril, Glen Lyon. Traverse upstream from zone of smash '0' at NGR NN 4600 4280

Sample No. CZR	Sample interval (m) min. max.	% Exposure	Av. % Sulphide	Max. % Sulphide	ppm Cu	ppm Zn	ppm Ag	ppm Pb	ppm Au	ROCK DESCRIPTION
571	0-20	100	c0.3	c1.5	70	50	1	30	nd	Fault zone : mashed mica schist and quartzite passing upstream into highly contorted siliceous Ben Lawers schist with many disrupted flaggy quartzite ribs. Moderate uneven dissemination (≤0.3 cm) or sporadic crystals (≤1.5 cm) of pyrite. Malachite
572	20-40	100	c0.5	c1.0	40	50	0	10	<0.02	Highly contorted calc-chlorite-sericite (biotite) schist. Many thin quartzite bands. Some large quartz segregations. Moderate pyrite dissemination. 10 cm band of pyritous garnet-biotite-hornblende-schist
573	40-60	100	c0.4	c1.5	90	50	1	20	nd	Minor faulting : folded calc-chlorite-sericite-schist with many quartzite bands overlain by massive banded quartzite. A little garben-schiefer amphibole. Pyrite; sparse-abundant; tending to cluster
574	60-80	90	c0.3	c0.7	100	50	0	20	nd	Sheared and contorted siliceous calc-chlorite-sericite-schist. Minor quartzite. Lamprophyre dyke (not sampled). Fine dissemination of and rusty patches of pyrite
575	80-100	100	c0.3	c0.8	100	70	1	20	nd	Minor faulting : highly sheared and contorted calc-chlorite-sericite-schist with torn up flaggy quartzite ribs. Finely disseminated pyrite in both schist and quartzite. Sporadic rusty pyrite patches also in schist.

Table IV. Allt Phubuill Section (cont.)

575 (cont)										Pyrrhotite in some calc-quartzite pods and quartz (with or without calcite) segregations
576	100-120	100	c0.4	c2.0	80	60	1	10	<0.02	Prominent faulting : highly sheared and contorted calc-chlorite-sericite-schist. Many thin calc-quartzites. Thick hornblende-schist band with finely disseminated pyrite (cupriferous?). Haematite on some joints. Pyrite occurs as rusty patches and broken or distorted cubes (≤1 cm) in schist. Some crush rock (chlorite-biotite-hornblende) with angular quartz fragments. Thin breccias with calcite stringers. Small irregular quartz-feldspar segregations and quartz eyes
577	120-140	95	c0.3	c1.0	65	70	1	20	nd	Some faulting : highly contorted calc-chlorite-sericite-schist. Some amphibole development. Irregular pods of hornblendic rock. Sporadic pyrite (≤0.5)
578	140-160	100	c0.1	c0.5	40	70	1	20	nd	Highly sheared and contorted calc-chlorite-sericite-schist with thin calc-quartzite bands and sporadic pyrite patches (some fracturing). This passes upstream into less disturbed, banded schist with fairly thick quartzite horizons. Pyrite remains rather sparse except where the rock is rich in biotite and hornblende (finely disseminated streaked pyrite (≤0.3 cm)

NB Figures in parentheses denote grain size.

Table V. Sulphide and metal concentrations in the Roromore rock-sampled section, nr. Roromore Farm, Glen Lyon. Traverse upstream from a point 35.5 m up from confluence

'0' at NGR NN 6384 4678

Sample No. CZR	Sample interval (m) min. max.	% Exposure	Av. % Sulphide	Max. % Sulphide	ppm Cu	Zn	Ag	Pb	Au	ROCK DESCRIPTION
564	0-20	70	c0.3	c1.5	20	80	1	20	nd	Calc-biotite-chlorite-sericite-schist with quartzite and calc-quartzite ribs; rare garnets
565	20-40	50	c0.2	c0.7	5	120	1	20	nd	Calc-chlorite-sericite-biotite-schist with calc spots and lenses, and quartz knots. (TS 60833 Calc-schist) (PTS 2240 Calc-hornblende-mica-schist)
566	40-60	50	c0.3	c1.0	10	90	1	20	nd	Calc-chlorite-sericite-biotite-schist with calc ribs and lenses, and quartz knots
567	60-80	100	c0.4	c2.0	30	80	1	20	nd	Calc-chlorite-sericite-biotite-schist. Some amphibole and more rarely garnet development. Calc-quartzite horizons. Discontinuous pegmatite (c 10 cm thick) with quartz, feldspar, chlorite, muscovite and pyrite. Maximum pyrite development 30 cm from pegmatite. (PTS 2283 Micaceous calc-quartzite)
568	80-100	80	c0.5	c1.5	75	60	1	10	<20	Calc-chlorite-sericite-biotite-schist with calc ribs. (PTS 2284 Micaceous calc-quartzite)
569	100-120	60	c0.1	c0.5	10	80	1	20	nd	Calc-sericite-schist with thin bands and partings of mafics passing upstream into more typical calc-chlorite-sericite-biotite-schist with some amphibole development. A thin hornblende-schist band in section
570	120-140	90	Calc c≲0.1 H.S. c0.7	Calc c0.2 H.S. c1.0	60	80	1	20	nd	Calc-chlorite-sericite-biotite-schist with some amphibole development. Some massive calc-biotite ribs and hornblende-schist bands (2 bands : lower one c.2 m, upper one c.10 cm) (PTS 2285 Hornblende-schist)

Table VI . Sulphide and metal concentrations in the rock-sampled section of Glenlochsie Burn, Glen Lochsie, Glenshee. Traverse downstream from a point 15 m below ford at Glenlochsie Lodge

'0' at NGR NO 0643 7253

Sample No. CZR	Sample interval (m) min. max.	% Exposure	Av. % Sulphide	Max. % Sulphide	ppm Cu	Zn	Ag	Pb	Au	ROCK DESCRIPTION
501	0-25		c0.5	c10.0	40	60	1	20	0.028	Calc-sericite-schist. Quartz segregations with pyrite, chalcopyrite and pyrrhotite especially in areas rich in amphibole (PTS 2149 (CZR 522) Calc-chlorite-schist) (PTS 2280 (CZR 523) Quartz-biotite-schist with anthophyllite and epidote)
502	25-50		c0.1	c 5.0	10	50	2	10	nd	Calc-sericite-schist. Start of the appearance of randomly oriented garbenschiefer amphiboles
503	50-75	25	c≤0.1	-	25	40	2	10	nd	Quite well laminated calc-sericite-schist and hornblendic beds containing pink feldspar. Pyrite mostly associated with the hornblendic bands
504	75-100	80	c≤0.1	-	10	40	2	10	nd	Calc-chlorite-sericite-schist
505	100-125	30	c0.3	c 0.5	5	40	2	10	nd	Calc-chlorite-sericite-schist
506	125-150	50	0	-	0	80	1	10	nd	Calc-chlorite-sericite-schist. Some soft calc bands
507	150-175		c0.5	c 3.0	20	70	1	10	nd	Calc-chlorite-sercite-schist. Return of the garben-schiefer amphiboles

Table VI . Glenlochsie Burn Section (cont.)

508	175-200		-	c 1.5	5	70	1	10	nd	Calc-chlorite-sericite-schist. Maximum concentration of sulphide in the metabasic rocks
509	257-275	70	c1.0	c 5.0	25	40	0	20	<0.02	Homogeneous calc-chlorite-sericite-schist with some garbenschiefer amphiboles. Chalcopyrite identified. (PTS 2236 (CZR 524) Biotite-muscovite-schist)
510	275-300	70	-	-	185	40	1	20	nd	Calc-chlorite-sericite-schist with garbenschiefer amphiboles
511	\300-325		c0.4	c 8.0	75	60	1	20	nd	Calc-chlorite-sericite-schist with garbenschiefer amphiboles. Clots of pyrite associated with the quartz segregations. (PTS 2271 Banded hornblend-biotite-chlorite-schist)
512	325-350	35	c0.1	c 0.3	5	60	1	20	nd	Calc-chlorite-sericite-schist
513	350-375	20	c0.1	c 0.3	80	40	0	20	nd	Calc-chlorite-sericite-schist. A few clots and fine seams containing pyrite
514	375-400	70	0	0	0	50	1	10	nd	Homogeneous calc-chlorite-sericite-schist
515	400-425		c0.1	-	5	30	1	10	nd	Homogeneous calc-chlorite-sericite-schist
516	425-450		c1.5	c 6.0	5	30	1	10	<0.02	Calc-chlorite-sericite-schist with garbenschiefer amphiboles
517	450-475	70	c0.6	c 3.0	45	40	1	10	nd	Calc-chlorite-sericite-schist