Natural Environment Research Council

Institute of Geological Sciences

Mineral Reconnaissance Programme Report

A report prepared for the Department of Industry

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No. 42

Mineral exploration in the area around Culvennan Fell, Kirkcowan, south-western Scotland

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Bibliographical reference
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Photocopied in England for the Institute of Geological Sciences

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SUMMARY

Reconnaissance geochemical and geophysical surveys were carried out in the area of Culvennan Fell to investigate the possibility of porphyry copper mineralisation associated with the Culvennan diorite. Work was concentrated on the west of the intrusion where numerous dykes, mainly of intermediate composition, and three small bodies of intrusion breccia intrude folded greywacke, quartz-wacke, silty mudstone, siltstone and calcareous mudstone of the Silurian Gala Group. A zone of high chargeability was defined within which there are areas of low resistivity and narrow magnetic anomalies. The cause of these anomalies is most likely to be stratabound concentrations of sulphides within the sedimentary succession and the dykes, and there is no evidence to show that the high chargeability is associated with porphyry-style mineralisation. The results of the geochemical survey substantiate this, though minor secondary concentrations of metals and weak, local copper-arsenic-iron-lead mineralisation were indicated.

INTRODUCTION

Fell End and Culvennan Fell together form a conspicuous, rocky, NE-trending topographic feature about 2 km long and rising over 200 m above a generally drift-covered area of low relief.

The area (Fig. 1) contains a late Caledonian, stock-like intrusion first described as diorite by Irvine (1878), which was investigated in 1977 by Dr H Colley during a reconnaissance of intermediate intrusions in southern Scotland. He found signs of weak mineralisation near Barfad Loch [NX 325 662] and Fell End [NY 309 641]. A geophysical survey (Fig. 2), conducted to investigate the diorite intrusion and an associated aeromagnetic anomaly (IGS, 1978), identified interesting IP anomalies over sedimentary rocks of early Silurian age around Crunlae Fell [NX 315 645] to the west of the stock-like intrusion. At Black Stockarton Moor (Brown and others, 1979), an IP anomaly over similar slightly magnetic diorite and related porphyry dykes, in a subvolcanic complex of the same probable age, accompanies disseminated copper mineralisation. Subsequent mapping and geochemical sampling were therefore concentrated on Crunlae Fell, designed to investigate the geophysical anomalies and the possible occurrence of porphyry-style copper mineralisation.

GEOLOGY

The area investigated (Fig. 3) is underlain by folded sedimentary rocks of early Silurian age attributed to the Queensberry Grit Group by Irvine (1878) and later incorporated in the Gala Group (see Greig, 1971). One large dioritic intrusion, a number of dykes and some intrusion breccias were emplaced, probably during the Devonian period.

SEDIMENTARY ROCKS

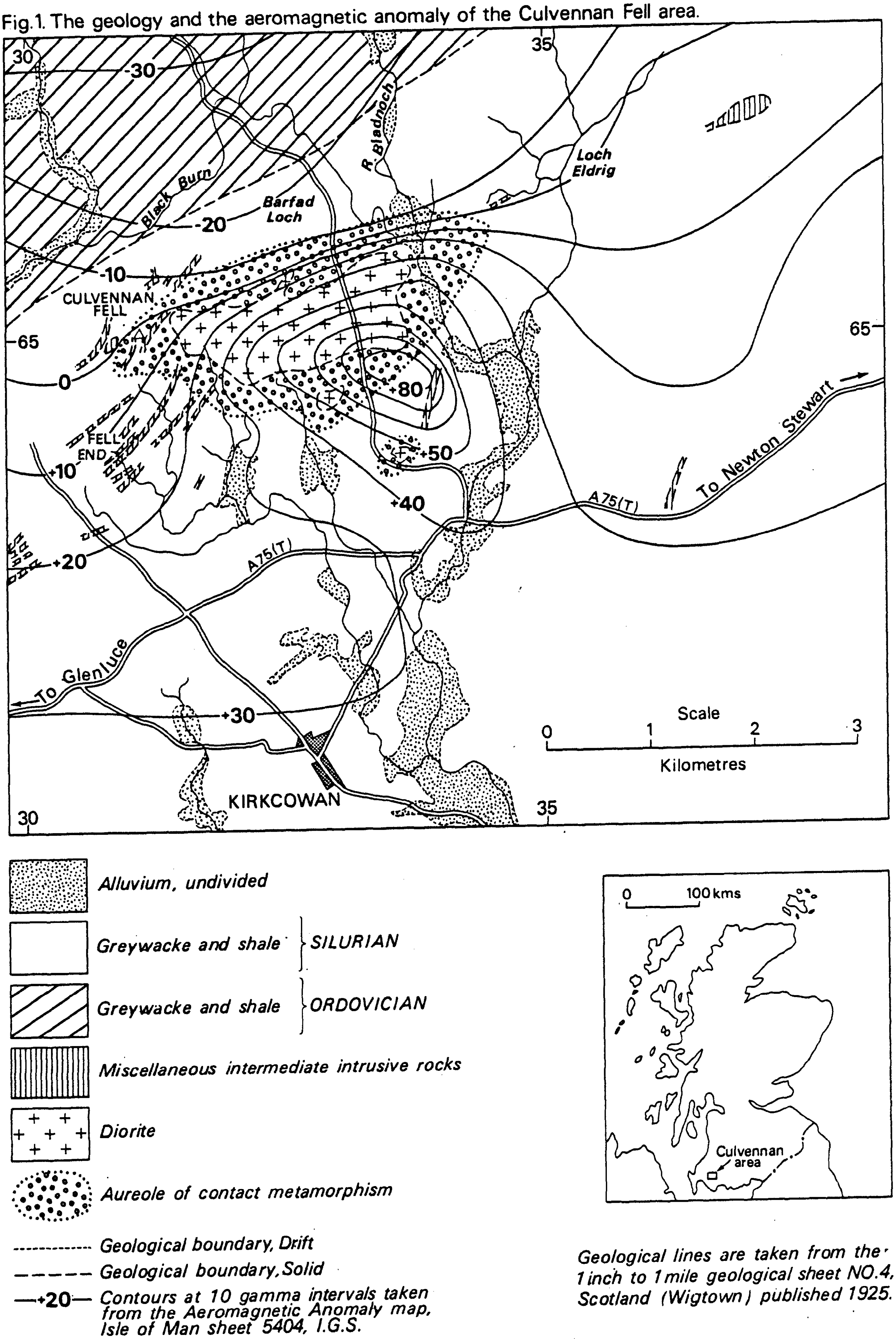
The succession consists of greywacke and quartz-wacke interbedded with silty mudstone, siltstone and rare calcareous mudstone. Coarse-grained, pebbly greywacke and quartz-wacke occur in either massive or graded beds up to several metres thick in which quartz pebbles and angular blocks of various sedimentary rock types are commonly present at the base. Traces of pyrite are present in some beds. In places the rock is conglomeratic and in the area north of the main intrusion such rocks dominate the succession.

Dark grey or greyish green, somewhat feldspathic and micaceous greywacke sandstone forms thin graded beds or, more commonly, laminated beds which may display intricate convolutions and complex ripple lamination. Dark grey silty mudstone and siltstone, usually thinly bedded, are interbedded with the coarse-grained rocks throughout and contain finely divided pyrite. Black or purplish-grey calcareous mudstone forms only thin beds locally.

In thin section features of the greywacke, siltstone and mudstone show that the rocks have been thermally metamorphosed. They contain, in addition to the clastic grains, plentiful sericite, some chlorite and fine, brown biotite.

Bedding usually strikes north-east and dips are steep or vertical. Overturned beds younging north-west and upward facing beds younging to the south-east suggest that the main folds are isoclinal overfolds with roughly horizontal axes. There are, however, minor, tight, upright folds with steeply plunging axes. The cleavage, developed in silty and argillaceous units, strikes parallel to the bedding. Apart from minor thrusts observed in outcrop the only faults recognised in the area trend NNW.

Fig.1. The geology and the aeromagnetic anomaly of the Culvennan Fell area.



Geological lines are taken from the 1 inch to 1 mile geological sheet NO.4, Scotland (Wigtown) published 1925.

FIG.2 Areas investigated by geophysical and geochemical surveys, showing traverse lines and drainage survey sample sites

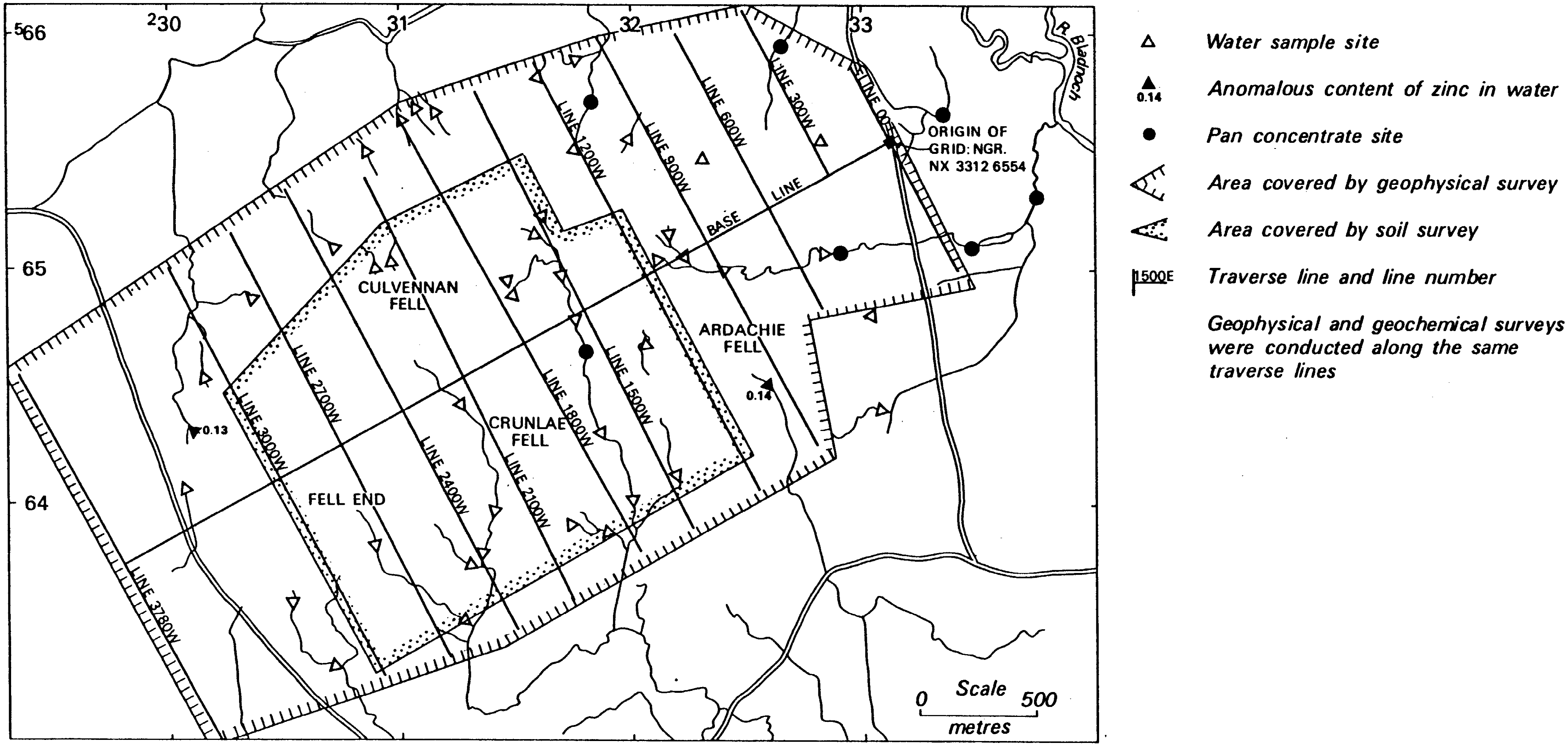


FIG.2 Areas investigated by geophysical and geochemical surveys, showing traverse lines and drainage survey sample sites

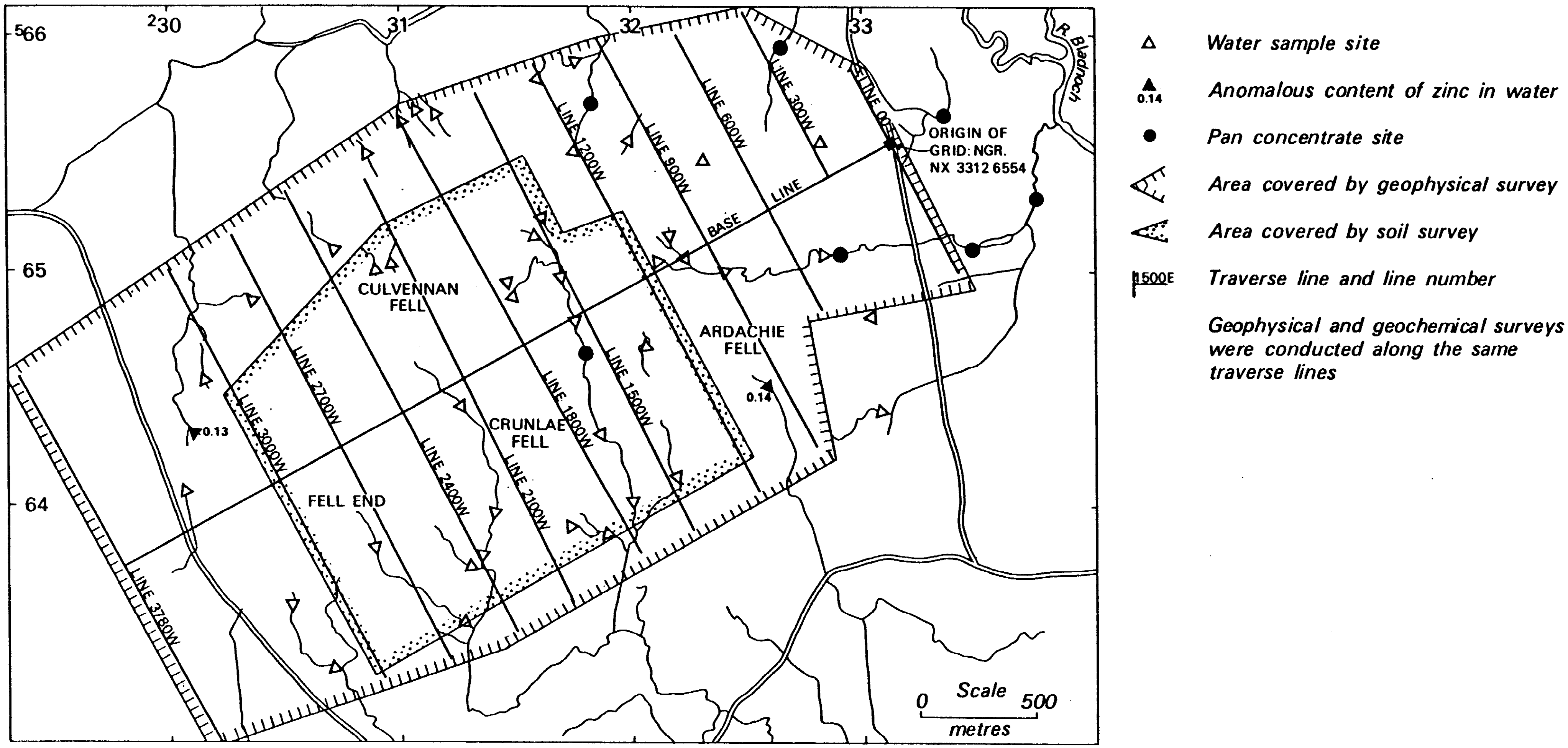
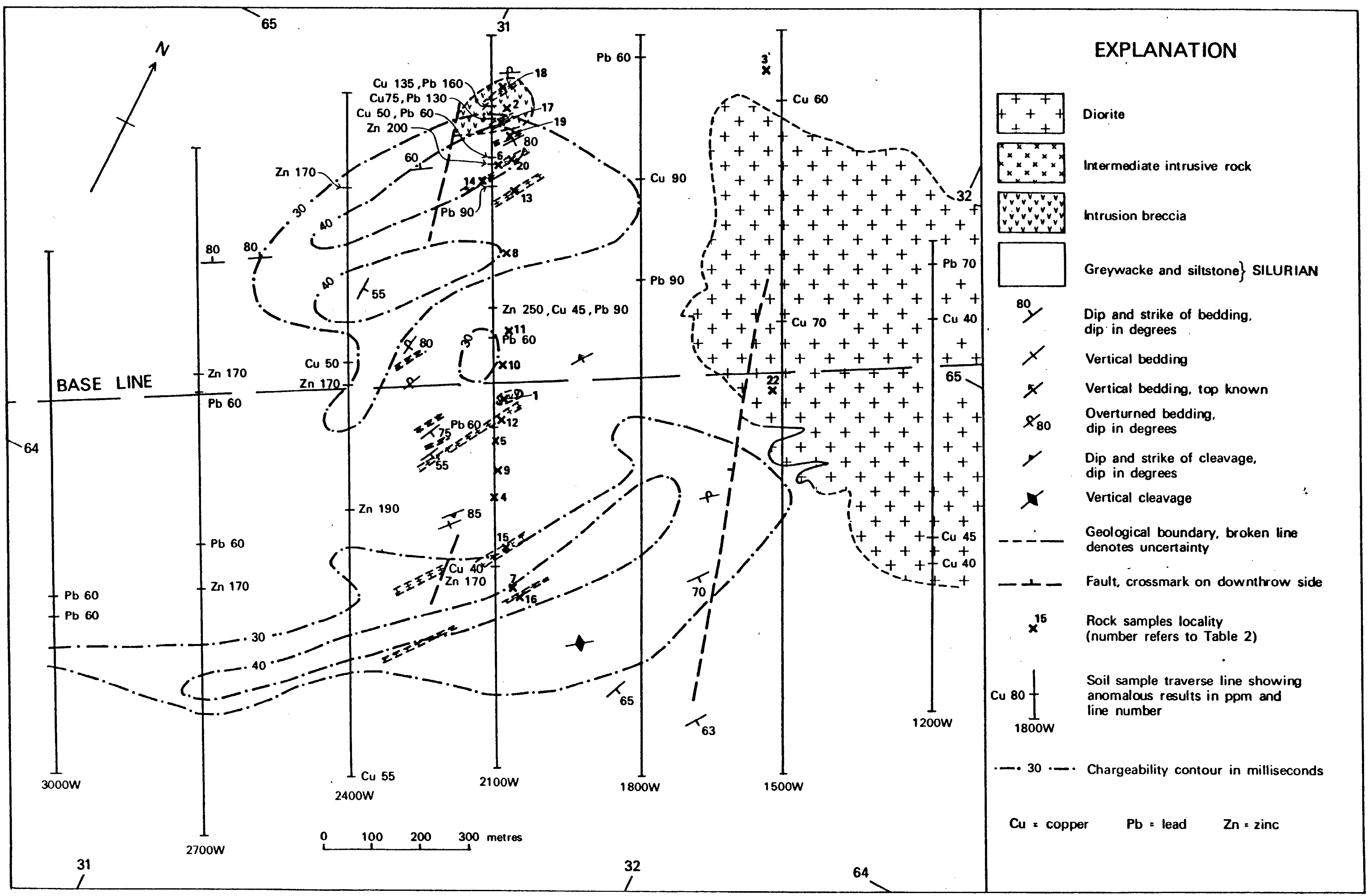


Fig 3 The main geological, geochemical and geophysical characteristics of the area around Crunlae Fell



IGNEOUS ROCKS

The main intrusive body in this area covers about 1.5 km^2 and was described by Irvine (1878) as diorite. The thermal aureole is broad. On the western side the intrusion is a medium-grained, non-porphyritic, fairly homogeneous and unfoliated rock. A sample from this section contains zoned andesine, quartz, biotite, and green hornblende commonly with a core of colourless amphibole (?cummingtonite). Compositionally this rock, which is fresh, is a tonalite, but the greater part of the intrusion is composed of pyroxene-mica diorite with a small proportion of quartz and both augite and hypersthene (Table 2, No. 21). Pyrite has been recorded at the western margin.

A number of sheet-like intrusions 1–12 m thick, are present in the area to the west of the main body. They are usually parallel to the bedding, but the presence of intrusions intersecting the intrusion-breccia on Culvennan Fell suggests that they are dykes not sills. Compositionally they include porphyritic hornblende microdiorite; non-porphyritic quartz-hornblende microdiorite; porphyritic and non-porphyritic biotite micro-tonalite; porphyritic microgranodiorite and quartz micromonzonite; and hornblende lamprophyre. They all contain small amounts of pyrite. One sample of red porphyritic microtonalite contains abundant limonite or goethite.

INTRUSION-BRECCIA

An intrusion-breccia on the peak of Culvennan Fell [NX 3108 6502] is oval in outcrop, about 100 m long and tapers towards the south-west where it terminates at a fault. It contains subangular and angular blocks, from a few millimetres to a metre long, of silty mudstone, siltstone and other rocks recognisable in the adjacent country rock. In addition there are usually rounded blocks of quartzose sandstone. Besides the lithic fragments, there are crystals of plagioclase, quartz and biotite up to 3 mm long. The matrix is microcrystalline feldspar, quartz and biotite, presumably recrystallised clastic material. Voids in the matrix have been filled with hematite and quartz crystals. Joints are stained with black manganese oxides. Pyrite is locally abundant in the enclosed blocks.

The breccia forms a discrete body though small veins of it penetrate the wall rock, and its overall textural and structural characteristics are those of an intrusion-breccia. It is cut by dykes of porphyritic microgranodiorite, one of which contains xenoliths of the breccia.

Small outcrops of breccia were also recorded at [NX 3134 6454] and [NX 3150 6537]. They are similar to the rock on Culvennan Fell and carry pyrite both disseminated and in veilets.

MINERALISATION

The only recorded mineral working in this general area was at Wauk Mill, 1.2 km south-east of Kirkcowan, where a north-south trending vein was exploited for copper (Wilson and Flett, 1921). Irvine commented on veins, presumably not worked, of copper-pyrite within the Queensbury Grit Group in the area to the west. Signs of mineralisation at outcrop within the area investigated are poor. The main intrusion has been subjected to mild propylitisation, locally along the margin, and contains some disseminated pyrite. Sulphides also occur near a fault along the western margin. Analysis of the rock (Table 2, No. 22) shows Cu, Fe and As enrichment. Quartz and calcite veining is locally intense in the country rock, though associated sulphides are seen only at [NX 3182 0480]. Veinlets containing pyrite and magnetite are also of local occurrence. Disseminated pyrite is abundant in some blocks of sedimentary rock incorporated in the intrusion breccia on Culvennan Fell, where a small excavation indicates an early trial for minerals.

GEOPHYSICS

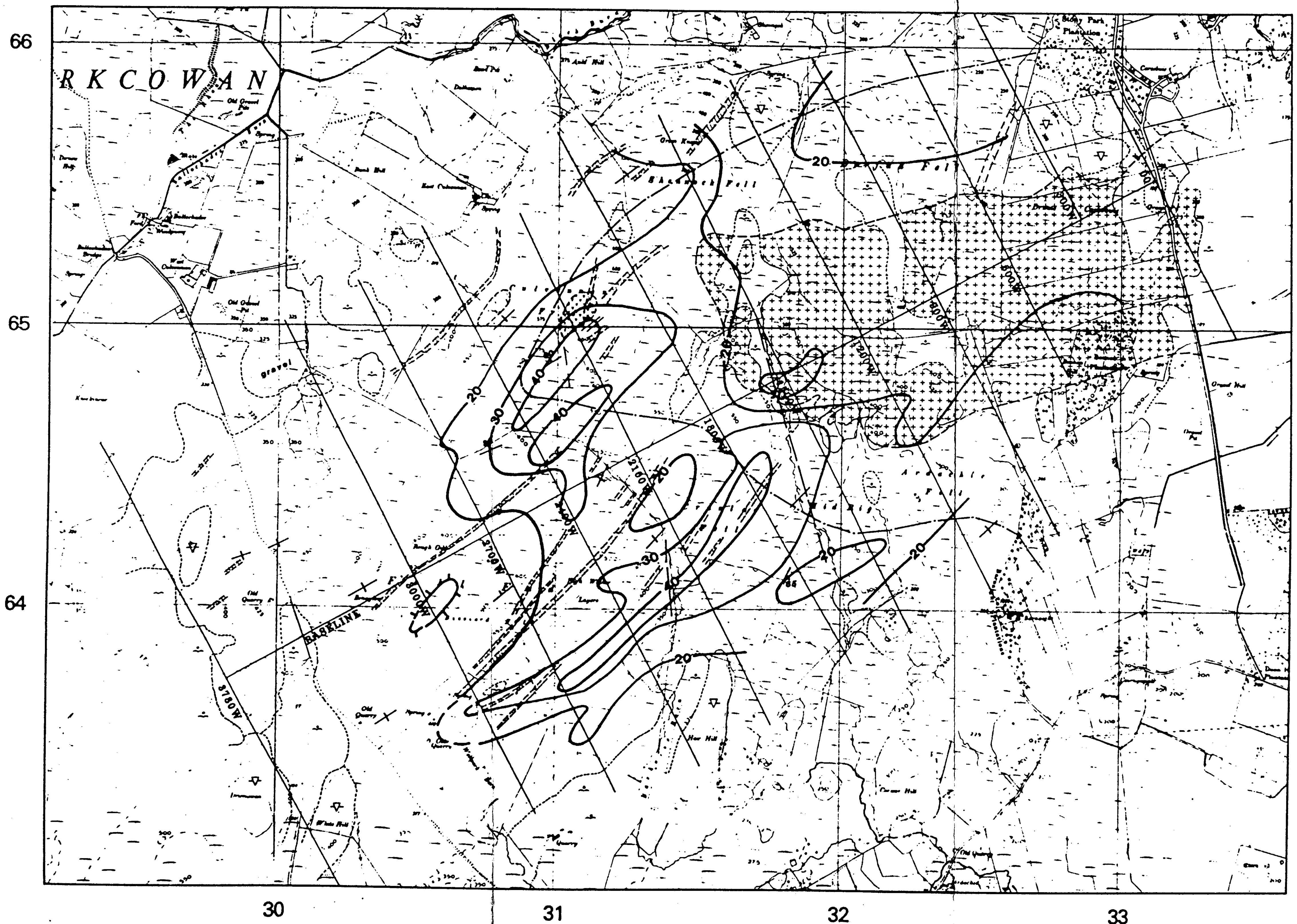
Induced polarisation (IP), resistivity and magnetic total force measurements were made along traverse lines of 300 m or 600 m spacing (Fig. 2). The expanding dipole-dipole array was used for the IP/resistivity survey, with a dipole length of 60 m and transmitter-receiver dipoles centre-to-centre separation of 120 m to 360 m.

RESULTS

The profiles for each line are presented and discussed in Appendix I. Figs. 4 and 5 are the hand-contoured maps of chargeability and resistivity at n = 3.

A high chargeability zone about 1½ x 2 km in size occurs in the centre of the survey area, immediately to the west of the main intrusion. Two maxima lying within this zone are elongated approximately along the strike of the sedimentary rock and the trend of the dykes. A zone of high resistivity lies between them, also elongated along strike. Chargeability over the main intrusion is low (Fig. 4).

The main control on the resistivity pattern (Fig. 5) seems to be the drift deposits, with peaty and boggy ground in the east, south, and north-west exhibiting low resistivity, as does the elongated boggy area along the fault near the western end of the main intrusion. High resistivities occur mostly over well-drained sloping ground. Some geological responses due to the solid geology can be identified, however. The main diorite exhibits somewhat low resistivity and, within the sedimentary rocks, alternating bands of high and moderate resistivities are aligned more or less along strike. The higher resistivity bands tend to have low chargeabilities and the general pattern of high IP is preserved when the specific capacitance is calcula-



EXPLANATION

Alluvium

Peat

Boulder clay

Diorite

Intermediate intrusive rock, undivided

Intrusion breccia

Greywacke & siltstone

Geological boundary, drift

Geological boundary, solid

Strike of bedding, dip in degrees

Vertical bedding

Overturned bedding

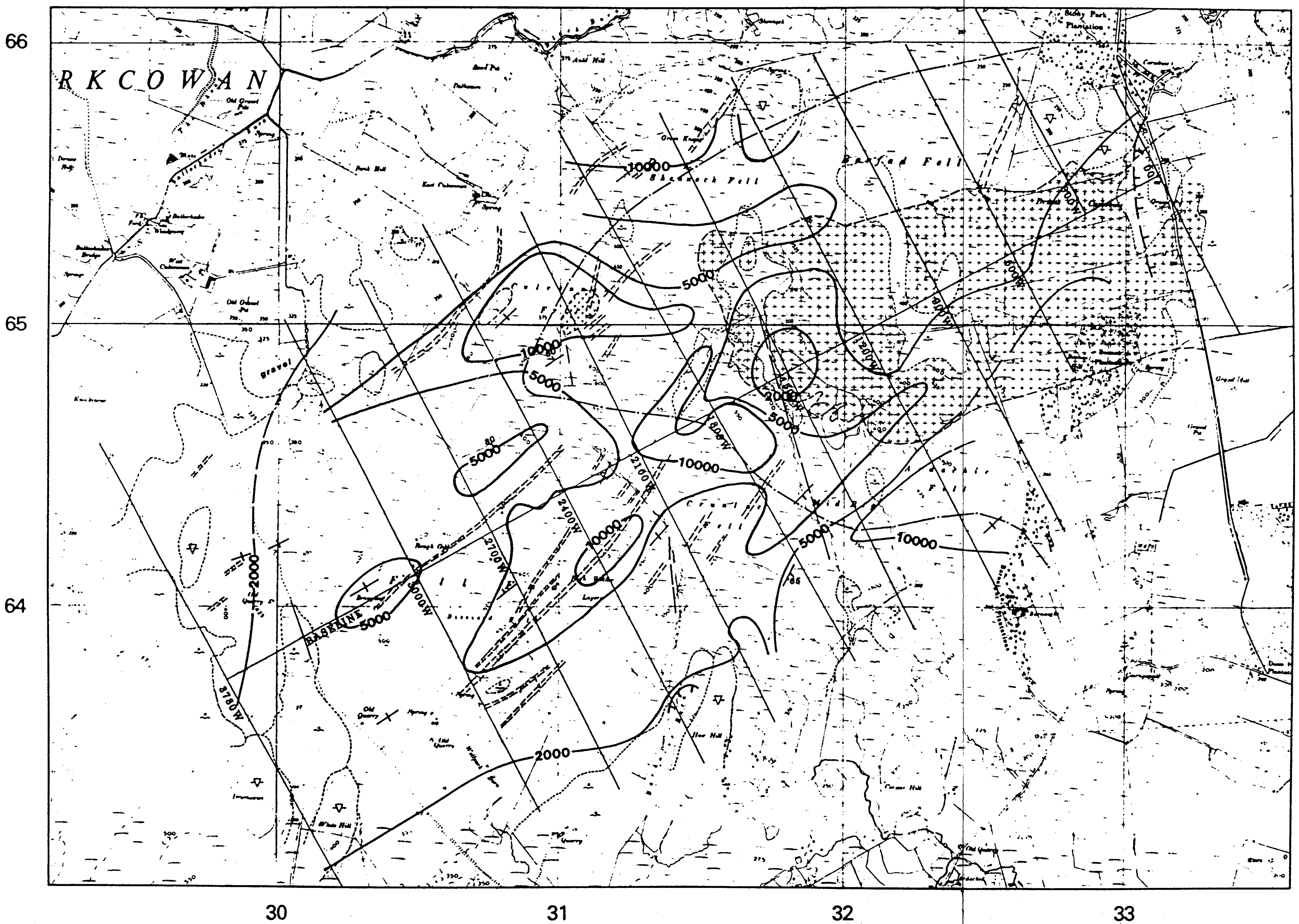
Limit of thermal aureole

Fault

Geological data taken from the original field maps of D.R.Irvine with additional data by P.M.Allen

FIG : 4

CONTOURS OF CHARGEABILITY AT n=3



EXPLANATION

- Alluvium
- Peat
- Boulder clay
- Diorite
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- Greywacke & siltstone
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- Strike of bedding, dip in degrees
- Vertical bedding
- Overturned bedding
- Limit of thermal aureole
- Fault

Geological data taken from the original field maps of D.R.Irvine with additional data by P.M.Allen

FIG : 5

CONTOURS OF APPARENT RESISTIVITY AT n=3

ted.

Magnetic anomalies occur mostly over the main diorite, which gives a 'noisy' high with individual anomalies up to 1000 nT. The south-east part of this intrusion is more strongly magnetic than the rest, as was indicated by the airborne survey (Fig. 1). Closer geological examination of the diorite may reveal two phases of intrusion, as the magnetic boundary is quite distinct. Outside the diorite, isolated narrow anomalies cannot reliably be correlated from line to line and most of them cannot be ascribed to any known source. In one case, such an anomaly lies close to a dyke of porphyritic hornblende microdiorite, but elsewhere such dykes have little or no effect. The density of these narrow anomalies decreases away from the main intrusion. If intrusive rocks are not responsible, the most likely sources are thin horizons of magnetic sedimentary rocks, particularly as the magnetic anomalies occur mostly within the zones of high chargeability.

DISCUSSION

As at Black Stockarton Moor, the high chargeability zone measured on Culvennan Fell occurs close to a small, slightly magnetic intrusion with associated dykes. The form of the Culvennan IP anomaly, namely a high resistivity core with flanking IP maxima, is commonly indicative of porphyry-copper deposits. However, the low IP response of the main intrusion and the alignment of the chargeability features more-or-less along the strike of the sedimentary rocks, do not lend support to such an interpretation in this case. The coincidence of high chargeability and low resistivity, in zones tending to contain narrow magnetic anomalies, suggests instead a stratabound cause for the geophysical features. Siltstone beds with a high iron content due to iron oxides and sulphides in veinlets and disseminations have been recognised in the anomalous area, while some of the dyke rocks and the large breccia are pyritic.

GEOCHEMISTRY

SAMPLE COLLECTION, PREPARATION AND ANALYSIS

Samples of water and pan concentrates were collected over a large area incorporating the whole of the Culvennan intrusion (Fig. 2). Soil and rock samples, however, were taken only from the area of interest as indicated by IP anomalies immediately to the west of the main intrusion (Fig. 3).

Seven heavy mineral pan concentrates were collected from streams in the Culvennan area. The samples were quartered, ground in a Tema mill with elvacite for five minutes, pelletised and analysed for a range of elements by X-ray fluorescence spectrometry (XRF).

Forty-seven water samples were collected in 30 ml polythene bottles, from streams above confluences or at approximately 500 m intervals; acidified with 0.3 ml perchloric acid in the field, and subsequently analysed for copper and zinc by AAS without further sample preparation.

Soil samples (of c. 200 g) were collected from maximum depth accessible to hand augers 120 cm long, at 50 m intervals along the geophysical traverse lines (Fig. 3), except on line 2100 W where a 25 m interval was used. Soil profiles were poorly developed; samples came dominantly from the 'B' horizon, some from 'C', 'E' and, occasionally, where peat cover was greater than 120 cm, the 'O' horizon (Hodgson, 1976). Samples were dried and sieved, and the -85 mesh (0.18 mm nominal aperture) fraction analysed for copper, lead and zinc by atomic absorption spectrophotometry (AAS), after dissolution in hot concentrated nitric acid for one hour.

Twenty-two rock samples were collected close to traverse line 2100 W and at a few other localities (Fig. 3). A minimum of 2 kg of each sample was crushed and a split ground in a Tema mill with elvacite for five minutes before pelletising. Samples were analysed for a range of elements by XRF.

Detection limits for AAS were Cu:3 ppm, Pb:5 ppm, Zn:5 ppm. For XRF they were Cu 6 ppm, Pb 13 ppm, Zn 3 ppm, As 2 ppm, Ba 27 ppm, Mn 6 ppm, Ni 5 ppm, Sr 1 ppm, Rb 1 ppm, Zr 2 ppm, Ce 21 ppm, Th 2 ppm, Y 1 ppm and U 2 ppm.

RESULTS

Pan concentrate samples

Analytical results do not indicate any base-metal enrichment. The sample from [NX 3290 6509] (Fig. 2) shows enrichment in elements normally concentrated in basic rocks whereas the sample from [NX 3266 6598] shows enrichment in tin and antimony, both of which can be indicative of contamination as well as mineralisation. Mineralogical examination of the latter sample failed to clarify the source of the anomalies as only a small, unrepresentative portion remained after analysis.

Water samples

Levels of copper and zinc in water samples were below or close to the detection limits (0.01 ppm Cu, 0.01 ppm Zn) with the exception of two samples containing 0.13 ppm Zn and 0.14 ppm Zn (Fig. 2). Neither of these could be directly related to a geological feature.

Soil samples

A summary of the soil results is given in Table 1; the results are plotted out along traverse in Figs. 6A-D.

Log cumulative frequency plots indicate that the copper and lead sample populations have an apparently binormal form (Parslow, 1974). Threshold levels were set at the break points (Lepeltier,

Table 1. Summary of copper, lead and zinc results in ppm for 223 soil samples from Culvennan.

	Median	Mean	Geometric Mean	Geo. Mean + Geo. Dev.	Geo. Mean + 2 x Geo. Dev.	Max.	Min.	Threshold
Copper	20	21	18	30.5	52.4	135	5	40
Lead	30	34	32	46.8	69.2	160	10	60
Zinc	A 85 B 40	70	58	114	225	250	10	170

1969) which occur at 40 ppm and 60 ppm respectively. With these values taken as thresholds 5% of copper and 2.8% of lead results are defined as anomalous.

Zinc has a bimodal distribution with medians of 85 ppm (sub-population A) and 40 ppm (sub-population B). Both sample populations appear to be lognormal (Sinclair, 1974). The threshold level for zinc was taken from the intercept of the cumulative frequency curve with the 2.5 percentile. Zinc values above 170 ppm (4% of sub-population A and 1.2% of B) were therefore considered to be anomalous. For all three elements the background levels were taken as the median values.

Rock samples

Samples of all the main rock types were collected for analysis, but the small number of each type precluded meaningful statistical analysis of the results, which are given in Table 2.

Because of the large scale inhomogeneity of the breccias none of the samples can be considered representative, and the textures suggest that some leaching of sulphides may have occurred. However one of the samples shows copper and another, from the Culvennan Fell intrusion, strong arsenic and perhaps weak lead and copper enrichment. All three samples contain pyrite and secondary iron oxides and this is reflected in their high iron content. Despite the manganese oxide staining on joints manganese contents are not high.

The siltstones show element levels similar to world averages for slates (Turekian and Wedepohl, 1961) except for iron which is about twice the average value, and arsenic which is three times the average in one sample (Table 2, No. 5). The high iron content can be attributed in part to veinlets and disseminations of iron oxides and sulphides. The sulphides probably also contain most of the arsenic. The sandstones show high levels of iron, zinc and titanium compared with world average (Turekian and Wedepohl, 1961) but these can be accounted for by the impure character of rocks at Culvennan. The high levels of arsenic in two samples may be related to disseminations and veinlets of sulphide.

Of the intrusions, the sample of diorite from the main intrusion and unaltered lamprophyre are chemically distinct from the microgranodiorites and microtonalites, containing higher amounts of the elements normally concentrated in basic rocks (Cu, Fe, Zn, Mn, Ti, Ca, Sr, Ni). The various microgranodiorites and microtonalites are chemically indistinguishable on the available data. Comparisons with available data (e.g. Vinogradov, 1962; Allen and others 1976, 1979; Saunders and others, 1980) suggests that whilst these intrusives show some weak enrichments, such as copper in No. 16 and nickel in No. 12 (Table 2), the element levels are within the ranges normally reported for these lithologies. A possible exception is the copper content of the diorite from the main intrusion which is rather high for a fresh unmineralised rock. The highly altered lamprophyre shows a pronounced arsenic enrichment compared with all the other intrusives, and suggests that weak mineralisation may accompany the alteration in this rock. The chemistry of the HFS (high field strength) elements suggests that these intrusions may have been emplaced in a plate margin environment (e.g. Pearce and Gale, 1977; Pearce and Norry, 1979), but because of the alteration of these rocks and other unknown factors a high degree of uncertainty exists.

DISCUSSION OF RESULTS

In general the soil anomalies occur in isolation and no tie-up across traverse lines is evident. The majority of the single-site anomalies can be explained by secondary concentrations of metal which may be unrelated to mineralisation. For example, the weak lead anomaly at 200 m north on traverse line 1800 W is in a peat bog, the lead probably being fixed as organometallic complexes. The copper, lead and zinc anomalies at 150 m north on line 2100 W appear, from changes in soil colour, to be caused primarily by Eh variation.

The nearest soil sample to the vein mineralisation at NX 3182 6480 was taken uphill of it and shows no base metal enrichment, but the weak copper anomaly in soil (70 ppm) at 100 m north on line 1500 W may be over a continuation of this mineralisation as indicated by a NNW trending feature.

At the northern end of line 2100 W two adjacent soil samples overlying the intrusion breccia, which is known from rock analyses to be enriched in copper, arsenic and lead, yield the highest copper and lead results recorded in soil in

FIG.6A Metal values in soils. Traverse numbers refer to FIG.3

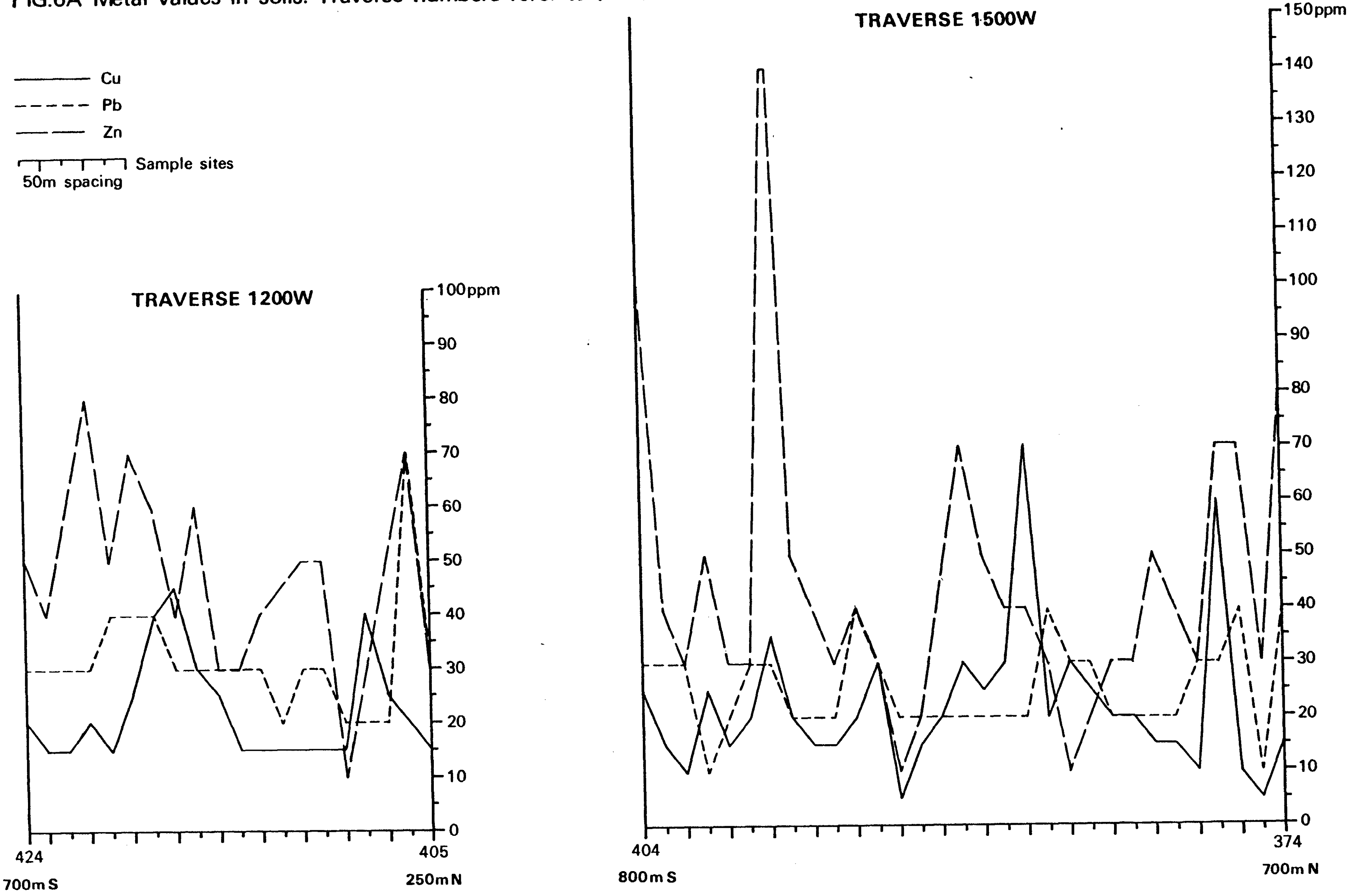

FIG.6B Metal values in soils. Traverse numbers refer to FIG.3

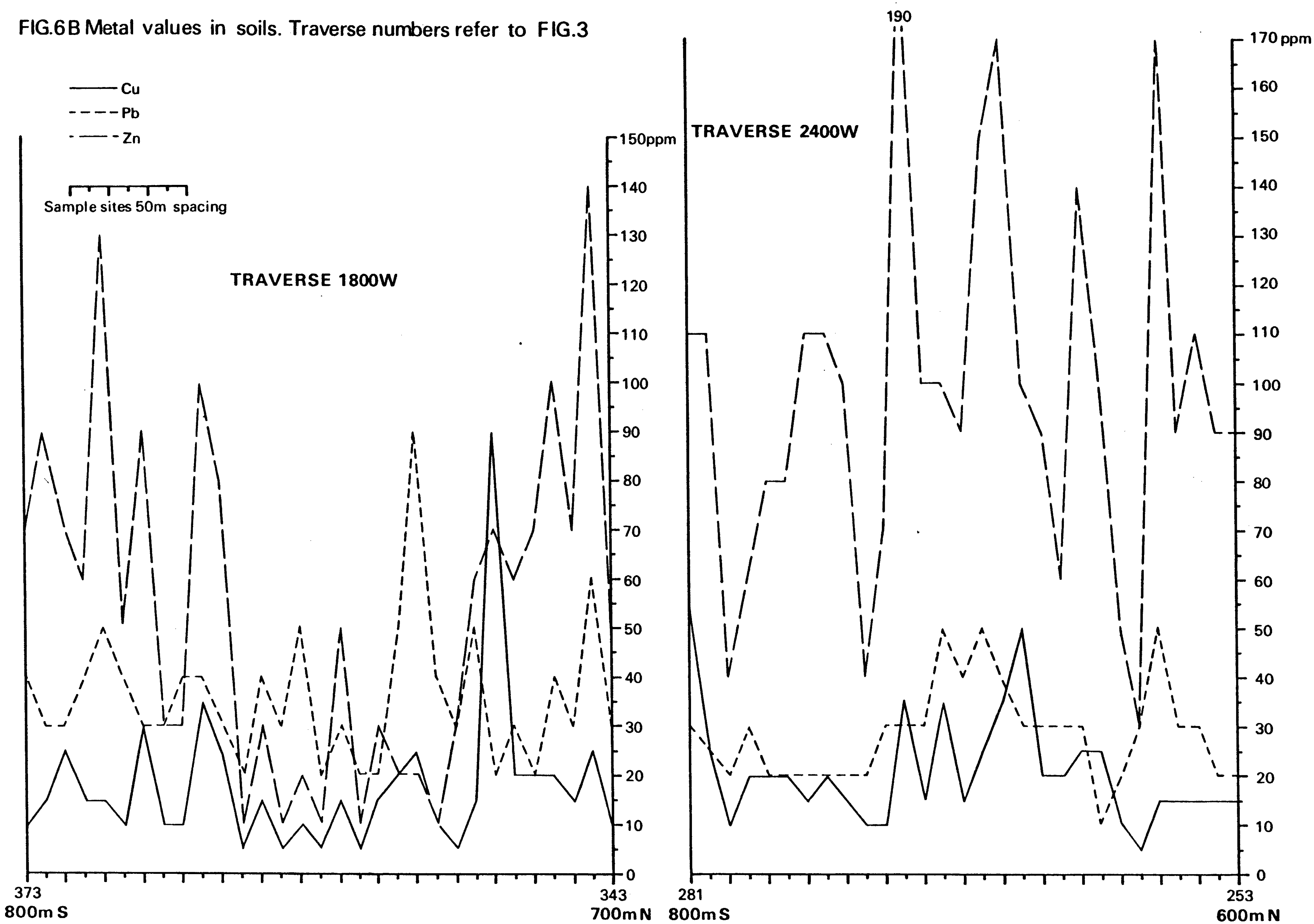

FIG.6C Metal values in soils. Traverse numbers refer to FIG.3

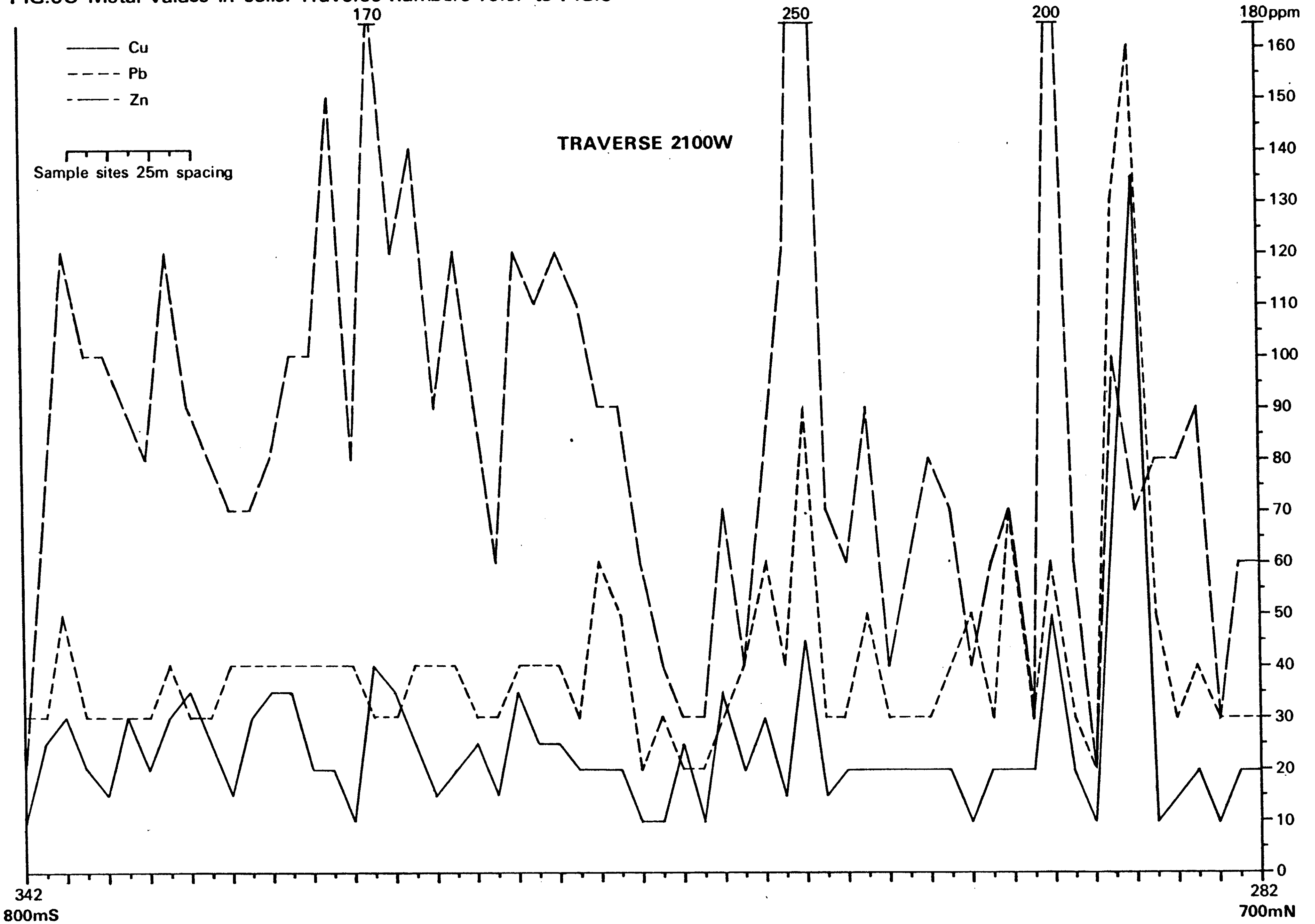

FIG.6D Metal values in soils. Traverse numbers refer to FIG.3

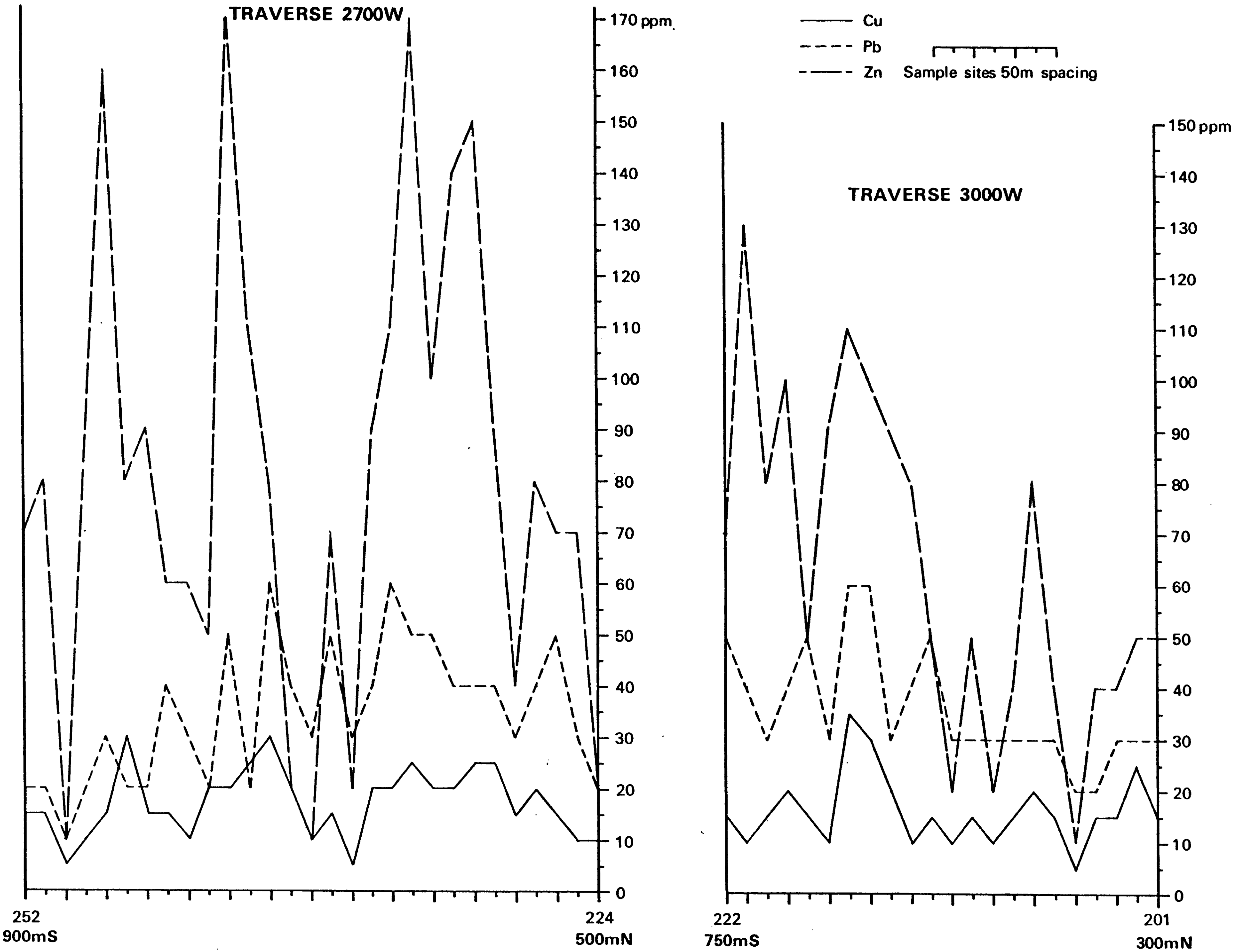

Table 2. Rock analyses from Culvennan.

NUMBER		GRID REFERENCE NX	Cu	Pb	Zn	As	Ba	Fe	Mn	Ti	Ni	Ca	Sr	Rb	Zr	Th	Ce	Y	U
INTRUSION BRECCIA																			
1.		3134 6454	141	21	57	26	329	88890	590	5140	82	9020	248	84	181	10	44	22	2
2.		3106 6505	83	53	19	900	254	40050	210	5200	22	1590	60	80	299	9	47	20	3
3.		3150 6537	17	<13	38	18	559	68520	370	5210	76	880	91	97	193	10	50	14	3
SILTSTONES																			
4.		3141 6434	43	<13	122	15	674	84820	680	5880	138	4240	86	164	179	9	59	29	2
5.		3136 6444	23	13	96	48	482	68440	720	5580	131	12260	286	120	182	10	41	24	<2
6.		3109 6495	24	19	116	27	618	70130	610	5930	70	5500	133	134	246	10	68	30	3
SANDSTONES																			
7.		3154 6421	9	<13	52	22	293	42900	380	5310	40	5270	78	61	330	9	53	26	2
8.		3120 6480	12	15	76	23	302	46560	370	5430	29	6860	117	73	323	10	51	30	4
9.		3139 6440	8	<13	50	20	266	40650	320	5510	23	5440	86	54	306	8	54	23	<2
10.		3131 6460	15	<13	48	137	209	42580	360	4870	28	6050	89	49	304	7	34	21	3
11.		3128 6466	18	<13	46	84	254	44380	400	5710	24	6090	107	53	393	9	56	25	3
INTRUSIVES																			
12.	Microtonalite	3135 6448	<6	<13	48	15	679	44660	580	3830	72	18370	388	63	163	8	<21	16	<2
13.)	Porphyritic	3115 6492	26	<13	49	13	641	43580	690	4090	18	19670	484	95	190	13	52	20	6
14.)	microtonalite	3109 6489	<6	<13	55	9	701	42950	670	3970	25	19530	450	106	202	15	58	21	5
15.)		3149 6426	30	<13	33	12	978	37100	400	3670	22	15700	489	90	245	16	44	22	<2
16.)	Porphyritic	3158 6421	60	<13	39	6	876	42750	390	3910	24	14740	537	94	275	16	44	24	6
17.)	microgranodiorite	3105 6501	10	14	47	8	776	38780	510	3690	58	16830	470	100	208	18	51	20	5
18.)		3103 6509	9	13	57	7	603	41440	530	3770	49	20770	432	94	208	15	41	19	5
19.)	Hornblende-	3111 6500	17	<13	50	56	439	36840	480	3760	44	22320	383	82	128	6	<21	11	<2
20.)	lamprophyre	3112 6497	58	<13	68	14	978	64680	910	4520	197	37050	759	27	130	7	39	15	<2
21.	Diorite	3281 6551	93	17	79	6	805	58000	820	5850	58	31130	697	50	182	7	31	24	<2
FAULTED AND MINERALISED INTRUSIVE MARGIN																			
22.		3182 6480	818	142	58	>1000	477	111580	660	3070	92	1180	67	44	114	22	28	13	<2

Mo was also determined but all results except two (No. 17 = 3 ppm, No. 14 = 5 ppm) were < 2 ppm, the detection limit.
All results are in parts per million.

the area. However, the copper-enriched breccia exposed at NX 3133 6454 generates no copper anomalies in nearby soil samples.

The traverse plots (Fig. 6A-D) show that copper and lead anomalies in soil are more closely related than those of copper and zinc or lead and zinc. However, correlation coefficients on log transformed data indicate a closer relationship between copper and zinc ($r = 0.539$) than between copper and lead ($r = 0.328$) or lead and zinc ($r = 0.363$). All three correlations are highly significant (> 99.95% confidence level). This suggests that the cause of the anomalies is different from that of the background pattern, which in the case of zinc can be related to variations in rock type; the lower population derived from greywackes and the higher from the other lithologies.

A comparison of rock and soil results on line 2100 W indicates that zinc shows patchy enrichment in soils, related to secondary concentration, whereas lead shows substantial enrichment, presumably caused by the uptake of lead by organic matter and the tendency of AAS to give higher results than XRF at low lead levels. Copper is modestly enriched in soils, but over thin, relatively copper-rich intrusions or mudstone bands the soil may appear depleted because of the dilution effects in drift derived largely from relatively copper-poor greywacke. Consequently small areas of weak copper mineralisation may not be registered by soil sampling in this area, whilst concentrations of lead and perhaps zinc may be unrelated to bedrock mineralisation.

Maximum levels of all three metals in soil are low compared with most other mineralised areas including two other areas of upland Britain containing disseminated copper mineralisation, Black Stockarton Moor (Brown and others, 1979) and Coed-y-Brenin (Rice and Sharp, 1976). Threshold levels for copper are also higher in both these areas than at Culvennan, but the background level for all three elements at Black Stockarton Moor is similar. There is clearly a lack of copper enrichment in the superficial deposits at Culvennan to a level which might be expected, at least within the IP anomaly, if near surface porphyry-style copper mineralisation were present.

Element levels in rocks agree with the soil results in giving no indication of near surface porphyry-style mineralisation, but they do suggest the presence of weak Cu - As - Fe ± Pb sulphide mineralisation. A mineralised sample taken from the side of a NNW trending fault feature marginal to the main intrusion shows levels of copper, lead and arsenic indicative of mineralisation as do the breccia samples. Arsenic enrichment in other rock types reflects patchily developed veinlets or disseminated mineralisation in most lithologies. No clear spatial link between soil or rock samples enriched in metals and IP anomalies or the margins of the intrusion could be discerned, but the possibility that such a spatial associated does exist cannot be ruled out because of the small number of rocks analysed and, in the case of soils, the lack of arsenic analyses and the probability that some anomalies are transported.

The lack of copper anomalies in panned concentrates and water samples is further evidence against substantial porphyry-style mineralisation in the area, for at Coed-y-Brenin the disseminated copper mineralisation is clearly indicated by very large copper in streamwater anomalies (Cooper, 1976), and the pyrite halo there produces very large amounts of iron in panned concentrates as well as copper anomalies.

CONCLUSIONS

1. There is no evidence from the available data of appreciable copper enrichment or other chemical changes associated with porphyry-type mineralisation at or near surface in the Culvennan area. Among the factors which indicate this are:
   - i. Lack of copper-in-water anomalies
   - ii. The presence of only small isolated copper anomalies in soils. With a sample spacing of 25 m or 50 m these are considered to be of no significance in terms of near-surface porphyry-style mineralisation.
   - iii. The coincidence of copper with lead and zinc anomalies in soil.
   - iv. The absence of a copper-molybdenum association in rocks.
2. There is no chemical evidence of substantial metal enrichment related to any other form of mineralisation in the area sampled. Soil anomalies are small, scattered and weak, and can be related to minor secondary concentration of metals and weak copper-arsenic-iron-lead mineralisation. There is an untested possibility that gold may be associated with the arsenic mineralisation, as elsewhere in Southern Scotland.
3. There is no evidence to show that the high chargeability zone around a high resistivity core in the area west of the diorite intrusion is indicative of porphyry copper mineralisation. There is a correlation between the resistivity, chargeability and local magnetic anomalies in zones parallel to the local strike and the trend of the dykes. It is believed that low concentrations of non-economic sulphides and iron oxides in sedimentary rocks and some of the dykes are the most likely causes of the geophysical anomalies.
4. An intrusion breccia was emplaced on Culvennan Fell after the folding of the early Silurian sedimentary rocks, but before the intrusion of the local dykes. The age of this and other smaller bodies in this area relative to the main Culvennan intrusion of diorite is not known. Intrusion breccias are commonly found in association with porphyry copper orebodies and rock samples from intrusion breccia outcrops here are mildly enriched in copper. There is little evidence, however, to support the expectation of extensive copper mineralisation associated with the intrusion breccias at surface in this area.

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APPENDIX I LINE-BY-LINE DESCRIPTION OF GEOPHYSICAL RESULTS

The results are presented as pseudosections of apparent resistivity, chargeability, and specific capacitance, and as profiles of total magnetic field. A topographic profile with the solid geology at surface marked on it is also given for each line.

Line 00. Resistivity is low on this traverse in comparison with most of the survey area, but much of the line is low-lying with thick peat. Chargeability is also very low. The intrusion gives short wavelength magnetic anomalies up to 1000 nT, the strongest anomalies lying south of 200S.

Line 300W. Only magnetic measurements were made on this line. The diorite again gives a "noisy" high.

Line 600W. A strong resistivity contrast at about 300N coincides with the northern edge of the intrusion. To its south, over the diorite, values are generally less than 5000 ohm metres, while over the greywackes to its north they rise above 5000 ohm metres. The northern end of the line also has high chargeability, with values north of 480N rising to 35 ms. Most of the line has chargeability in the range 12–17 ms, but south of 120S values increase to about 25 ms. Once again the intrusion gives a magnetic "noisy" zone, with individual anomalies up to 500 nT. The part of the intrusion south of 50S gives stronger anomalies than the rest.

Line 900W. Only magnetic measurements were made on this line. The "noisy" zone over the diorite has a maximum amplitude of 400 nT, about half that of previous lines. The noisy zone extends at least 500 m beyond the mapped intrusion in the south. Although a fence could account for one peak, it seems likely that diorite is at or very near the surface near the south end of the traverse.

Line 1200W. Resistivity is generally high (> 5000 ohm metres) with a surface low on the north end of the traverse (800-1000N) and narrow lows at 300-360S, 120-180N and about 400N. At the south end of the line, very high values occur, up to 22000 ohm metres. Chargeability is mostly low except at 360-660S, where values rise above 20 ms to a maximum of over 30 ms near the southern end of the anomalous zone. Once again the magnetic profile shows a noisy high over the intrusion, though it is less marked than on previous lines. A small (150 nT) anomaly at 880S could indicate near surface diorite, otherwise the noisy zone on this traverse agrees well with the mapped extent of the intrusion.

Line 1500W. Resistivity is low at the centre of this line and high at the ends. The minimum values arise from 50-200N and 350N. Much of this is low boggy ground in a depression along a fault which crosses the traverse at a small angle at about 200N. The high resistivity zones lie north of 700N and south of 400S, values in both rising to 15000 ohm metres. Two zones of high chargeability occur: north of 700N, where values are about 25 ms, and at 240-720S, where the maximum is about 35 ms. The intrusion is again marked by a noisy magnetic high, but it is weaker again than on previous lines, reaching a maximum of only 200 nT above background.

Line 1800W. Resistivity is high on almost the whole line, reaching 14000 ohm metres in places. Lows (<5000 ohm metres) occur at 540-660N, 420-480S and south of 900S. A very narrow low lies at about 150N. Chargeability is greater than 20 ms on almost the whole traverse, except the ends (north of 600N and south of 600S). The highest chargeability occurs at 200-450S, with values exceeding 40 ms. Although this traverse passes to the west of the diorite, several magnetic anomalies occur, including a "noisy" zone at 200-400S, over the maximum chargeability zone. Narrow highs at 700N, 540N and 780S are probably due to natural sources, despite their short wavelength.

Line 2100W. Resistivity is high, except on the southern third of the traverse (south of 500S). A narrow minimum is seen at 780-840S. Chargeability is high on most of the line. A zone of greater than 20 ms chargeability extends from the north end of the line to about 50S, with a maximum at 480-540N, and other lies between 360S and the southern end of the line, with its maximum at 450-550S. Several magnetic anomalies occur. The largest, at 330S is 800nT above background, and approximately coincides with a "dyke" of porphyritic hornblende microdiorite. Similar dykes elsewhere on the traverse however do not produce magnetic anomalies. There is no anomaly over the intrusion breccia.

Line 2400W. Two zones of high resistivity occur, at 800-400N and 00-700S. The southern end of the line shows low resistivities due to boggy ground along the Barhoise Burn. A single zone of chargeability values above 20 ms occurs between 360N and 660S, with two maxima, at about 180N and at 480-540S. Four magnetic peaks occur, but the strongest may be due to a fence.

Line 2700W. Resistivities vascillate around 5000 ohm metres, except at the extreme south where lower readings were obtained over flat marshy ground. Two chargeability high zones occur, the northern (00-300N) being weaker than the southern (420S-600S with a maximum at 480-540S). A single magnetic peak is probably due to a fence.

Line 3000W. Resistivities are mostly in the range 2000 to 6000 ohm metres. A narrow low at 780-840N lies over a stream. High resistivities occur at about 450S. Only a hint of the northern IP anomaly remains, but the southern high remains, lying between 300 and 500S with maximum at 300-360S. A magnetic high (200nT) lies close to this high IP zone, at 570S.

Line 3780W. Low resistivities occupy the northern half of this line, and the far southern end. Both are low-lying peat bogs. A single zone of chargeability slightly above 20 ms is seen at 240-300S. A 200nT magnetic anomaly occurs at 450N.

Baseline. Resistivity is high on most of the line, rarely falling below 2500 ohm metres. The only significant low resistivity zone occurs over a fault at about 1560W, close to the western edge of the main diorite. The fault is accompanied by boggy ground, which must at least contribute to the low resistivities. To its west for 600 m, resistivity is very high, with values up to 15000 ohm metres. A single chargeability anomaly occurs on this line, extending from 2000 to 2500W. It lies about 400 m west of the main diorite. Maxima at 2040 and 2250W approximately coincide with narrow magnetic peaks. Elsewhere over the greywackes the magnetic profile is very flat. The intrusion however gives fluctuations of up to 300 nT, particularly further east. The wavelengths of these fluctuations are generally short, from 50 to 200 m.

APPENDIX 1

LINE - BY - LINE DESCRIPTION OF GEOPHYSICAL RESULTS

The locations of the lines are shown in Fig 2
The apparent resistivity, chargeability, specific capacitance and total magnetic field are given for all lines except 300W and 900W for which only total magnetic field results are available.

KEY TO PROFILES

APPARENT RESISTIVITY — OHM METRES

- < 2000
- 2000 - 5000
- 5000 - 10000
- > 10000

CHARGEABILITY — MILLISECONDS

- < 20
- 20 - 30
- > 30

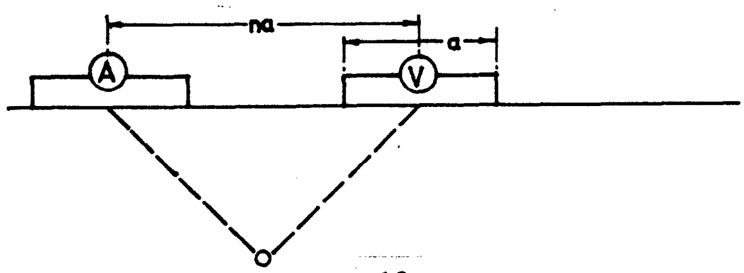
SPECIFIC CAPACITANCE

TOPOGRAPHIC PROFILE & SOLID GEOLOGY

- R — ROAD
- F — FENCE
- FAULT
- SILURIAN SEDIMENTARY ROCKS
- DIORITE
- PORPHYRITIC HORNBLENDE MICRODIORITE
- INTRUSION BRECCIA

NB : Geological boundaries are shown vertical for convenience only
Vertical scale of profile = horizontal scale

DIPOLE - DIPOLE ARRAY PLOTTING CONVENTION



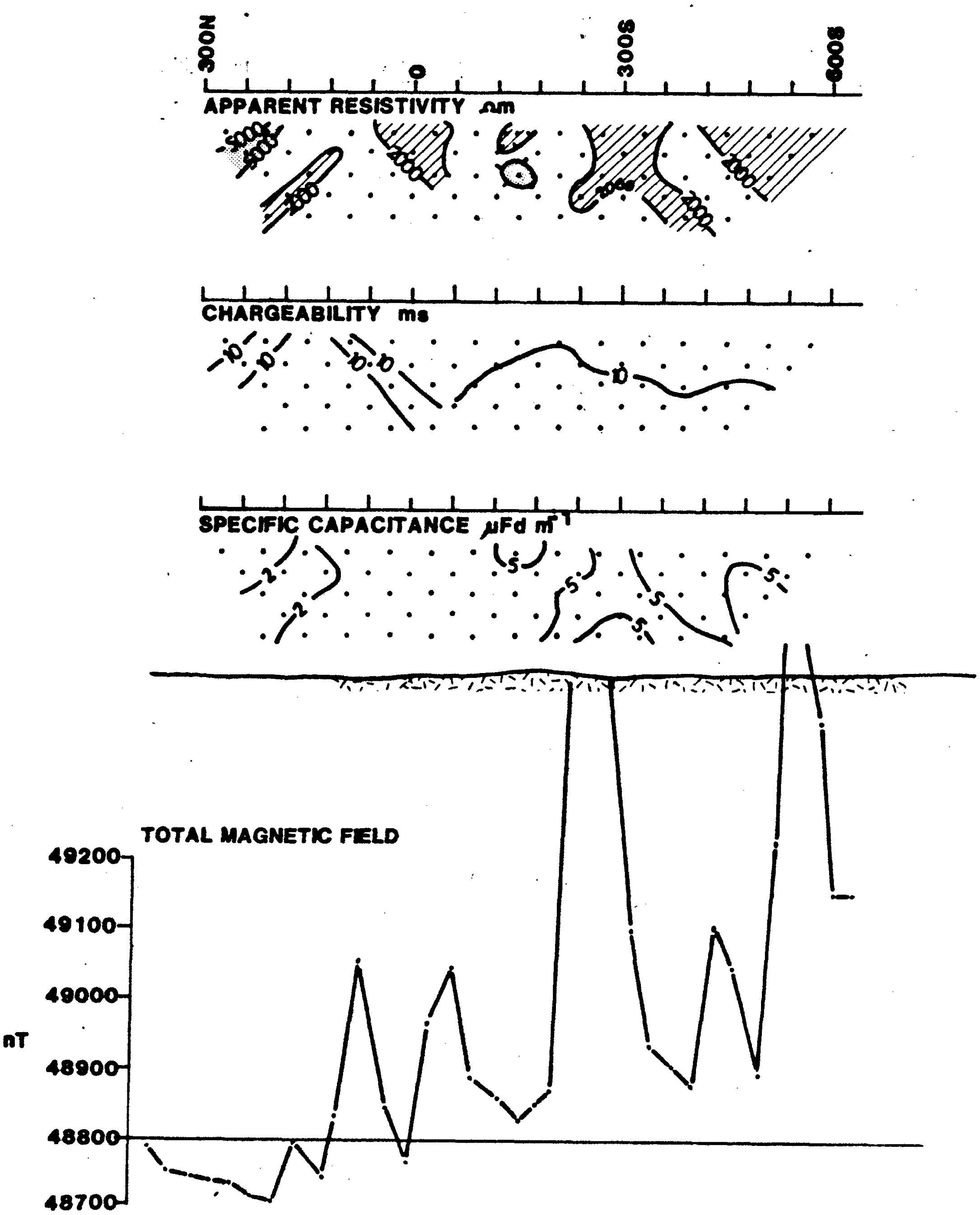


FIG. A1 CULVENNAN LINE 00

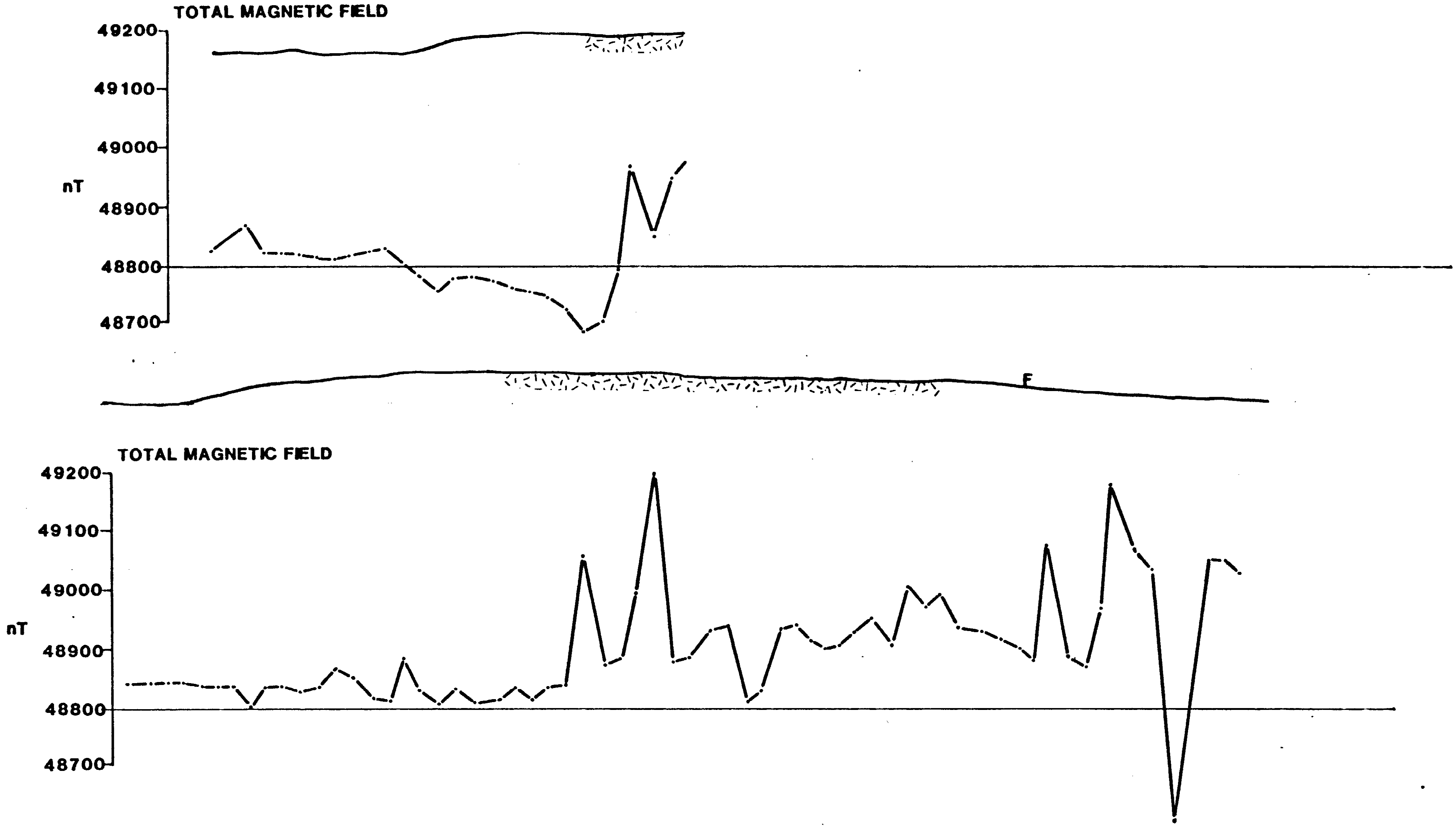


FIG A2 CULVENNAN LINES 300W & 900W

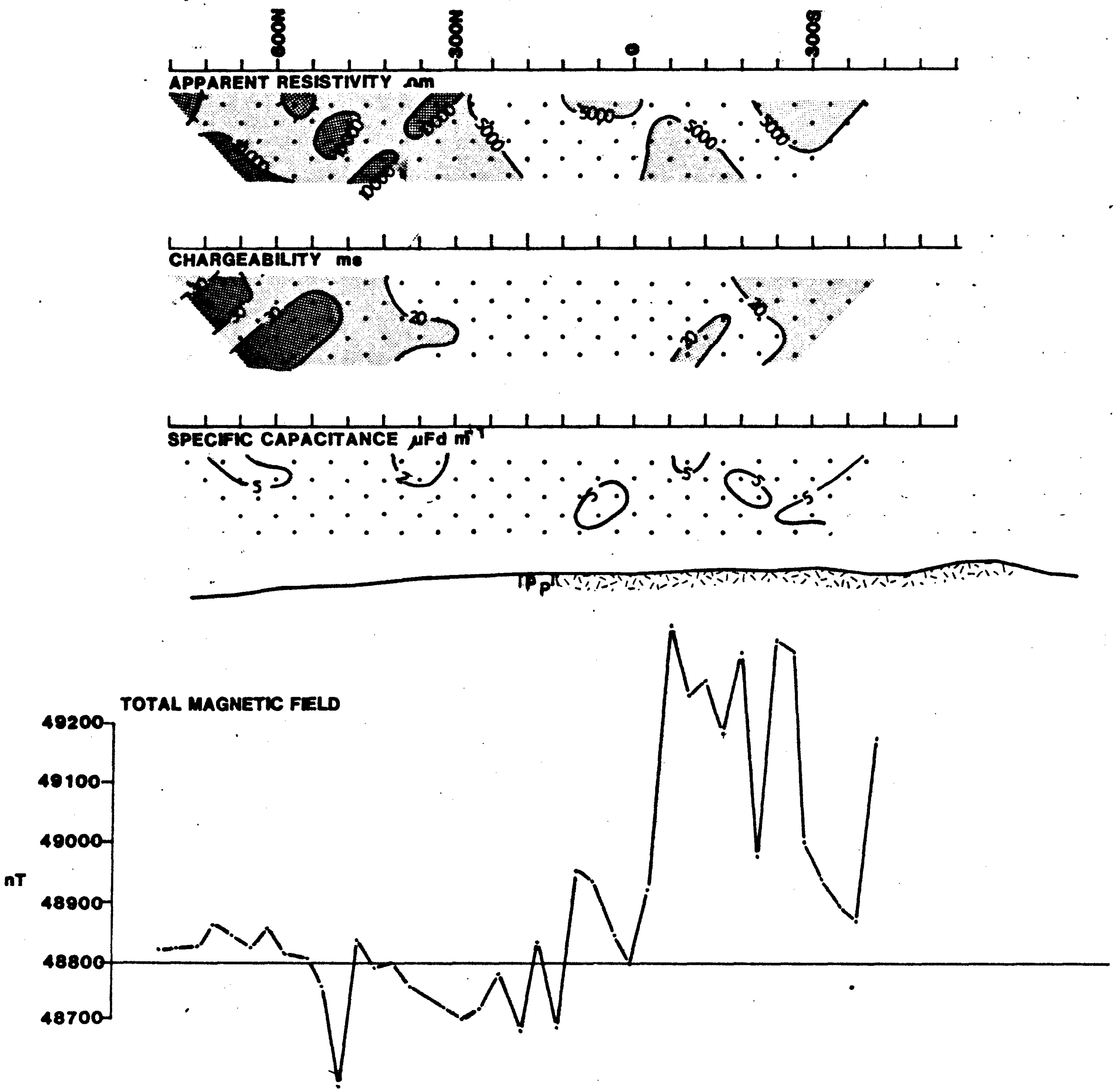


FIG A3 CULVENNAN LINE 600W

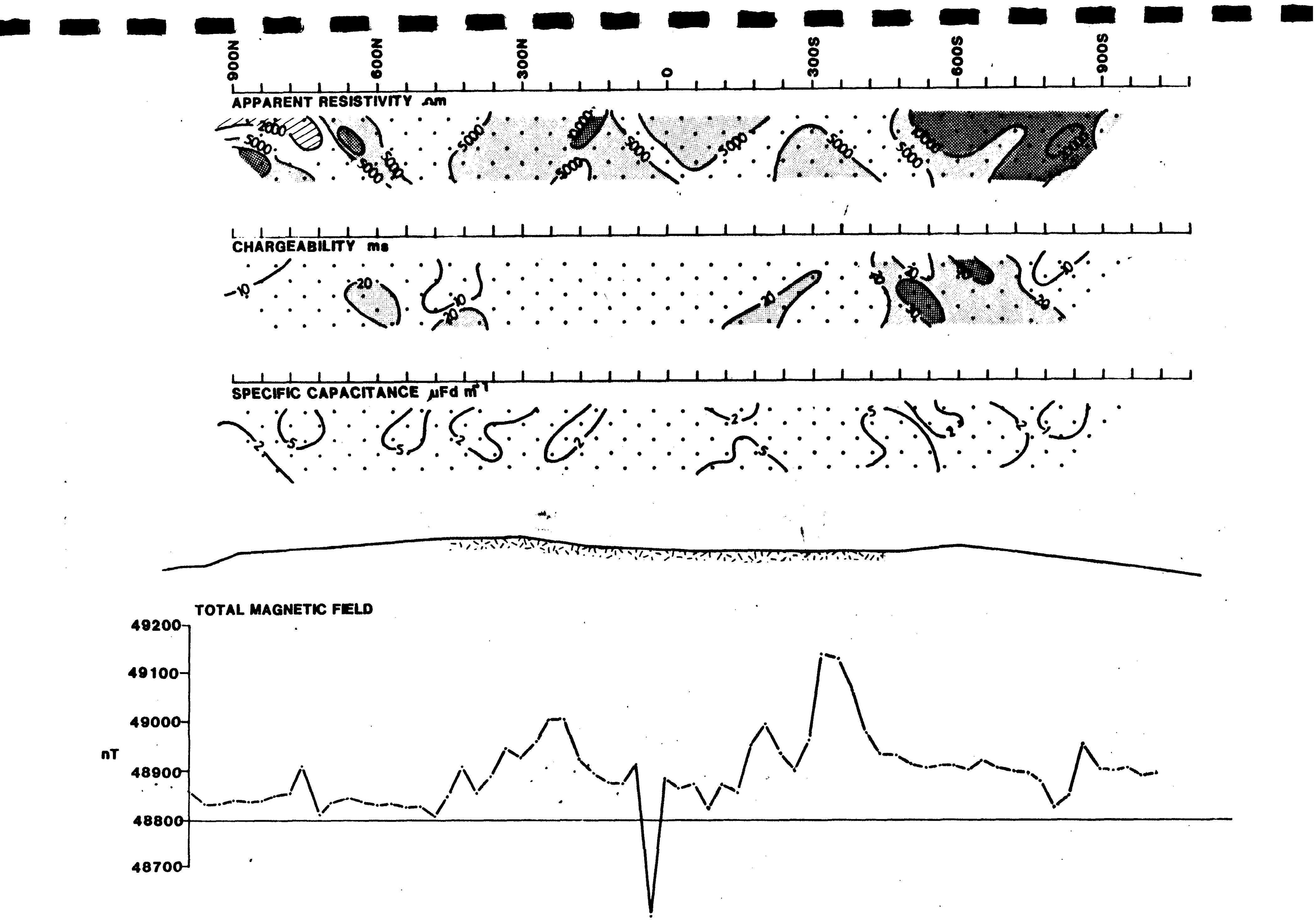


FIG A4 CULVENNAN LINE 1200W

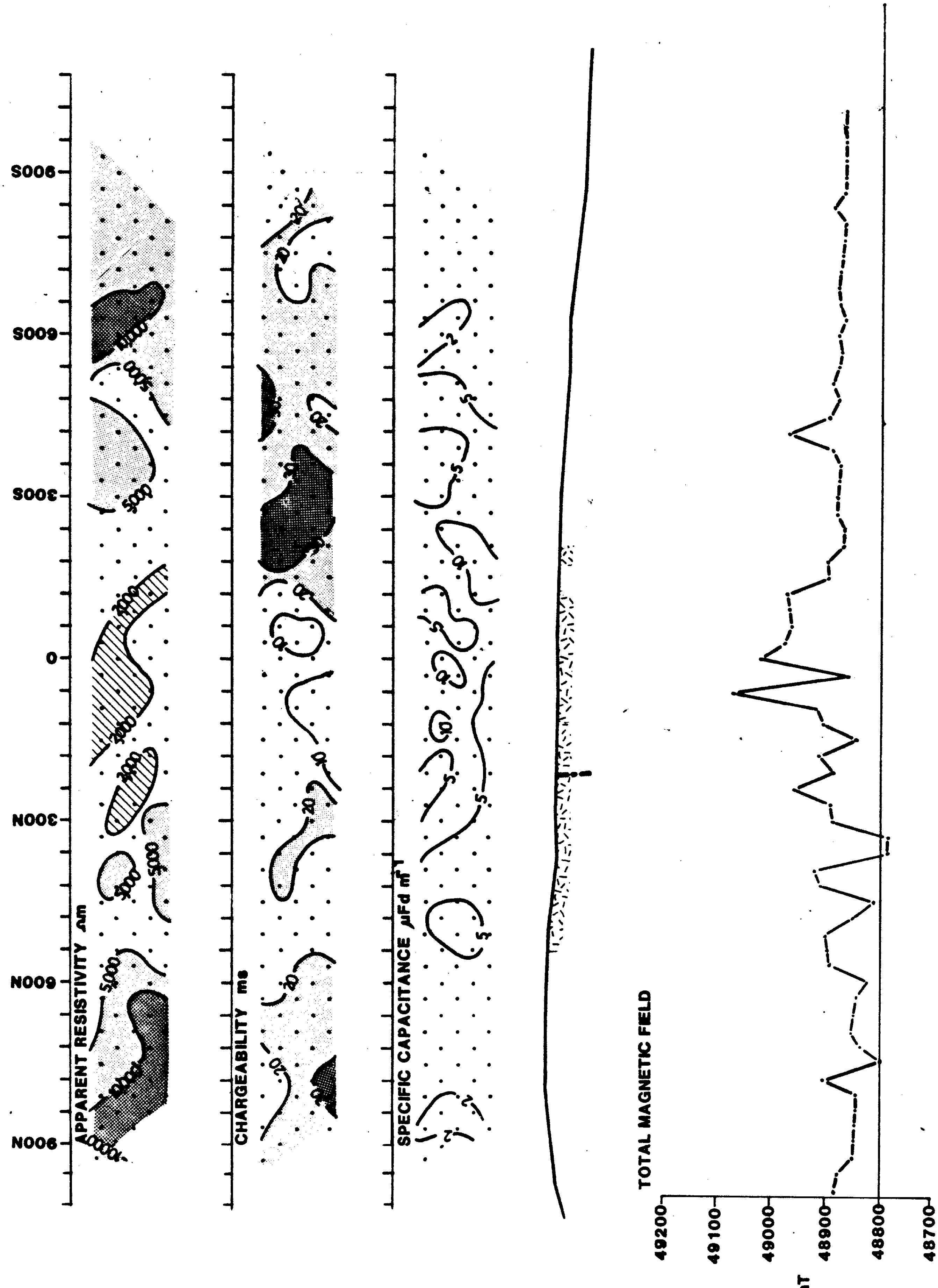


FIG A5 CULVENNAN LINE 1500W

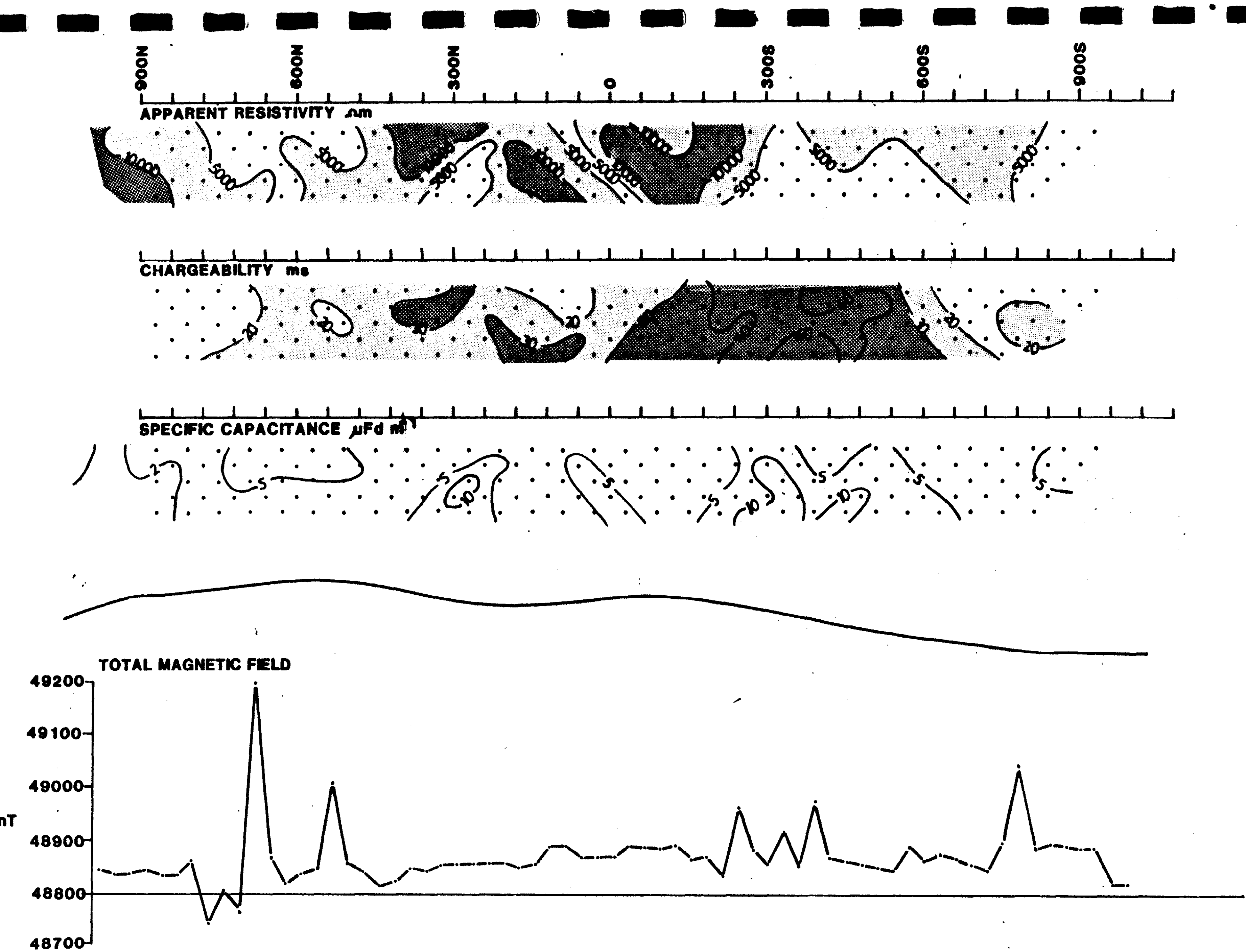


FIG A6 CULVENNAN LINE 1800W

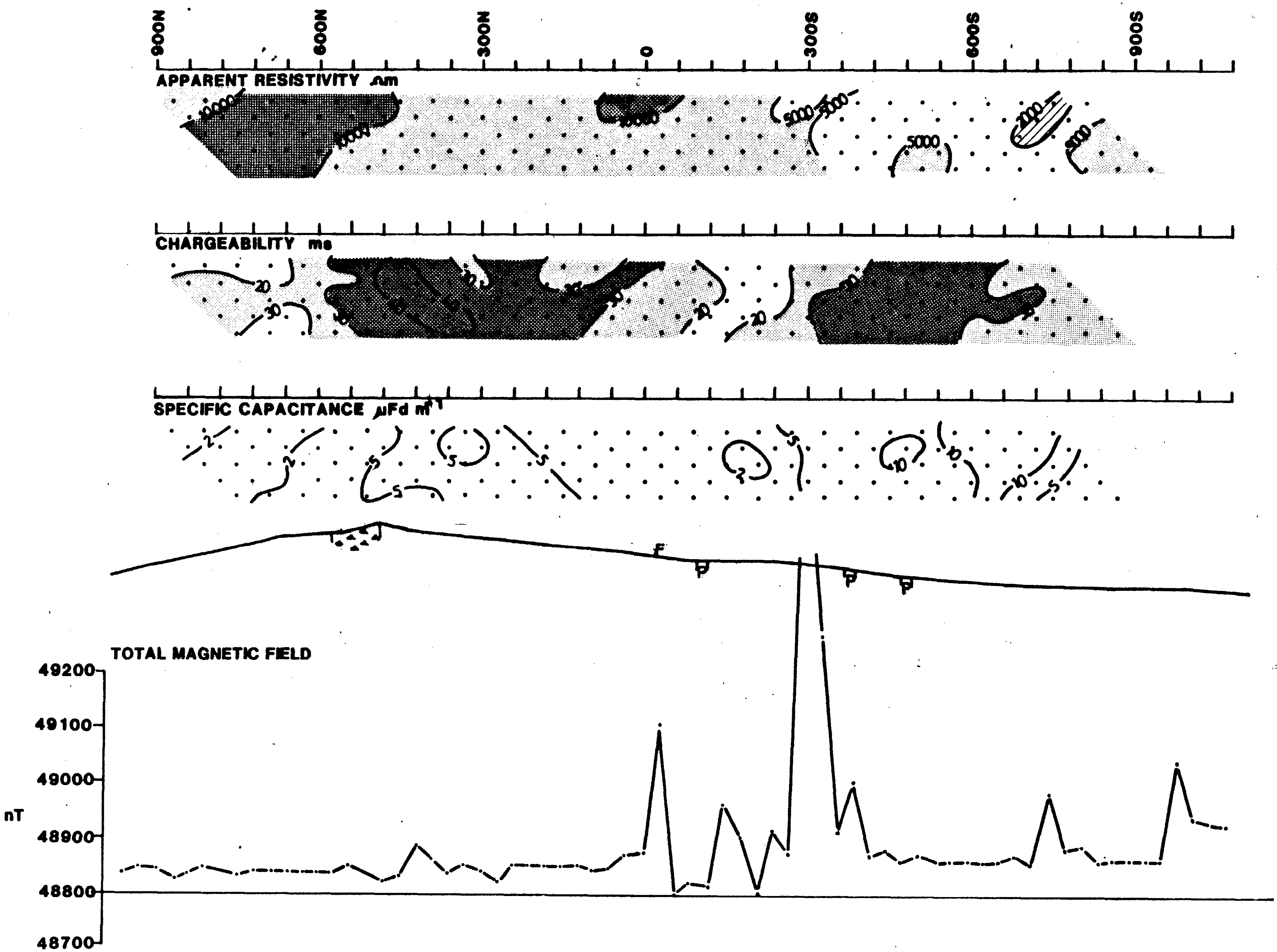


FIG A7 CULVENNAN LINE 2100W

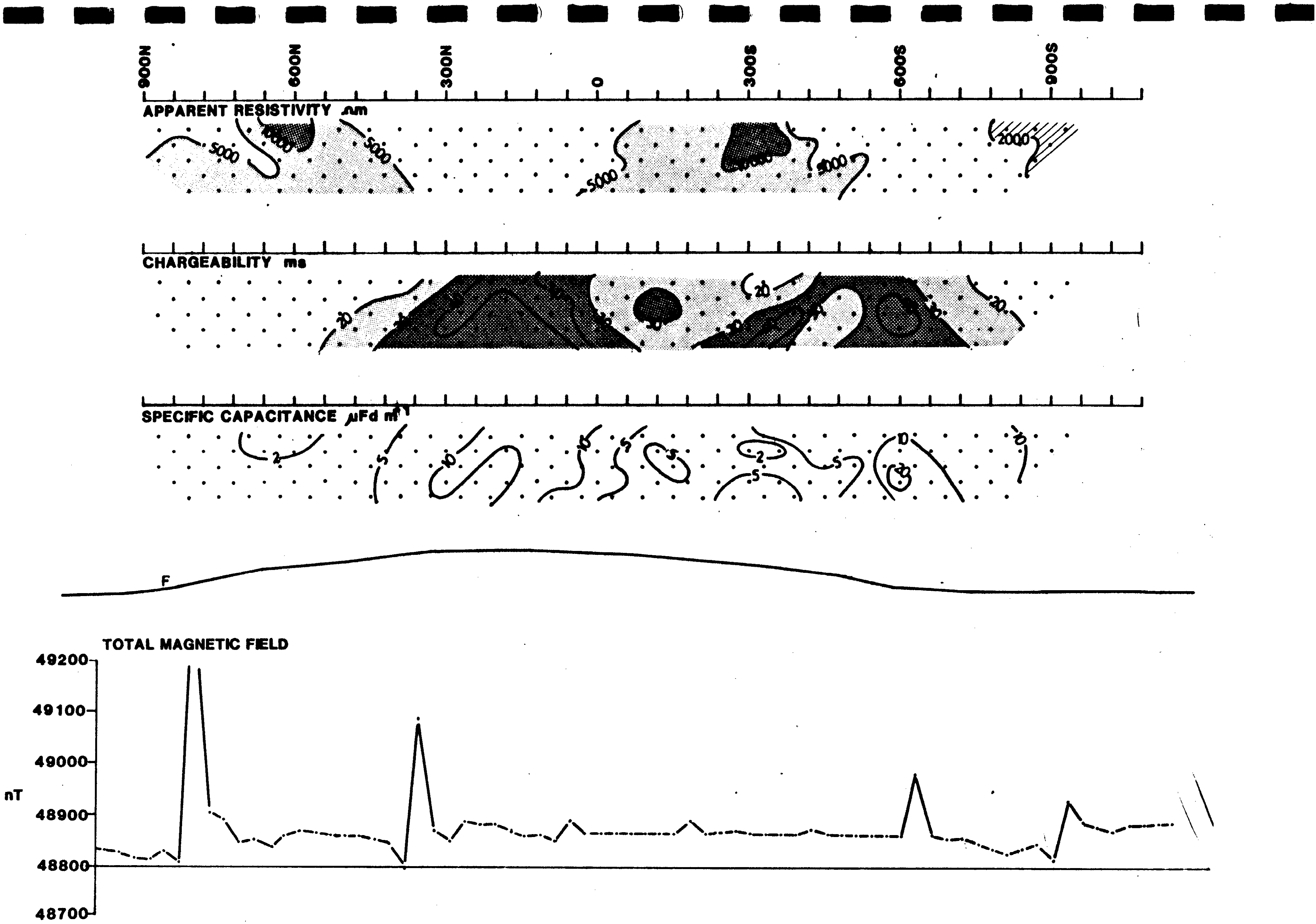


FIG A8 CULVENNAN LINE 2400W

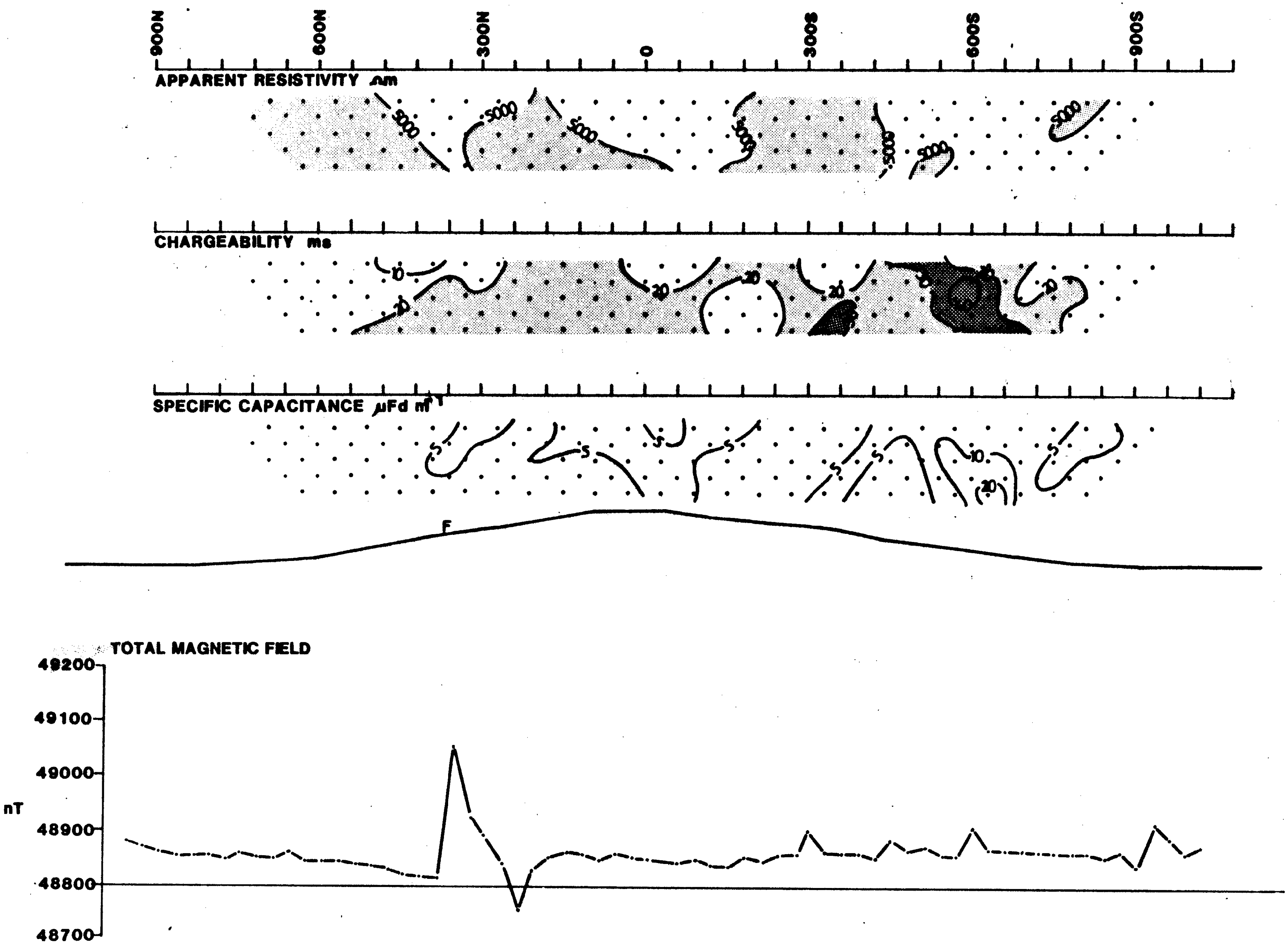


FIG A9 CULVENNAN LINE 2700W

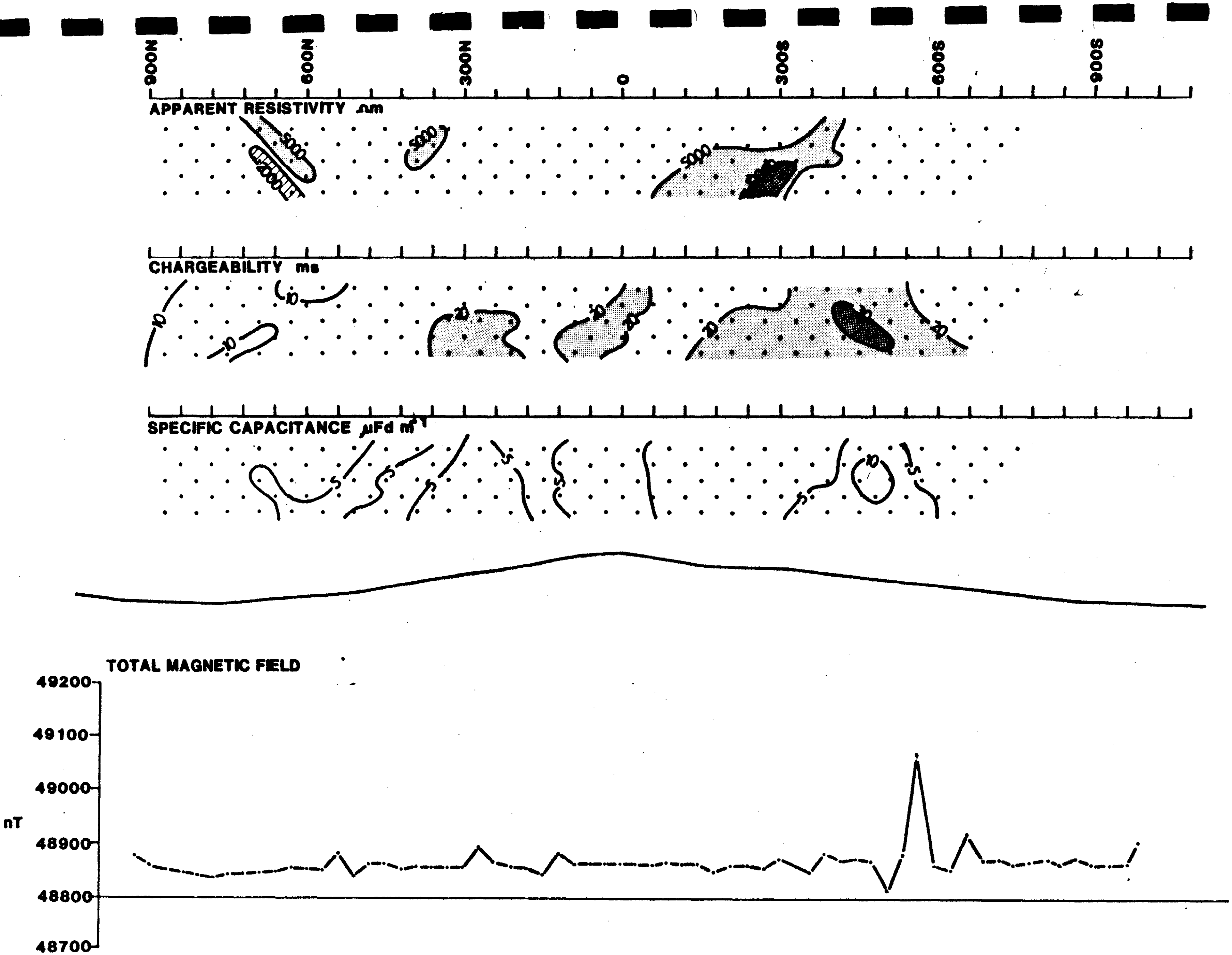


FIG A10 CULVENNAN LINE 3000W

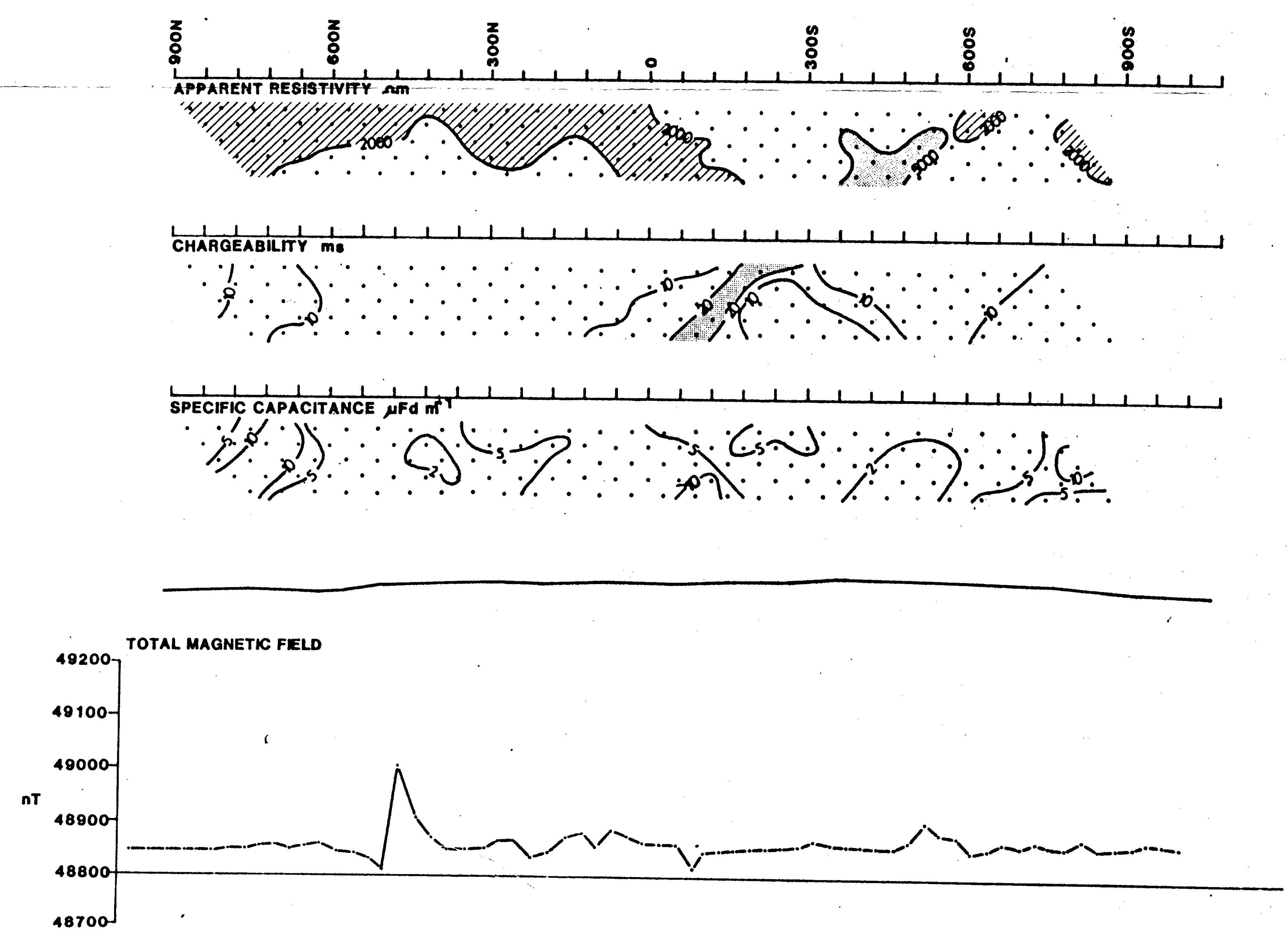


FIG A11 CULVENNAN LINE 3780W

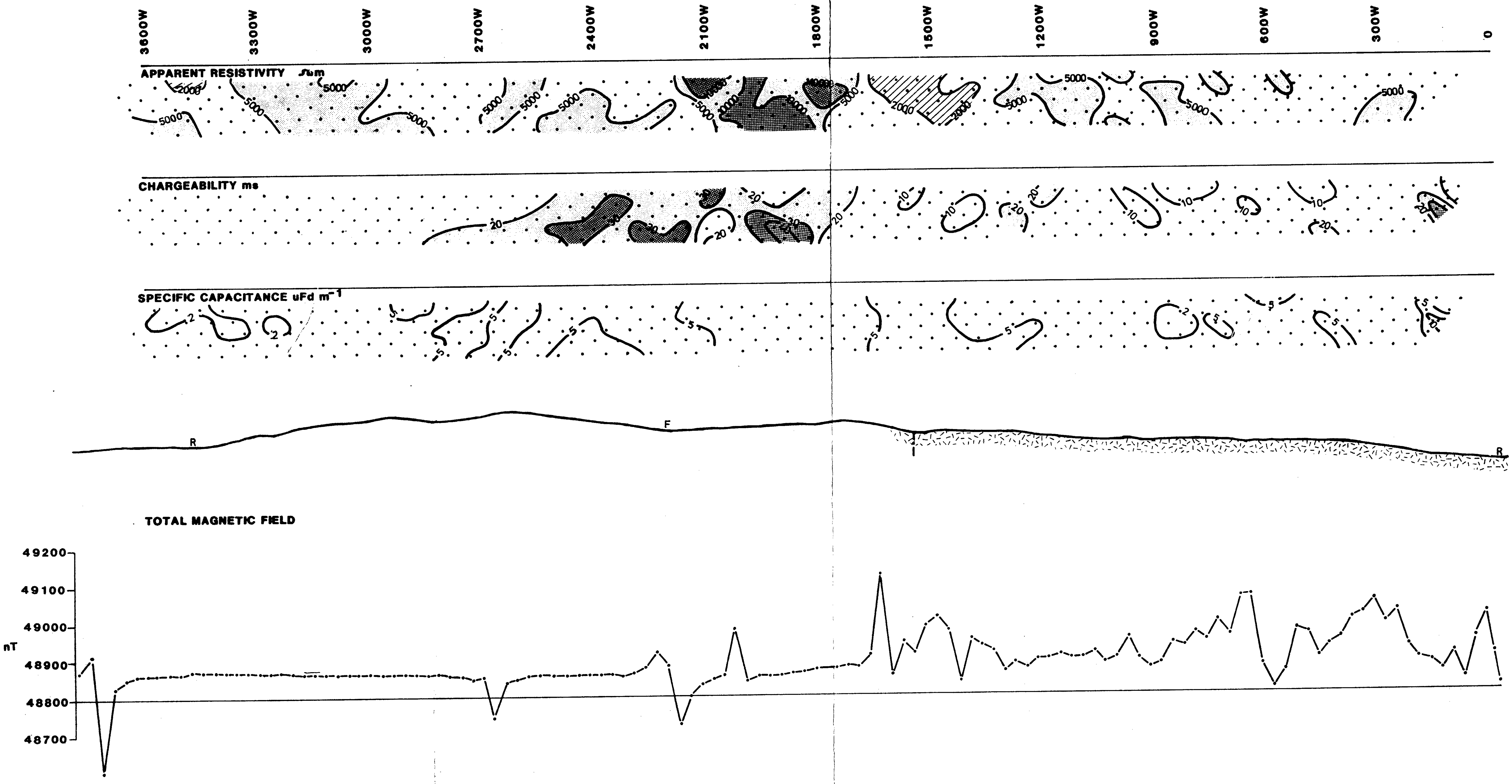


FIG A12 CULVENNAN BASELINE