Natural Environment Research Council

Institute of Geological Sciences

Mineral Reconnaissance Programme Report

A report prepared for the Department of Industry

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rogramme Manager
nstitute of Geological Sciences
eyworth,
lottingham NG12 5GG

No. 35

Geophysical investigation of chromite-bearing ultrabasic rocks in the Baltasound-Hagdale area, Unst, Shetland Islands

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Geophysical investigation of chromite-bearing ultrabasic rocks in the Baltasound–Hagdale area, Unst, Shetland Islands

Geophysics
C. E. Johnson, MSc

Geology
C. G. Smith, PhD

Mineralogy
N. J. Fortey, PhD

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A report prepared for the Department of Industry

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35 Geophysical investigation of chromite-bearing ultrabasic rocks in the Baltasound–Hagdale area, Unst, Shetland Islands

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ILLUSTRATIONS

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SUMMARY

Economic deposits of chromite were discovered in Unst, Shetland Islands in the early part of the nineteenth century and extraction continued intermittently until exhaustion of the known near-surface deposits in 1945. Since it is likely that further comparable deposits exist at shallow depth, detailed geophysical surveys employing magnetic and electrical methods were carried out over 1 km^2 of the area of known mineralisation to test the feasability of detecting and delineating them. Seven of 16 small positive gravity anomalies were tested by shallow boreholes but only two were attributed to chromite concentrations. The gravity anomalies at the other borehole sites remain unexplained; they may be due to unidentified variations in bedrock density at depth; they may be related to variation in the degree of weathering and the thickness of the weathered zone, or to variatons in overburden thickness.

INTRODUCTION

History of investigation

Production of chromite in Unst commenced in 1820, some three years after its initial discovery by Dr S Hibbert (Sandison, 1948), and over the ensuing 125 years fluctuated in response to changes in world prices and the availability of labour. Initially only surface eluvial material was gathered but in 1824 the first quarry was opened in bedrock. Output gradually increased to a maximum of over 1500 tons per annum in the early 1840's (Rivington, 1953) but there was then a brief decline in production, reflecting the industry's inability to compete with fishing as the principal employer of local labour. The 1840's peak was regained briefly in 1871, but by then the market price, as a result of foreign competition, was dropping sharply and all quarrying ceased in 1877. Few details of ore grade are available for pre-1877 workings, but it is probable that the best or 'firsts' contained about 37% Cr_2O_3.

Quarrying recommenced in 1908, partly because herring fishing was in the doldrums, and by 1927, when production again ceased, 6081 tons had been shipped to the mainland. The main reason for curtailment of production was the lack of amenability of the ore to upgrading to the level of 45% Cr_2O_3 required by the chemical industry, then the sole purchaser. In addition, the shipping slump of 1921 greatly reduced the price of imported ores. However, in 1937 research in the field of refractories identified a potential market for low-grade ores and in the ensuing 7 years 4163 tons of ore, with as little as 20% Cr_2O_3, were shipped south. Unsafe workings and the exhaustion of near-surface deposits were principally responsible for the cessation of shipment in 1945. Finally, in the early 1950's a number of shallow inclined boreholes were drilled on behalf of the United Steel Company to test strike extensions of the worked out bodies, but these established no economic ore bodies.

Prospects for a further revival of the industry then lay in the exploitation of previously undiscovered sub-surface bodies, which could in theory, be delineated by geophysical methods. Magnetometric prospecting for chromite in Unst was first attempted in the 1930's, and although the exercise was deemed unsuccessful at the time, it was subsequently suggested by Rivington (1953) that the results might have been incorrectly interpreted. As part of the United Steel Company's investigation, an electrical resistivity anomaly was drilled but no chromite was intersected. Finally, in 1975, magnetic VLF and geochemical surveys were undertaken over an area partly overlapping that of the investigation reported herein (Brzozowski, 1977). Anomalous geochemical values for Cr, Al, Ni and Co in soil and vegetations could be attributed to contamination.

Location and geographical setting

Unst (Fig. 1) is the most northerly of the Shetland Islands, lying about 240 km north-east of the Scottish mainland and 320km west of Bergen in Norway. The village of Baltasound lies on the north side of the prominent inlet of Baltasound midway along the east coast. The area investigated (Fig. 2) lies to the north of the village between 30 and 130 m OD on the southern flank of the ridge formed by Nikka Vord, Muckle Heog and Little Heog. The ridge rises to over 130 m and has a pronounced concave profile on its southern side. Drainage is primarily by southern flowing streams, but in times of high precipitation the absence of thick drift and the impermeable bedrock generate a certain amount of sheetwash. Bedrock exposure over the area is extremely good and some depth is provided by the many abandoned quarries, although in most cases acess is limited by steep sides and flooding.

The area is reached by a track running west from the A968 Belmont-Haroldwick road at Hagdale. Port facilities are available at Baltasound, the main outlet for talc from the quarry on the north side of Nikka Vord. There is a regular car ferry service linking Unst with the neighbouring island of Yell and the mainland of Shetland.

General geology

Unst is covered by the one inch geological special sheet for Northern Shetland and, although there is no descriptive memoir, the geology has been summarised by Mykura (1976). Through the works of Phillips (1927), Read (1934a, b, c, 1936) and Flinn (1958, 1959 and 1970) Unst is geologically the best known of the Shetland Islands. The island consists almost entirely of igneous and sedimentary rocks deformed and metamorphosed during the Caledonian orogeny. Two major divisions may be recognised: the Basement (including, for the purposes of this report, the Saxa Vord Block) and the Nappe Pile (see Fig. 1).

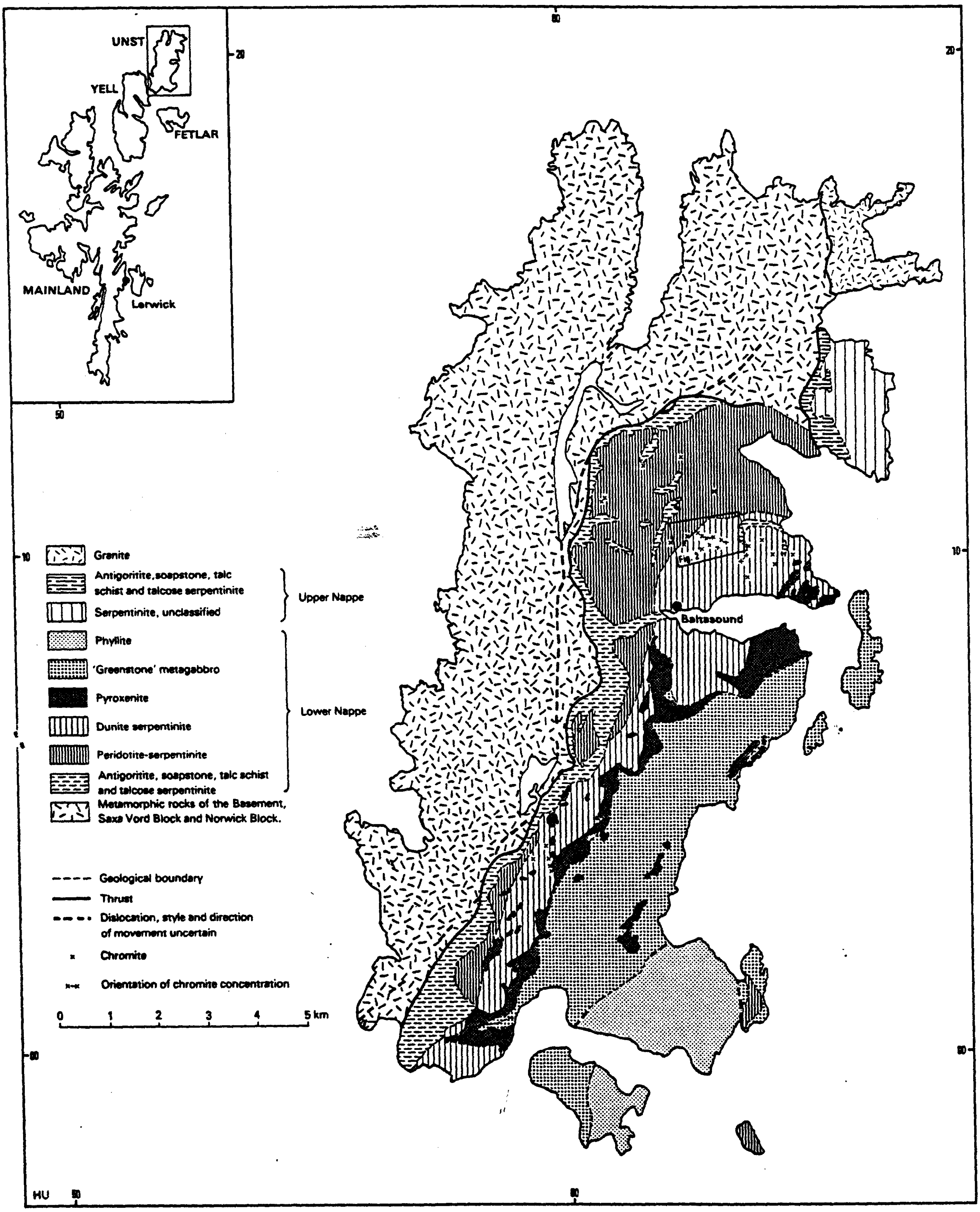

Fig 1 Unst: Geology and location of survey area.

The Basement occupies the entire western and much of the northern part of the island and comprises paraschists and gneisses which have been correlated with lithologically similar rocks of Precambrian and Cambrian age on the Mainland of Shetland. Three metamorphic events have been recognised in these rocks; the first, which preceeded the emplacement of the Nappe Pile, was prograde whereas the second and third were retrograde.

The Nappe Pile consists of two main blocks separated from each other and from the Basement by major shear or "schuppen" zones. The Lower Nappe (or main serpentine and greenstone block) has an easterly tilt and consists of metamorphosed ultrabasic and basic rocks. The ultrabasic portion, presumably as a result of in situ differentiation, contains three compositional zones (Amin, 1954) which, from west to east (or in ascending order) are peridotite serpentinite, dunite serpentinite and pyroxenite. The basic portion (greenstone) is thought to have been intruded later. The Upper Nappe comprises peridotite serpentinite. Both Nappes are considered to be parts of the same ultrabasic mass transported to the west and thrust over the Basement. Some erosion of the Lower Nappe occurred after emplacement, but before it was overridden by the Upper Nappe, and the resultant sediments underwent two period of prograde metamorphism which have been correlated with the second and third events in the Basement.

Massive chromite has been observed only in the dunite serpentinite layer and in dunite lenses in the peridotite serpentinite and is thus restricted to the Lower Nappe. It occurs as streaks and pods elongated along planes parallel to the zoning (podiform chromite). The chromite is almost certainly the product of magmatic segregation and, since the zoning is now subvertical, it is reasonable to conclude that further chromite lenses are present at depth.

The form of the deposits dictated that they were worked by small quarries which seldom exceeded the following dimensions; length 80 m, width 30 m, depth 40 m. Upwards of 20 quarries have been recorded, over half of which occur in the Baltasound-Hagdale area.

SCOPE OF THE PRESENT SURVEY

The main object of the present survey was to ascertain whether, in an area of known chromite mineralisation, it was possible to detect concealed concentrations by geophysical methods. The first phase was to establish the presence of geophysical anomalies and the second to evaluate their significance by shallow drilling.

Gravity, magnetic and induced polarisation (IP) surveys were carried out by A.J.Burley, M.E.Parker and C.E.Johnson in 1976 and the last-named returned in 1977 to define in more detail the most promising of the gravity anomalies by further gravity, magnetic and VLF surveys. The 1976 magnetic and VLF surveys were also extended eastwards during 1977.

Seven boreholes of rod-length between 15 and 38 m were subsequently sited on positive gravity anomalies defined by the 1977 survey and drilled by the Encore Drilling Company using Diamec 250 equipment (see Apendix I). After geological logging the entire core was analysed semi-quantitatively for chromium using a portable radioisotope X-ray fluorescence analyser (the Mineral Analyser). Cores containing fine grained native copper were also analysed for copper. Six lengths of core were split and analysed in the laboratory by XRF methods in order to calibrate the readings obtained by the portable analyser. A further 10 samples of split core, representative of most of the observable lithological variations, were selected for mineralogical and petrological examination. Density measurements were undertaken on 21 core samples.

GEOPHYSICS

Gravity surveys

The theoretical limits for the detection of chromite ore bodies by gravity surveys have been discussed by Bosum (1963), Hammer (1945) and Davies and others (1957). The ore bodies which have been worked on Unst are mostly podiform but in the analysis of their gravitational effect, outlined in Appendix I, they are assumed to be spherical to simplify the mathematical treatment.

In 1976, 800 gravity stations were established using a LaCoste and Romberg gravity meter, over a 30 m x 60 m 'coarse' grid situated 360 m north of the main Baltasound-Haroldswick road. The longer axis of the rectangular grid is parallel to the road and the origin is on the road at National Grid Reference HP 6143 0923. One section of this area (Fig. 4) was covered by a 15 m x 30 m 'fine' grid to detail a relatively large residual positive anomaly. About 150 more widely-spaced stations were established within 1 km of the 'coarse-grid' boundary. A Bouguer anomaly map was produced (Fig. 5), and a regional field determined by smoothing N-S profiles (Fig. 6) and smoothing the resulting contour map (Fig. 7). Residual anomaly maps for the 'coarse' and 'fine' grid surveys were then calculated (Figs. 8 and 9) and 16 positive residual anomalies each exceeding 0.07 mGal, were identified and numbered in order of significance.

In 1977 1500 gravity stations were established using LaCoste and Worden gravity meters, over 13 N-S traverses of length 240-540 m and station spacing 2.0 or 2.5 m. The traverses (Fig. 10) were positioned in order to cover those 13 of the positive anomalies identified in 1976 which were relatively free from terrain effects due to quarries and tips. All Bouguer anomaly profiles are shown in Appendix II. Sixteen positive anomalies (Table 3) were selected as being significant after repeated gravity traverses. Parallel traverses 10 m either side of

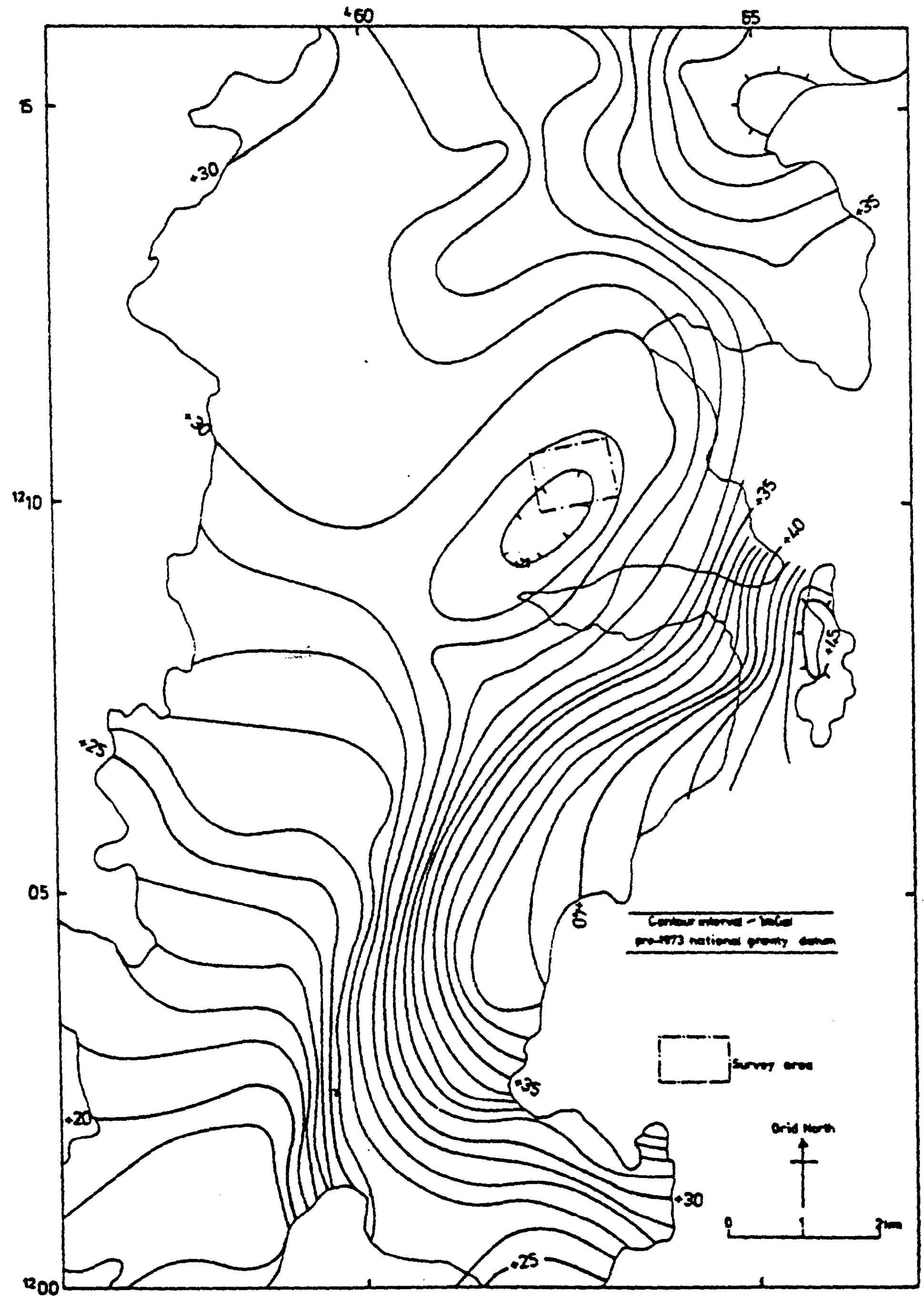

Fig. 3 Regional Bouguer anomaly map of Unst (after McQuillin and Brooks, 1967)

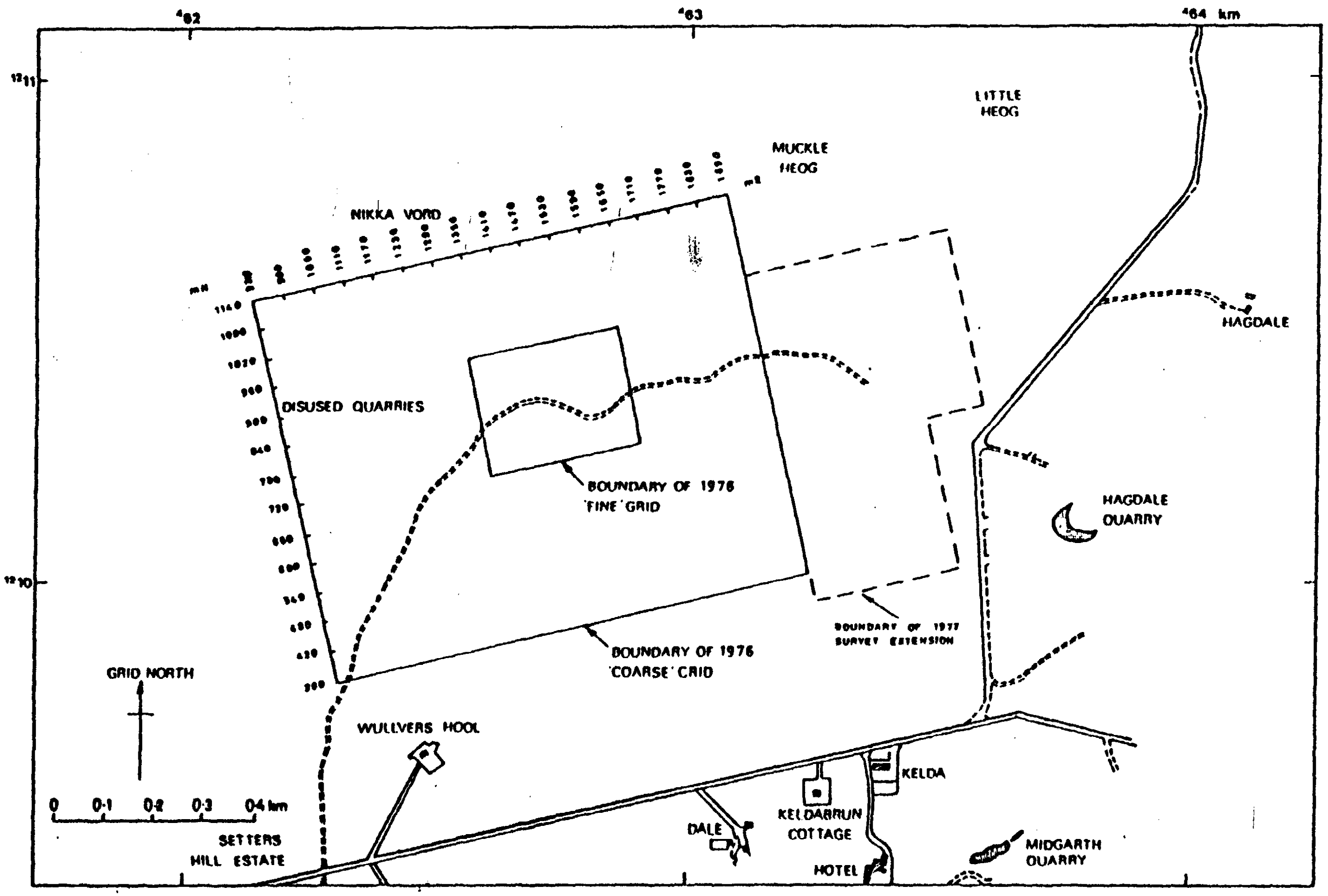

Fig. 4 Location of geophysical surveys.

anomalies 882 N and 784/802 N on lines 1680 E and 1800 E respectively showed similar positive anomalies along strike, of slightly smaller magnitude and less well-defined shape.

Reduction of gravity data

Temporary gravity base stations set up at Seaview [HP 6213 0889] in 1976 and Hamarsgarth [HP 6379 1233] in 1977 were linked to the base at Baltasound (McQuillin & Brooks 1967) and converted to the NGRN 73 system. Base readings taken at least twice per day showed an average instrumental drift of about 0.03 mGal per day. When possible the instrument was read to half a scale division (0.005 mGal).

Elevations were calculated initially by levelling from and to a bench mark at the start and finish of a loop. Subsequently stations of known elevation were used to tie in heights within the survey area. Elevation misclosures over the initial grids were less than 7 cm (equivalent to 0.014 mGal), and over the detailed traverses less than 3 cm (equivalent to 0.006 mGal).

Gravity readings were corrected for an assumed linear instrumental drift, gravity tides, normal gravity, elevation, and terrain (Hammer zones A-H). The data were reduced to sea level (i.e. Bouguer anomalies) using a density of 2.63 g cm^{-3} for the elevation correction. (Tables 1 and 2). For the 1976 grid surveys, the accuracy of individual Bouguer anomaly values is considered to be $\pm$0.02 mGal; for 1977 traverses the relative accuracy along any one traverse should be within 0.01 mGal, this being determined almost entirely by the reading accuracy of the instrument.

Problems were encountered due to the small size of the anomalies measured (0.05 to 0.1 mGal). Small 'jumps' in reading (0.02 to 0.05 mGal and easily identified from the plotted data) were common and found to be

Table 1 Physical properties of Unst rocks and minerals

Type of Rock	No. of Samples	Saturated density ($g\ cm^{-3}$)	Magnetic Susceptibility ($cgs \times 10^{-6}$)	Resistivity (Ωm)		Source
				Dry	Saturated	
Serpentinite	-	2.4 - 3.1	250 - 1400			Telford *et al.*, 1976
Chromite	-	4.6 - 4.3	240 - 9400	$1 - 10^6$		
Greenstone	5	2.88 ± 0.05				McQuillin and Brooks, 1967
Granulite gneiss	4	2.78 ± 0.03				
Pyroxenite	2	2.44 ± 0.04				
Serpentinite	20	2.63 ± 0.04				
Serpentinite	1	2.59	3020	2700	2000	Institute of Geological Sciences 1976 and 1977
	1	2.66	440	72.3×10^6	1000	
	1	2.64				
	1	2.51				
Disseminated chromite	1	2.80				
	1	2.82	160	28,600	156	
Massive chromite ore	1	3.73	710	72.8×10^6	1600	
	1	3.92	160	46,700	170	
	1	3.46				

Table 2 Physical properties of Unst core samples

Borehole	Sample depth (m)	Rock type	Saturated density (gcm^{-3})	Porosity (%)	Magnetic Susceptibility (cgs x 10^{-6})
1	0.48- 0.65	Dunite-serpentinite	2.59	4.1	1780
	8.00- 8.14	" "	2.63	0.4	2650
	12.65-12.76	Altered serpentinite	2.50	4.0	1960
	18.02-18.11	Dunite-serpentinite	2.65	0.3	1400
2	3.61- 3.72	Altered serpentinite	2.55	4.1	3220
	8.53- 8.68	Dunite-serpentinite	2.61	1.2	7520
	17.65-17.85	" "	2.62	0.5	2960
3	6.02- 6.20	" "	2.59	0.6	2800
	21.58-21.62	Altered serpentinite	2.51	6.3	1520
	37.13-37.33	Dunite-serpentinite	2.67	0.8	4090
4	8.17- 8.40	" "	2.65	0.6	540
	14.26-14.47	" "	2.64	0.6	560
5	1.72- 1.94	Altered serpentinite	2.54	1.5	460
	12.21-12.54	Dunite serpentinite	2.62	0.5	1380
6	0.50-0.65	Partly altered dunite serpentinite	2.61	0.5	1410
	1.67- 1.80	Disseminated chromite	3.05	1.0	800
	2.23- 2.38	" "	2.92	1.1	750
	9.70- 9.85	Serpentinite with disseminated chromite	2.75	0.7	2080
	14.42-14.60	Serpentinite with disseminated chromite	2.77	1.4	1900
7	3.50- 3.70	Dunite serpentinite with disseminated chromite	2.73	3.9	8400
	19.30-19.50	Dunite serpentinite with disseminated chromite	2.78	1.1	7730

Table 3 Summary of positive gravity anomalies in 1977 Survey and their possible causes

Line (mE)	Northing (mN)	Amplitude of anomaly (.01 mGal units)	Half-width (m)	Minimum density ($g\ cm^{-3}$) contrast	Change in overburden thickness needed to cause anomaly (m)	Mass of orebody needed to cause anomaly (metric tons)	Depth to centre of sphere (m)	Radius of sphere (m)	Topography	Magnetic anomaly	Resistivity anomaly	Exposure present	Borehole No.	Borehole Northing (mN)
960	564	6	9	0.1	2.9	3500	11.7	5.9	F		+	No	7	564
960	594	4	8	0.07	1.9	1800	10.4	4.8	F	(centre 580)	+	No	6	596
1050	864	4.5	5	0.14	2.2	810	6.5	3.6	F	+ −		No		
1380	583	3	3.5	0.13	1.4	270	4.5	2.5	U		+	Yes		
1380	597	3.5	4	0.12	1.7	400	5.2	2.9	U	+	+	Yes		
1380	630	4	8	0.08	1.9	1800	10.4	4.8	U	−	+	Yes	5	632
1470	1012	6.5	4.5	0.22	3.1	940	5.8	3.8	U		+	Yes	4	1014
1680	791	8	14	0.09	3.8	11300	18.2	8.8	D	+	+	Yes	3	798
1680	882	8	13	0.09	3.8	9800	16.9	8.3		+	+	Yes		
1800	784	8	7	0.17	3.8	2800	9.0	5.5	D		+	Yes	1	789
1800	802	8	8	0.15	3.8	3700	10.4	6.0	U	(centre 795)		Yes		
1800	842	6	9	0.10	2.9	3500	11.7	5.9	F	+	+	No	2	849
1830	616	45	3.5	0.20	2.2	400	4.5	2.9	U	+	+	Yes		
1830	642	5	3.5	0.22	2.4	440	4.5	3.0	D	+	+	Yes		
1830	660	5	7	0.11	2.4	1800	9.0	4.7	D	+	+	Yes		
1830	946	4	8	0.08	1.9	1800	10.4	4.8	D	−	+	Yes		

F flat; U uneven; D definite correlation instrumental, necessitating repeat traverses over all promising positive anomalies to ensure adequate definition.

Interpretation of gravity anomalies

The regional Bouguer anomaly map of Shetland (McQuillin and Brooks, 1967), part of which is shown in Fig. 3, illustrates that the survey area is situated at the centre of a SW-NE-trending elliptical 'low' which reflects low density serpentinite (2.63 g cm^{-3}) bounded to the west by the Valla Field Block gneissic basement (2.76 g cm^{-3}); to the north by the Saxa Vord Block schistose rocks (2.7 g cm^{-3}), and to the southeast by greenstone (2.88 g cm^{-3}). The Bouguer anomaly map of the present survey (Fig. 5) shows the centre of the 'low' at the western boundary of the survey area, and an average gradient of about +1 mGal/km from west to east across the survey area. The difference in Bouguer anomaly values apparent in Figs. 3 and 5 is caused by the change in reference datum from Pendulum House, Cambridge to the modern National Gravity Reference Net 1973 (NGRN 73).

Residual anomaly magnitudes range from -0.08 to +0.16 mGal. Negative anomalies may be caused by: 1) terrain effects of quarries and tips; 2) antigorite and talc schists developed in shear zones; 3) pyroxenite within the dunite; 4) local decrease in density of the dunite; 5) local increase in thickness of the weathered zone, and 6) presence of unconsolidated rubble from disused quarries. Positive anomalies may be caused by: 1) chromite deposits; 2) local increase in density of the dunite, possibly caused by differential serpentinisation; 3) local decrease in thickness of the weathered zone and/or overburden.

The 16 significant positive gravity anomalies from the 1977 profiles are listed in Table 3. Boreholes were sited to investigate 7 of them and were drilled at angles of 60°, 70° or 90° from the horizontal, in a southerly direction such that the holes would intersect the centre of the anomalous, hypothetical, spherical mass. The holes were inclined because of the generally steep northerly dips of the exposed chromite

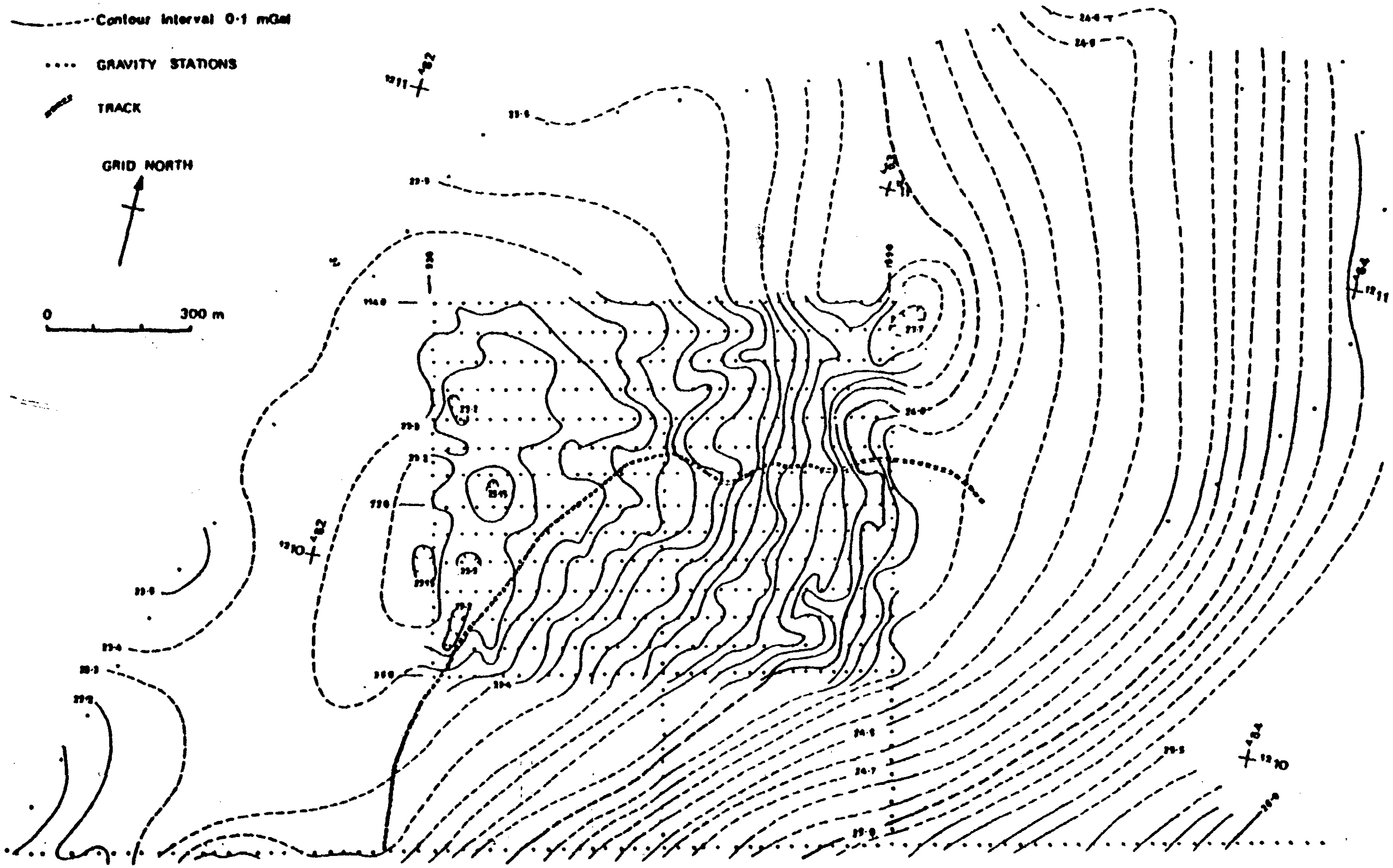

Fig. 5 Bouguer anomaly map based on 1976 surveys.

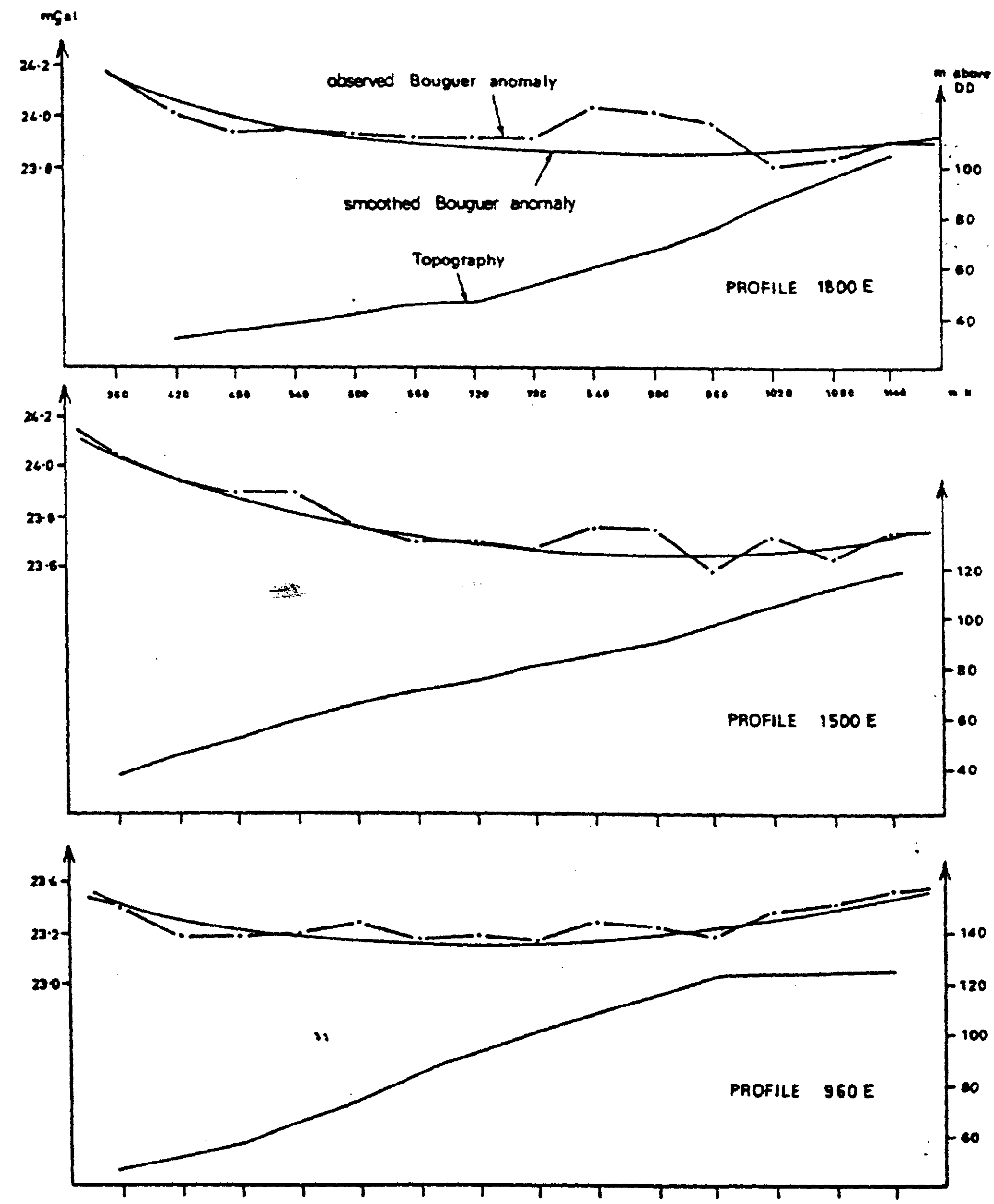

Fig. 6 Bouguer anomaly profiles (1976 survey) with 'smoothed' regional profiles and topography for lines 1800 E, 1500 E and 960 E

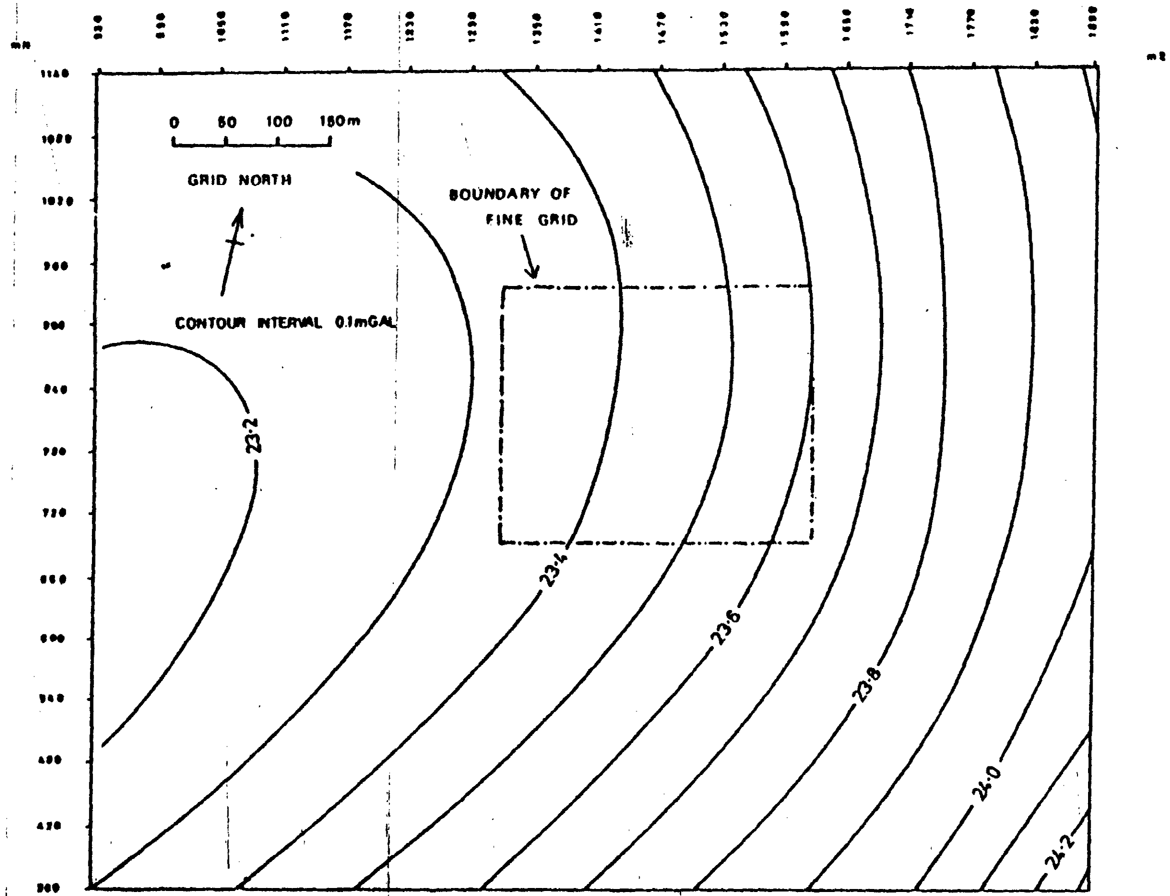

Fig. 7 Smoothed Bouguer anomaly map based on 1978 surveys.

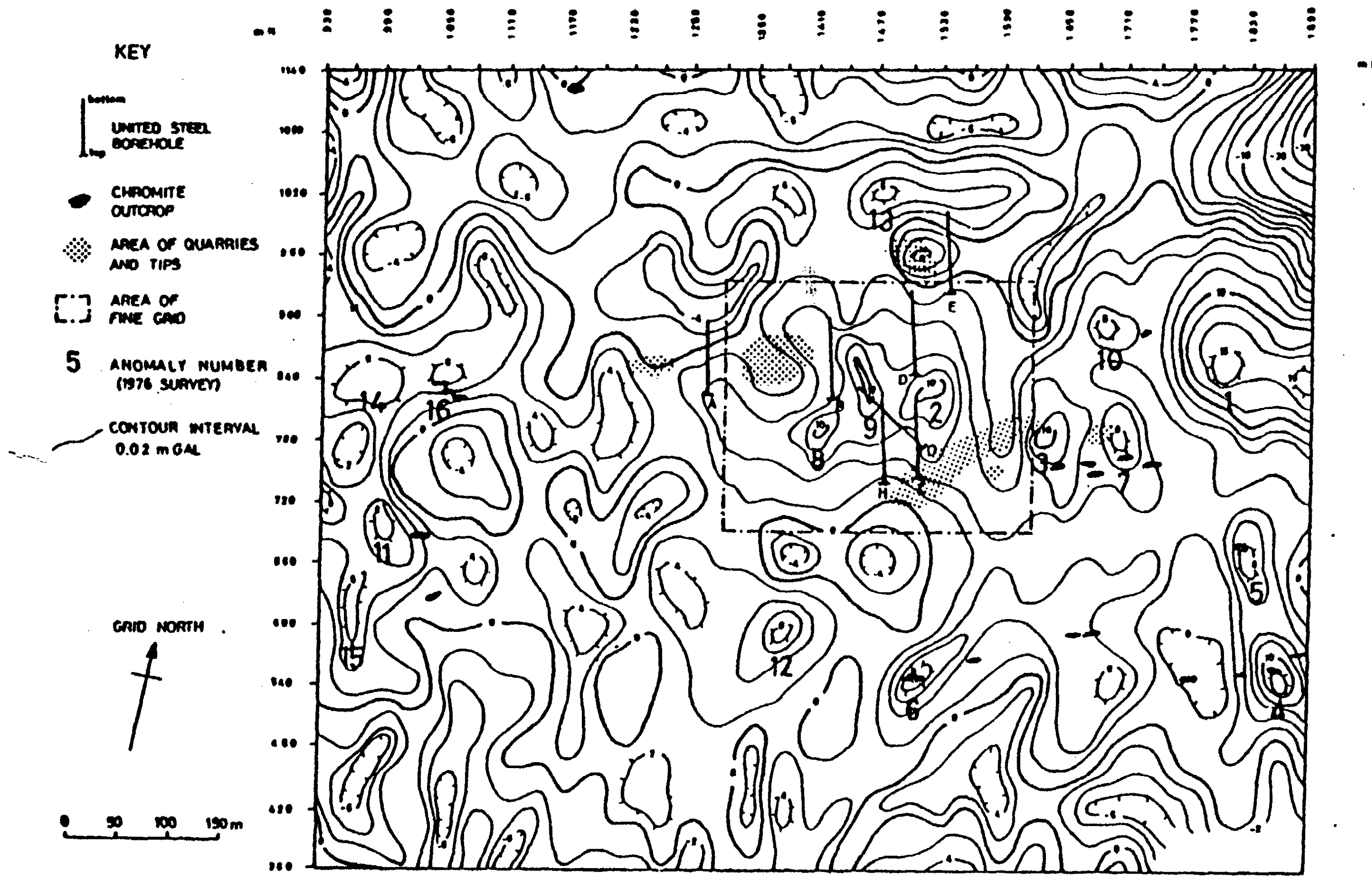

Fig. 8 Coarse grid residual Bouguer anomaly map based on 1976 surveys with the positions of 7 United Steel Co. boreholes

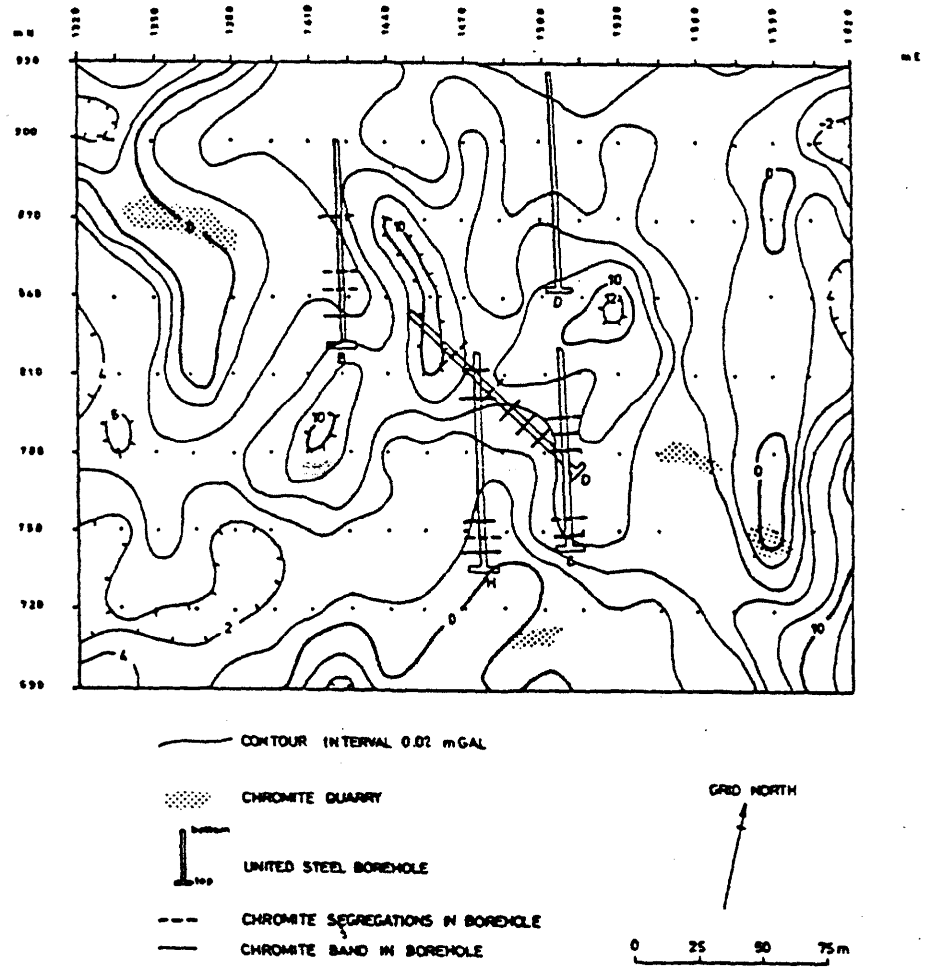

Fig. 9 Fine grid residual Bouguer anomaly map based on 1976 surveys with the positions of 5 United Steel Co. boreholes superimposed

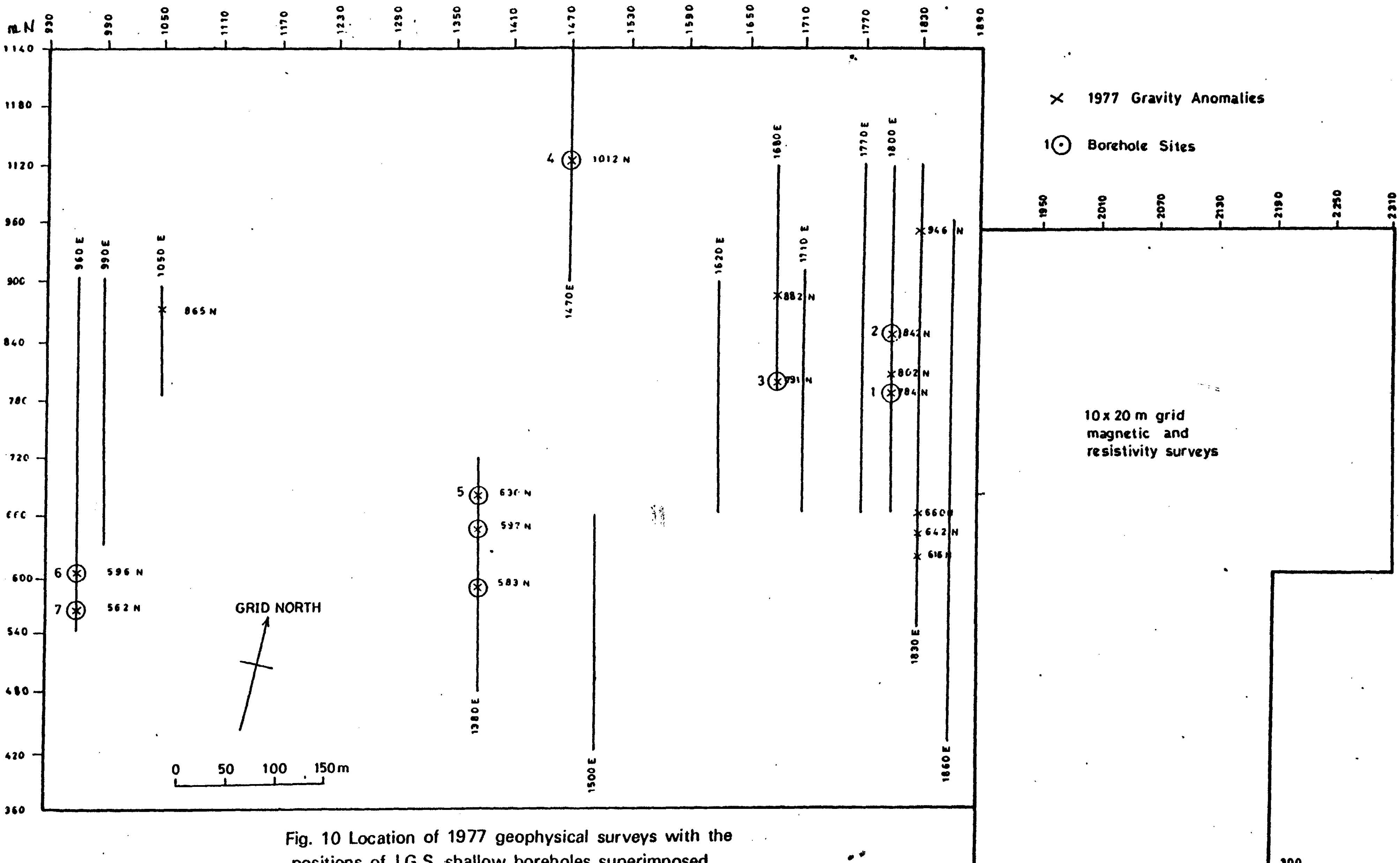

Fig. 10 Location of 1977 geophysical surveys with the positions of I.G.S. shallow boreholes superimposed.

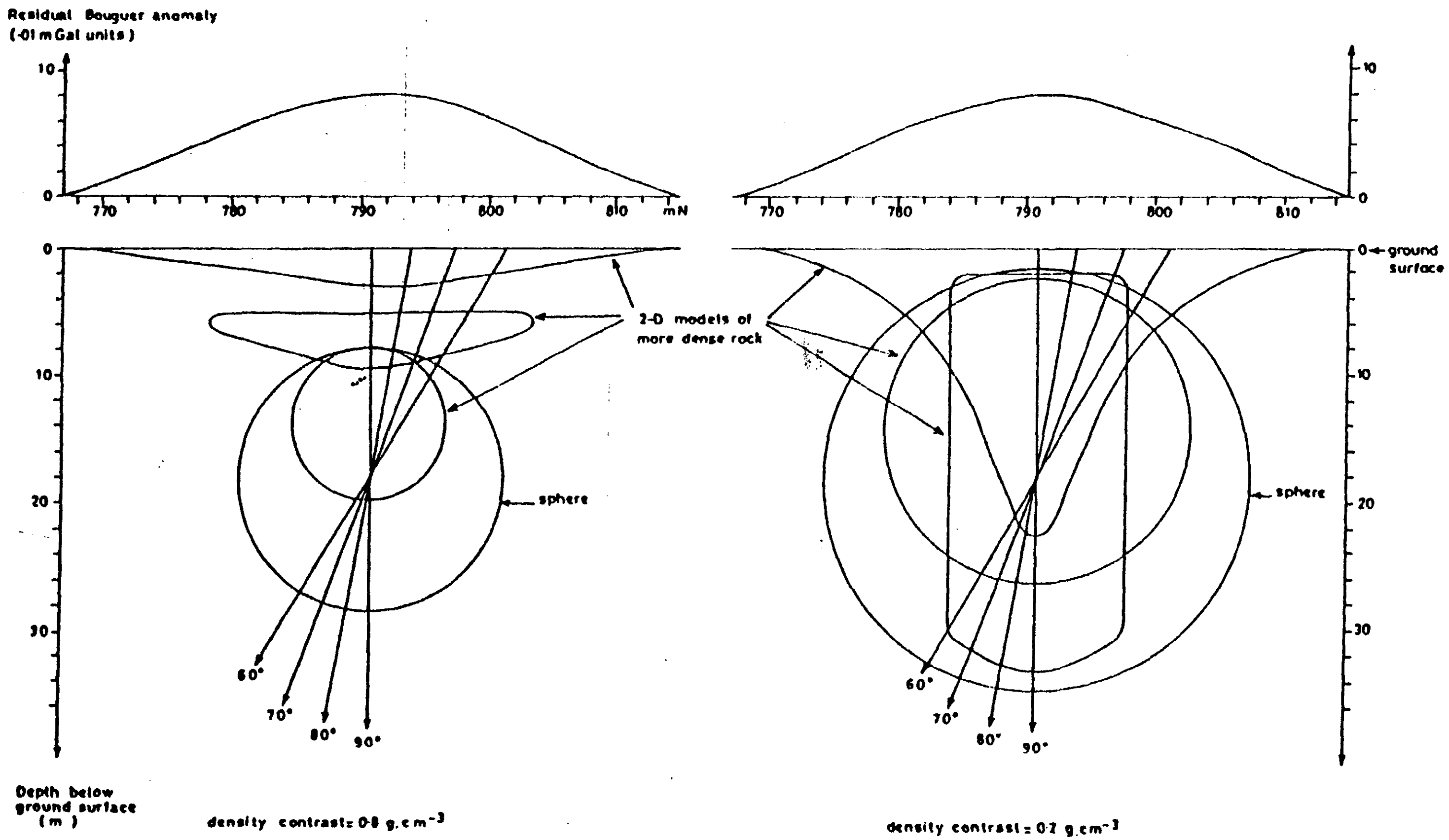

Fig. 11 Alternative 2-D models and borehole positions for anomaly 1680E , 791 N, (drilled as borehole 3).

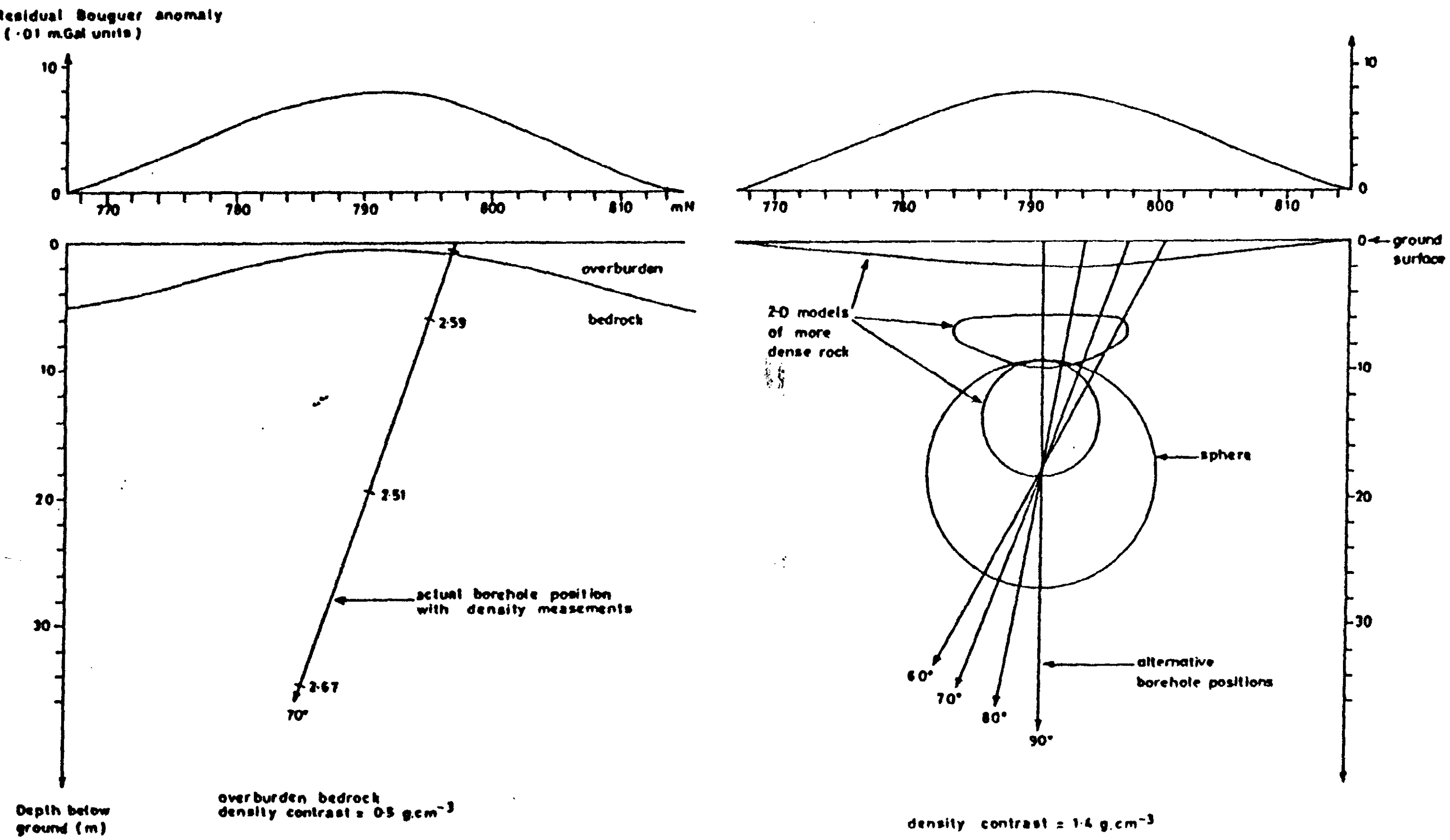

Fig.12 Further alternative 2-D models and borehole positions for anomaly 1680 E, 791 N (drilled as borehole 3).

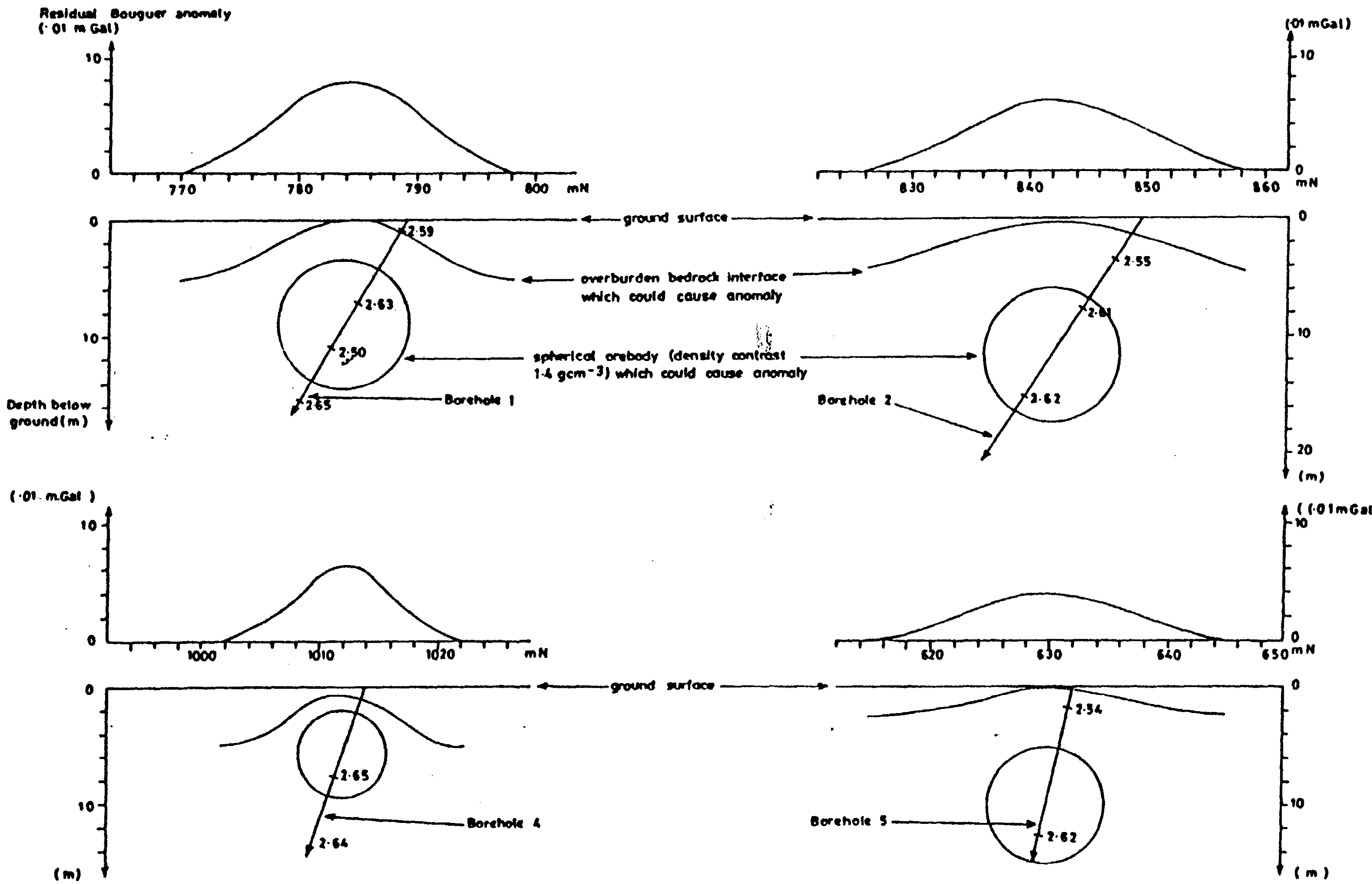

Fig.13 Models of overburden variations for anomalies at sites of boreholes 1, 2, 4 and 5

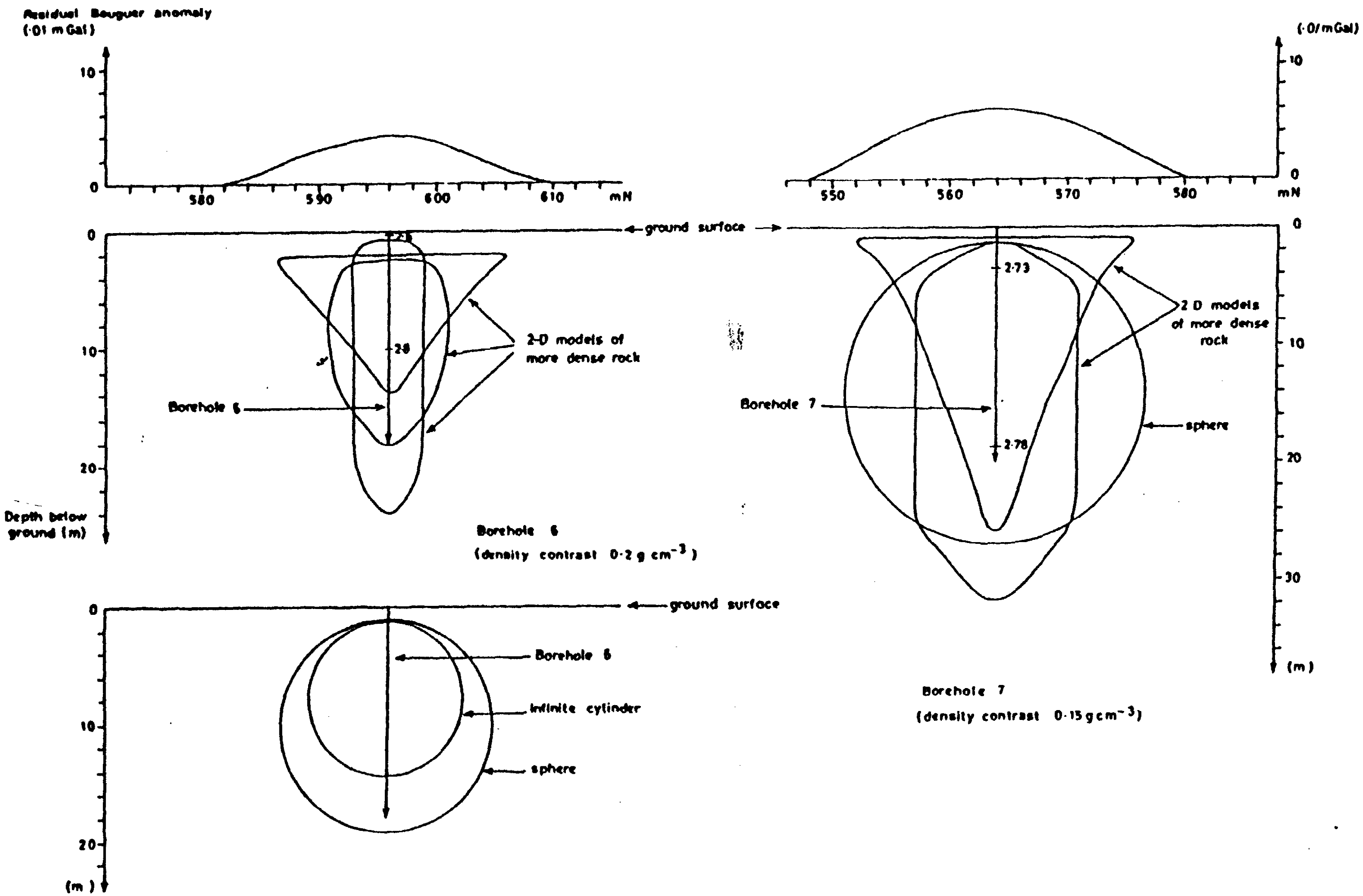

Fig.14 Alternative 2 D and spherical models for anomalies drilled at boreholes 6 and 7

lenses.

Two-dimensional models of possible anomaly causes were calculated using an iterative computing technique (Figs 11 to 14). Various 2-D models for anomaly 1680 E, 791 N (borehole 3), using density contrats of 1.4 g cm^{-3}, 0.8 g cm^{-3} and 0.2 g cm^{-3} for the 'orebody' are shown in Figs 11 and 12. Fig. 11 also shows a 2-D model for the bedrock-overburden interface using a density contrast of 0.5 g cm^{-3}. Any of these models would cause a gravity anomaly similar to that observed. However, measurements on the core failed to identify a significant density contrast.

Fig. 13 shows hypothetical spherical ore bodies of density contrast 1.4 g cm^{-3}, and 2-D models for the bedrock-overburden interface which could be the cause of the anomalies investigated by boreholes 1, 2, 4 and 5. However, these boreholes did not intersect significant amounts of chromite and there was no significant increase in the density of core samples.

Boreholes 6 and 7 intersected small amounts of chromite in the serpentinite (see borehole logs, Appendix IV); significant increases in core density of about 0.2 g cm^{-3} in borehole 6 and 0.15 g cm^{-3} in borehole 7 can be seen in Table 2. Fig. 14 shows various models of 2-D structures with these density contrasts which could cause gravity anomalies similar to those observed.

Most of the gravity anomalies are thus unexplained on present evidence. It is possible that large masses of dense rock exist at depth and that, as a result of heterogeneous distribution of dense material, they were not intersected by the boreholes or were not represented in the core samples selected for density measurement. Alternatively the anomalies may result from local changes in thickness of the weathered layer and of the overburden. In the latter model, it should be noted that it is the contrast between the overburden (or weathering) thickness flanking the borehole and that actually at the top of the borehole that defines the Bouguer anomaly profile. In other words a borehole sited at a positive Bouguer gravity anomaly will intersect the overburden (or weathering) at its thinnest parts and could be surrounded by overburden (or weathering) 2 to 6 times thicker, although there is no borehole evidence to test this model.

Magnetic surveys

Chromite ($FeOCr_2O_3$) is only weakly magnetic with susceptibility of the same order of magnitude as serpentinite (Table 1), although certain chromite ores show a strong remanent magnetisation if the ore contains sufficient amounts of magnetite and nickel ferrite (Parasnis, 1963). The feasibility of distinguishing chromite by magnetic methods in Unst was doubtful owing to, 1) the presence of variable amounts of magnetite in the serpentinite and, 2) the variability of chromite susceptibility due to peripheral alteration of some grains to iron-rich chromite. Tables 1 and 2 indicate large variations in the magnetic susceptibility of serpentinite which bear no obvious relationship to the presence of chromite. The regional magnetic anomaly map of Shetland (McQuillin and Brooks, 1967) shows a sharp positive anomaly of the order of 4000 gammas at the western margin of the Main Serpentinite and Greenstone Block, and many narrow, large amplitude anomalies across the serpentinite probably caused by large quantities of secondary magnetite.

A Geometrics proton magnetometer was used to measure total magnetic field at 7.5 m intervals along E-W traverses 60 m apart over the area of the 1976 survey grid. The profiles showed strong variations, with anomalies up to 2000 gammas commonly trending N-S or NE-SW. A plane surface regional background field was estimated, increasing from 50,240 gammas for line 360 N, to 51,140 gammas for line 140 N (Fig. 15), from which the residual magnetic field (Fig. 16) was calculated. A comparison of the 1976 residual gravity and the magnetic maps (Figs. 8 and 16) shows positive magnetic anomalies respectively located SW and S of gravity anomalies

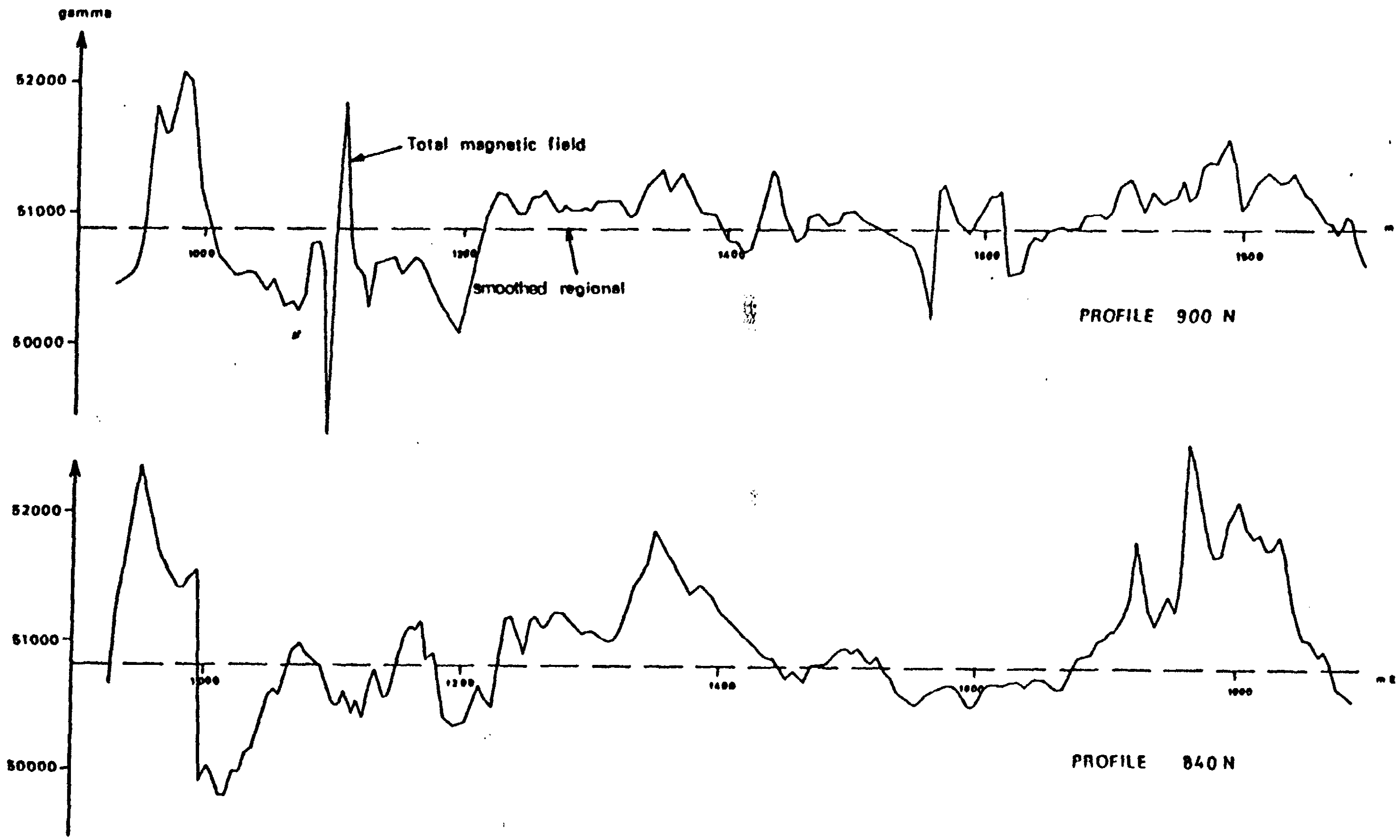

Fig.15 Total field magnetic anomaly profiles for lines 840N and 900N with background regional profiles (1976 survey)

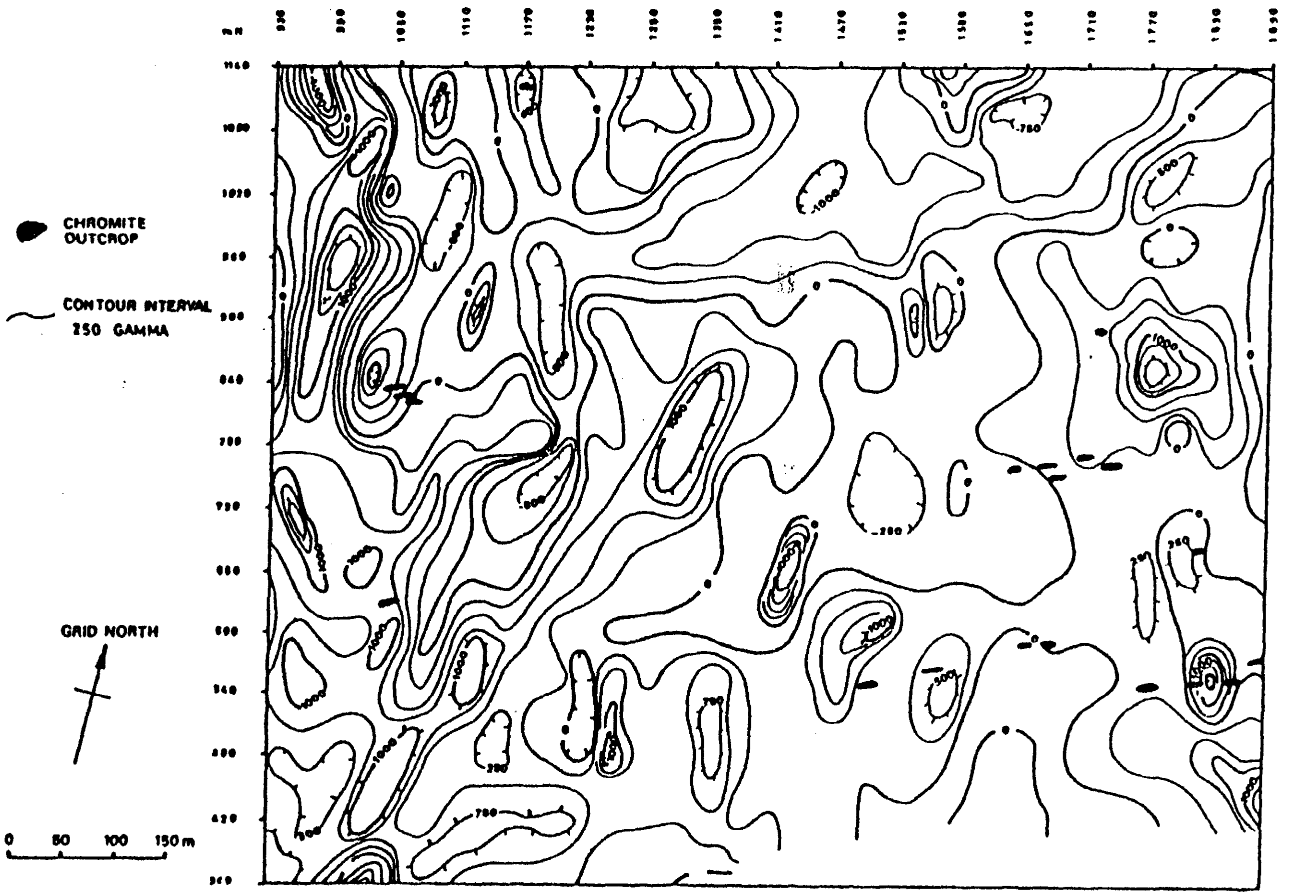

Fig.16 Total field magnetic residual anomaly map based on 1976 survey

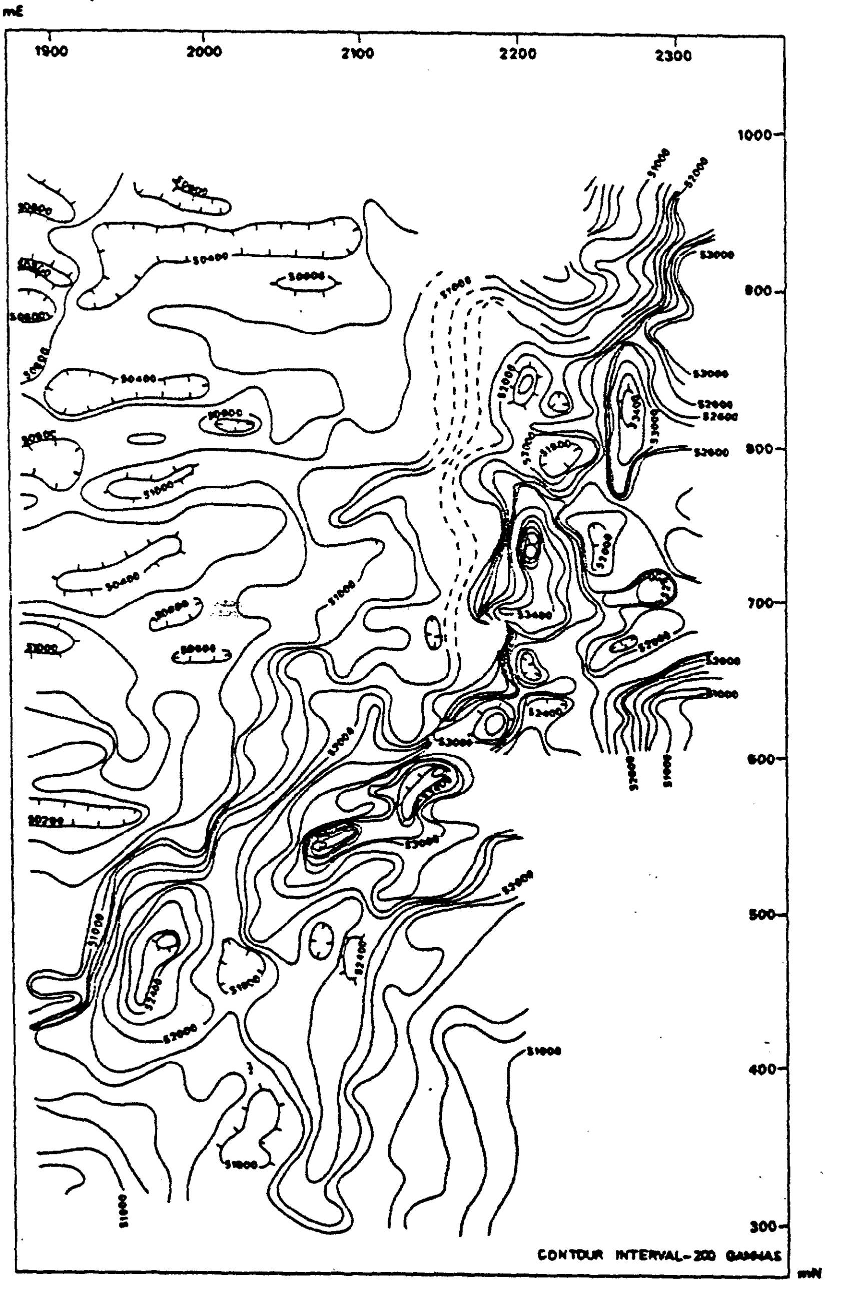

Fig.17 Total field magnetic anomaly map based on 1977 survey

1 and 15, and negative magnetic anomalies W, NW and NW of gravity anomalies 4, 5 and 13 respectively. Any of these correlations could be due to 1) magnetic chromite ore; 2) change in rock composition or 3) variation in thickness of overburden, although it is also possible that the correlations are coincidental.

In 1977 a Geometrics proton magnetometer was used to survey the 13 N-S gravity traverses and the eastern extension of the survey area (Fig. 4) on a 20 m x 10 m grid. The profiles (Appendix II) illustrate irregular variations of several thousand gammas, some of which coincide with positive gravity anomalies (Table 3). The 20 m x 10 m grid survey shows very strong magnetic gradients through the area, with a predominantly N-S trend (Fig. 17). This is probably the result of secondary magnetite developed along N-S trending swarms of joints.

Electrical surveys

Induced polarisation (IP), very low frequency (VLF) and resistivity surveys were carried out mainly for the purpose of detecting nickel sulphides or cobalt and copper minerals, which can be associated with chromite. Chromite itself has a very high resistivity (Table 1), but strong IP anomalies have been reported over chromite masses in Yugoslavia (Parasnis, 1963). Resistivity tests on samples from Unst (Table 1) show that chromite-bearing serpentinite generally has a higher dry resistivity than ordinary serpentinite, but saturated resistivity values are primarily dependent on porosity, which is not related to percentage of chromite. Hence chromite deposits would not necessarily show high resistivity values during field surveys, assuming some degree of saturation.

Geonics EM16 + R equipment was used in 1977 for VLF in-phase, quadrature (facing North) and resistivity (10 m dipole) measurements over the 13 N-S lines (Appendix II). Most of the gravity anomalies coincided with high resistivity values, many of which are associated with rock exposure (Table 3). These correlations could be due to 1) high resistivity

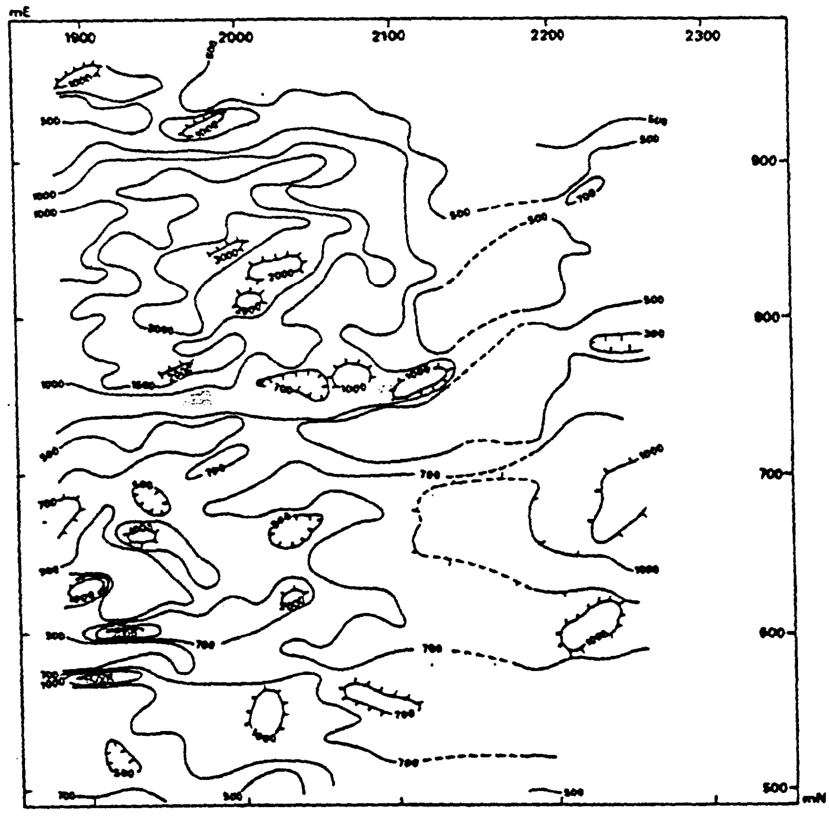

Fig.18 Map of apparent resistivity based on 1977 survey
Contours at 300, 500, 700, 1000, 1500, 2000, 3000 ohm.m

chromite, 2) change in rock compositions or, 3) the presence of relatively little or no overburden. In-phase and quadrature components show many small amplitude variations superimposed on larger regional variations, and no obvious correlation with positive gravity anomalies.

The 10 m x 20 m grid to the east was covered by the VLF resistivity survey only, and the contour map (Fig. 18) indicates one particularly high resistivity zone in the northwest of the area with no exposure, smooth terrain, and little magnetic variation. This resistivity anomaly may be due to a decrease in thickness of overburden or a local change in rock composition such as increased chromite content. If any further work is done in the area this anomaly should be investigated.

Huntec Mark III Equipment was used in 1976 for dipole-dipole IP/resistivity measurements over N-S lines 1470E, 1590E and 1890E for n = 2 to 6 using dipole length 30 m. Pseudosections for chargeability (M^{1140}_{240}) and apparent resistivity were plotted (Appendix III). Resistivity decreases with depth for lines 1470E, 1590E and 1740E, possibly due to mineralisation at depth. There was no correlation between high chargeability and positive gravity anomalies.

DRILLING RESULTS

Details of geology

The area lies mostly within the dunite serpentinite zone of the Lower Nappe, though in the extreme northwest there is a transition to peridotite serpentinite. At surface both rock types have a characteristic pale brown weathered crust. Three rock types were distinguished in the drill cores. Most abundant is a dark, grey-green serpentinite, which commonly displays bastite pseudomorphs (after pyroxene). Secondly, there is a reddish-brown serpentinite, which predominates in certain boreholes (e.g. BH. 4). It occurs most commonly adjacent to joint planes and includes patches of the dark grey serpentinite, suggesting that it has been

Table 4 - Borehole site descriptions

No	NGR	Collar Elevation (m above OD)	Azimuth (°T)	Inclination	Rod length (m)
1	HP 6305 1040	54.6	168	60	18.52
2	HP 6304 1046	61.4	168	60	24.25
3	HP 6293 1038	65.1	168	60	27.38
4	HP 6268 1056	108.6	168	70	15.13
5	HP 6267 1016	68.4	129	70	15.05
6	HP 6227 1003	72.9	-	90	15.43
7	HP 6228 1000	67.7	-	90	18.82

derived by alteration of the dark grey rock. The third variety of serpentinite is confined to borehole 6 and, in lesser amounts, to borehole 7. It varies in colour from pale grey to greenish lemon, resembling one of the commoner rock types found in the spoil heaps, and is the host rock for chromite concentrations. In the drill cores the pale rock is finely interbanded with the more usual dark grey serpentinite. Limonitic zones occur in the upper few metres of most boreholes.

Many joints in all three varieties of serpentinite are infilled with chrysotile, talc and calcite. In places calcite forms a comb structure which evidently post-dates the formation of the brown serpentinite. Magnetite, occupying the central part of joint assemblages, and native copper, forming grains up to 3 mm across, were also observed.

In many outcrops Rivington (1953) noted steep northerly or north-westerly dipping "bedding planes". Since their orientation coincides with that of the boundary between dunite serpentinite and peridotite serpentinite and is subparallel to the chromite streaks and pods, it seems probable that these planes represent some form of magmatic layering. Well developed banding is evident only in cores from boreholes 6 and 7, being intimately associated with the development of the pale variety of serpentinite. The banding is produced by alternating layers of pale and dark serpentinite and by chromite, where present, and may have a parallel schistosity. It usually dips at 60° to 90° but varies locally as a result of small-scale open folding.

The maximum thickness of overburden observed in boreholes and quarries is 1 m and it is unlikely that any greater thickness is present in the area. Although a considerable thickness of unconsolidated matter was recorded in one of the early United-Steel Company boreholes (BH E) and ascribed to the infill of a buried glacial channel, it seems more likely that this material represents the infill of an unrecorded, underground easterly extension of the nearby Long Quarry (see Fig. 2)

Petrography and mineralogy of core samples

In thin section the dark grey-green serpentinite comprises granules of relict olivine set in fine antigorite, with granules and irregular trails of magnetite, limonite and/or goethite. Boundaries of the original olivines (chrysotile with $2V_{\gamma}90^{\circ}$) are sometimes marked by iron staining which extends into the adjacent serpentinite. The antigorite is pale green and includes conspicuous straight acicular crystals in addition to the normal mat of minute grains.

The brown serpentinite on the other hand, is devoid of olivine relicts, comprising a mat of fine serpentine dusted with opaque limonite and/or goethite microgranules. Of more limited extent are minute, irregular patches of a very fine phase which is probably either a variety of serpentine or a clay mineral. Prismatic crystals of probable tremolite were noted in one specimen.

The pale grey-green serpentinite is formed of magnesite with darker antigorite bands ranging in thickness from 2 mm to 1 cm. In all but one of the ten thin sections, chromite was the dominant opaque phase, forming between 0.1% and 2% of the rock. However, a specimen taken from immediately below the chromite-rich section in borehole 6 (Appendix IV) was devoid of chromite but contained up to 1% magnetite. The majority of chromites noted in thin sections have rims of magnetite and /or ferrichromite, possibly indicating growth of magnetite at the expense of chromite. Magnetite of definite secondary origin was noted in at least one thin section, but its relationship to magnetite contained in serpentine veinlets could not be established. It was suggested above (p 30) that joint-bound secondary magnetite could be the cause of the prominant N-S magnetic anomalies.

Accessory pyrite is present to a greater or lesser extent in most thin sections and traces of possible bravoite and possible pentlandite were also noted. Small amounts of native copper were recorded in both serpentinite and serpentine veins.

Chromium concentrations

Geological logging and semi-quantitative chromium analyses of the drill cores indicated that, apart from short lengths of core in borehole 6, the chromite concentration is negligible and, in consequence, analysis of the entire core length not justified. Estimates of chromium content were derived from readings with a portable X-ray fluorescence analyser (Mineral Analyser) using a ^{238}Pu source to excite Cr K_α X-radiation. The instrument was calibrated against six samples of crushed drill core from Unst which had been analysed by conventional XRF methods, and readings were taken every 25 cm except on the cores from boreholes 6 where the interval used was 10 cm. The chromium values presented in Appendix I are based on the mean of four readings (ten readings in the case of borehole 6). Precision is approximately 0.15% at 95% confidence limits.

It is apparent from Appendix 1 that the amount of chromite in the cores is insignificant, the interpolated values seldom exceeding 0.6% Cr (equivalent to 1.3% $Fe Cr_2 O_4$). However, higher values were recorded in borehole 6 (3.8% Cr over 2 m) and borehole 7 (1.7% Cr over 1m). A maximum value of about 14% Cr was obtained from a small aggregation of massive chromite in borehole 6.

CONCLUSIONS

Table 3 summarises the significant positive gravity anomalies, dimensions of inferred models, associated magnetic and resistivity anomalies, rock exposures and some details of the seven boreholes. It can be concluded that the gravity surveys were partially successful in that they located the higher density rock, containing chromite intersected at shallow depth in boreholes 6 and 7. However, the inconclusive evidence of variations in rock density obtained from the other boreholes sited on gravity anomalies suggested that gravity surveys are not an effective exploration approach to the problem of detecting podiform chromite deposits in the Unst serpentinites.

Variations of magnetic susceptibility recorded by a magnetic survey are due to secondary magnetite and any correlation with gravity anomalies is speculative. Electrical surveys are also inconclusive because of the large variations of apparent resistivity due to varying thickness of the overburden and the weathered layer, and to serpentinite porosity.

Geophysical methods generally, therefore, cannot be recommended for further investigation of the Unst chromite potential. The results of the surveys described, and of the follow-up drilling, do not preclude the existence of deposits in depth and the geological reasons for ascribing potential to the down-dip extension of the chromite-bearing serpentinite remain valid in the Baltasound-Hagdale area.

In considering alternative exploration approaches, attention should be directed to the close spatial association of massive chromite and the pale grey-green (magnesite-rich) serpentinite. Although petrographical methods have had little success in the detection of this type of chromite deposit, detailed examination of the dunite layer, facilitated in areas of poor exposure by shallow drilling, could nevertheless be attempted and is likely to be no less effective than geophysical surveys.

ACKNOWLEDGEMENTS

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APPENDIX I

Theoretical limits for gravity surveys

The following relations can be derived between density of the orebody in g cm^{-3} (p2), density of surrounding rock (p1), mass of the orebody in metric tonnes (M), depth to the centre of the sphere in metres (a), radius of the sphere in metres (R), value of anomaly vertically above the sphere in mGal (g), and half-width of the anomaly in metres ($x_{\frac{1}{2}}$):

$$M/a^2 = \frac{149.9\ (p2)\ g}{(p2-p1)} \qquad (1)$$

$$M/R^3 = 4.19\ p2 \qquad (2)$$

$$x_{\frac{1}{2}} = 0.77a \qquad (3)$$

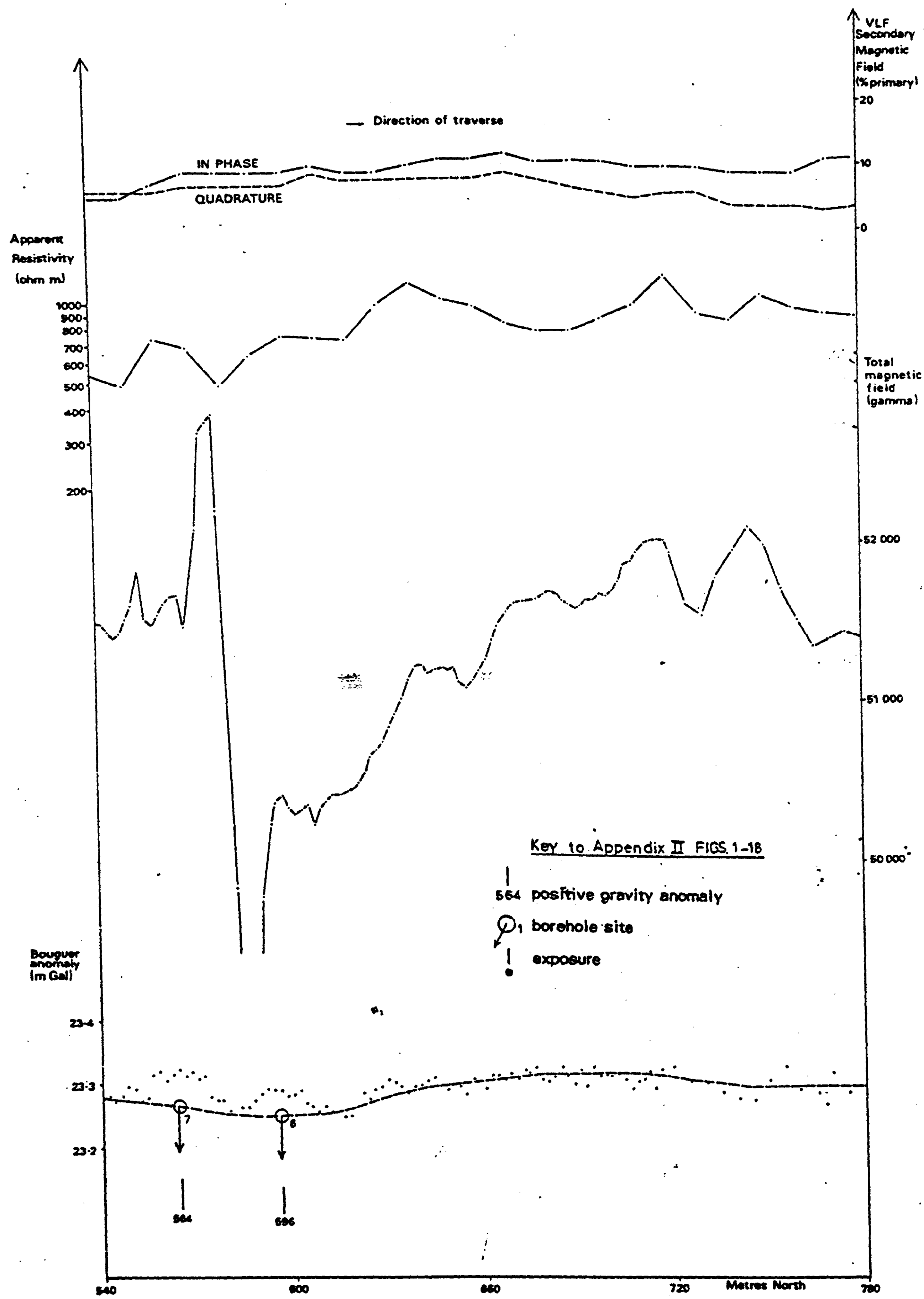
The smallest anomaly which could be detected reliably would be about 0.02 mGal. The following relationships between orbody mass, depth to the top surface, and anomaly half-width have been calculated from equations (1) to (3) for different sizes of orbody which would give a g value of 0.20 mGal for a density contrast of 1.4 g cm^{-3}:

Mass of ore body (metric tonnes)	Depth to top surface (a-R metres)	Half width anomaly ($x_{\frac{1}{2}}$ metres)
278	0	2
1,000	1	4
5,000	4	8
10,000	7	12
20,000	11	17
100,000	30	37

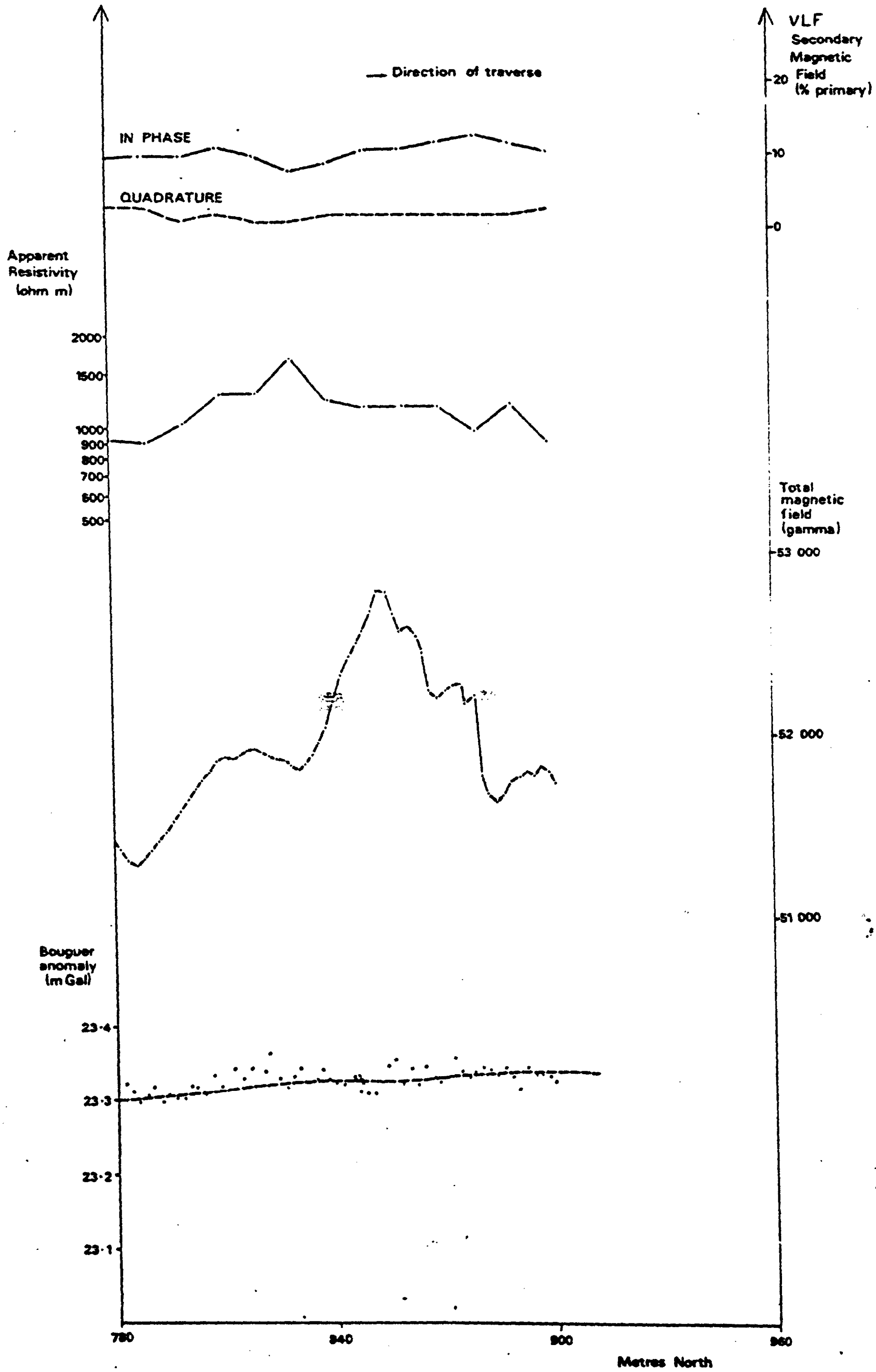
Since a non-spherical body would need to have its upper surface at a shallower depth to give an anomaly of the same magnitude as a spherical body of similar mass, the above table gives the maximum depth to the top surface for various sizes of orebody of density contrast 1.4 g cm^{-3} that might be detected by the gravity method. For example a 20,000 tonne orebody whose top surface is within 11 m of the ground surface will give a minimum anomaly of 0.10 mGal and half width 17 m, with a good chance of detection using a 30 x 60 m survey grid. Densities and other physical parameters of rocks and minerals from Unst are given in Tables 1 and 2.

APPENDIX II

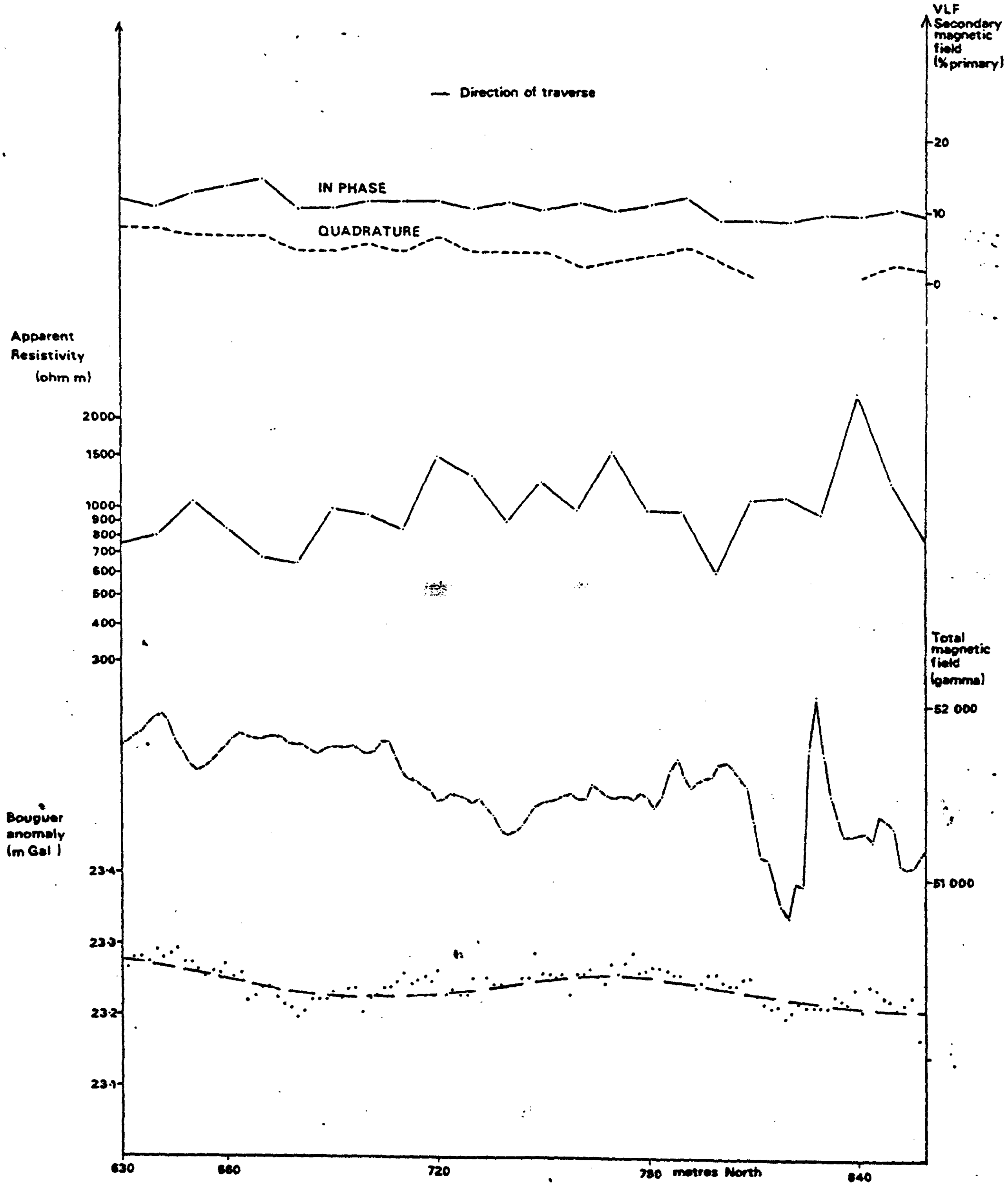
VLF, MAGNETIC AND GRAVITY PROFILES



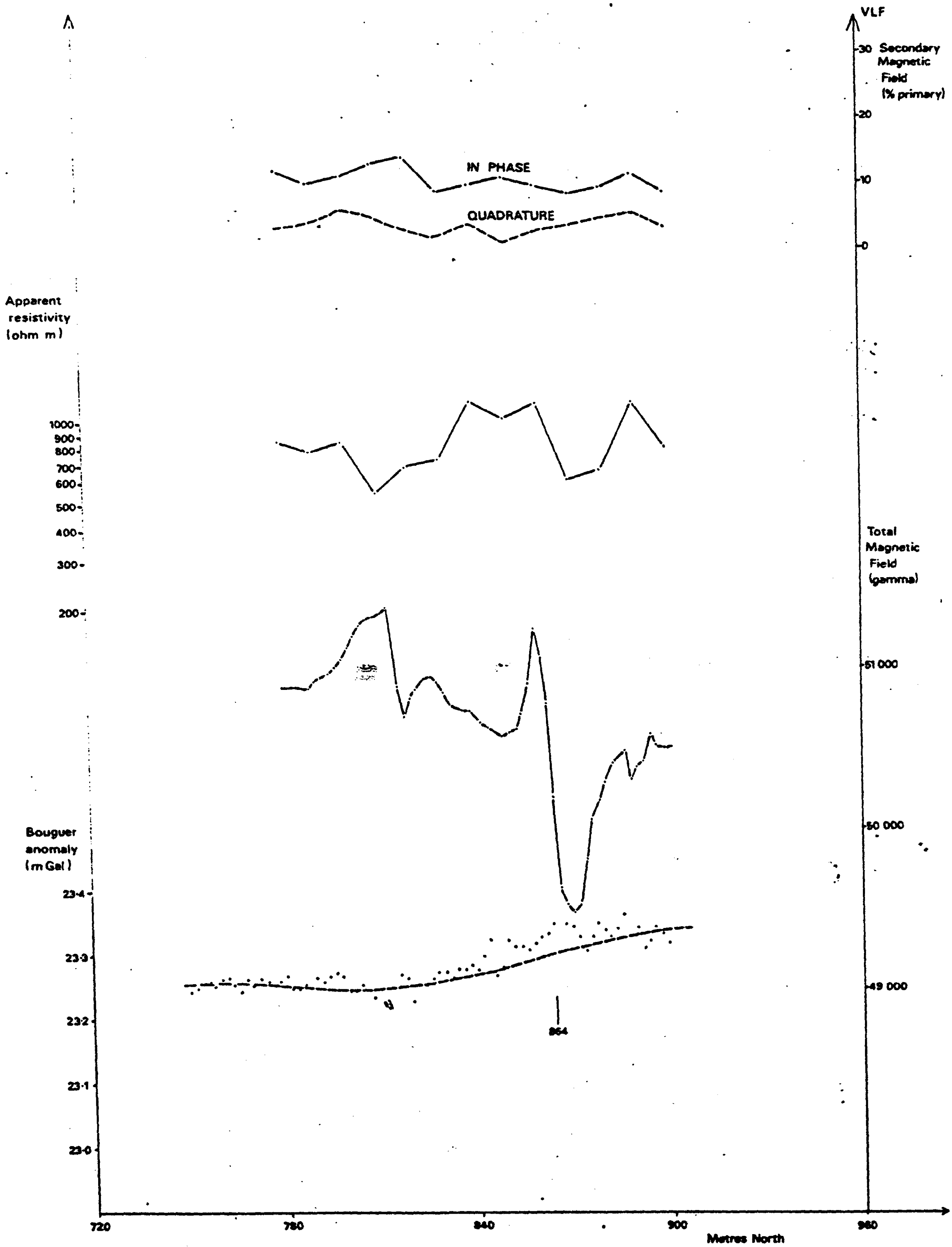
Appendix II Fig.1



Appendix II Fig. 2



Appendix II Fig. 3



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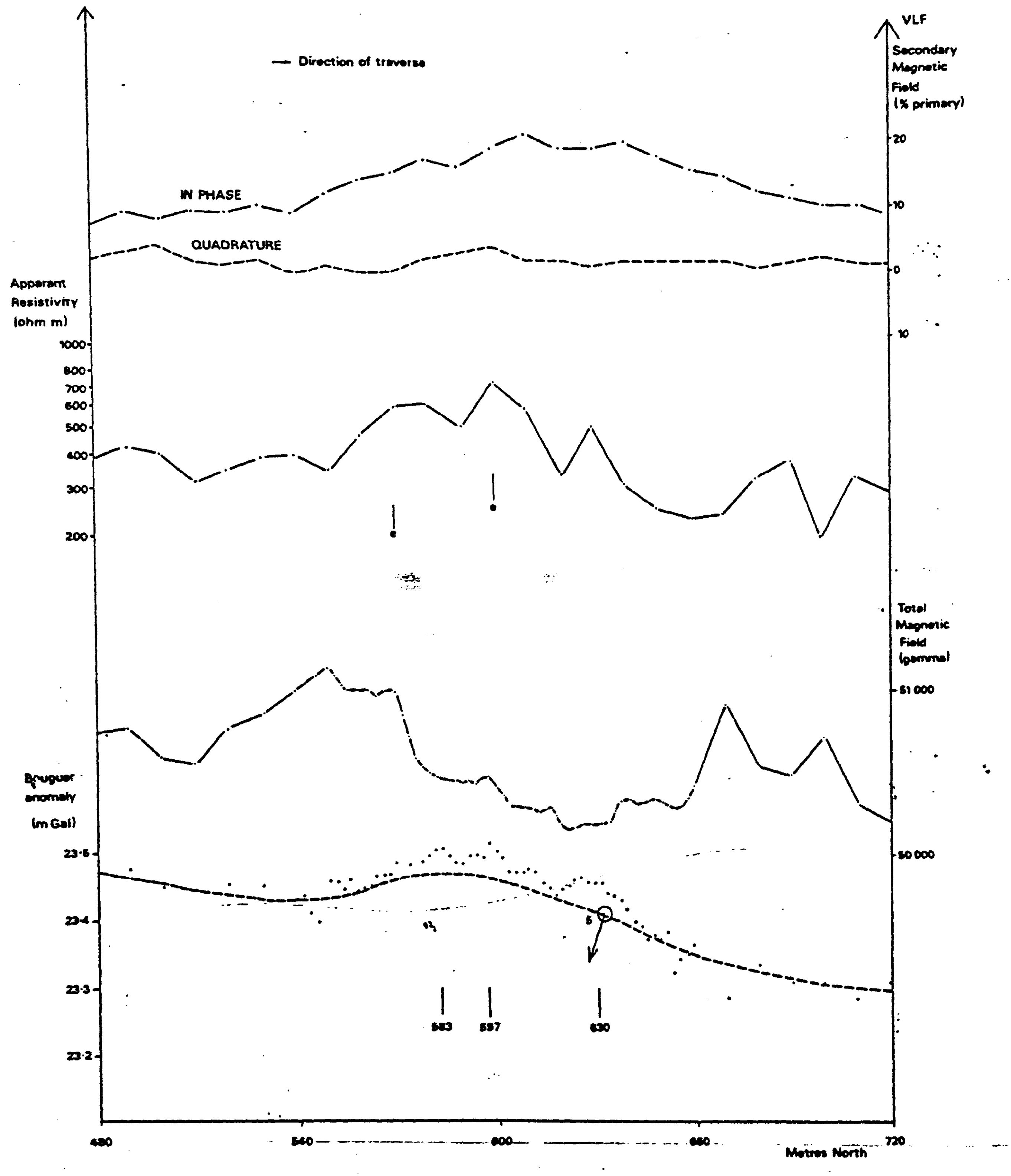

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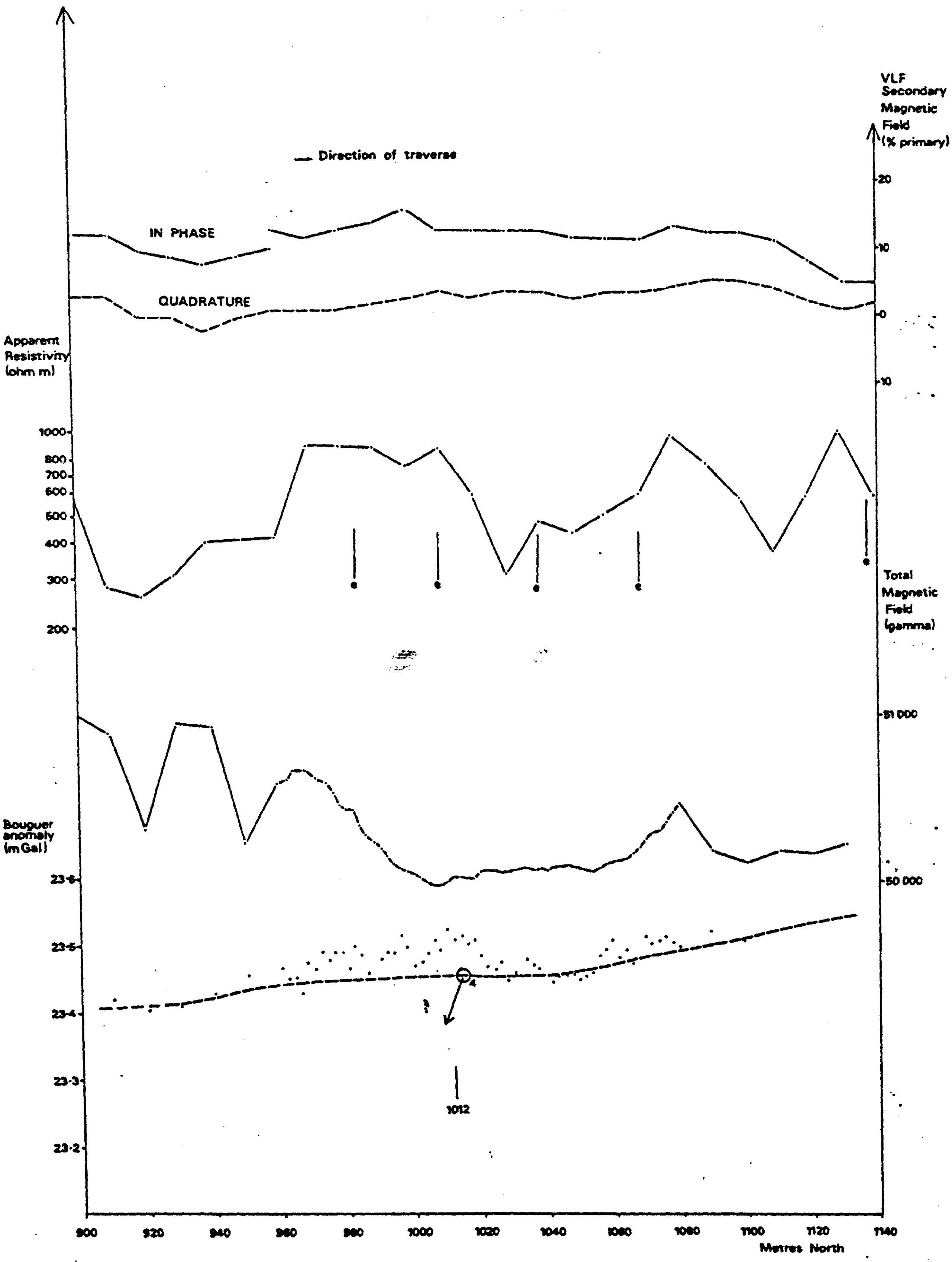

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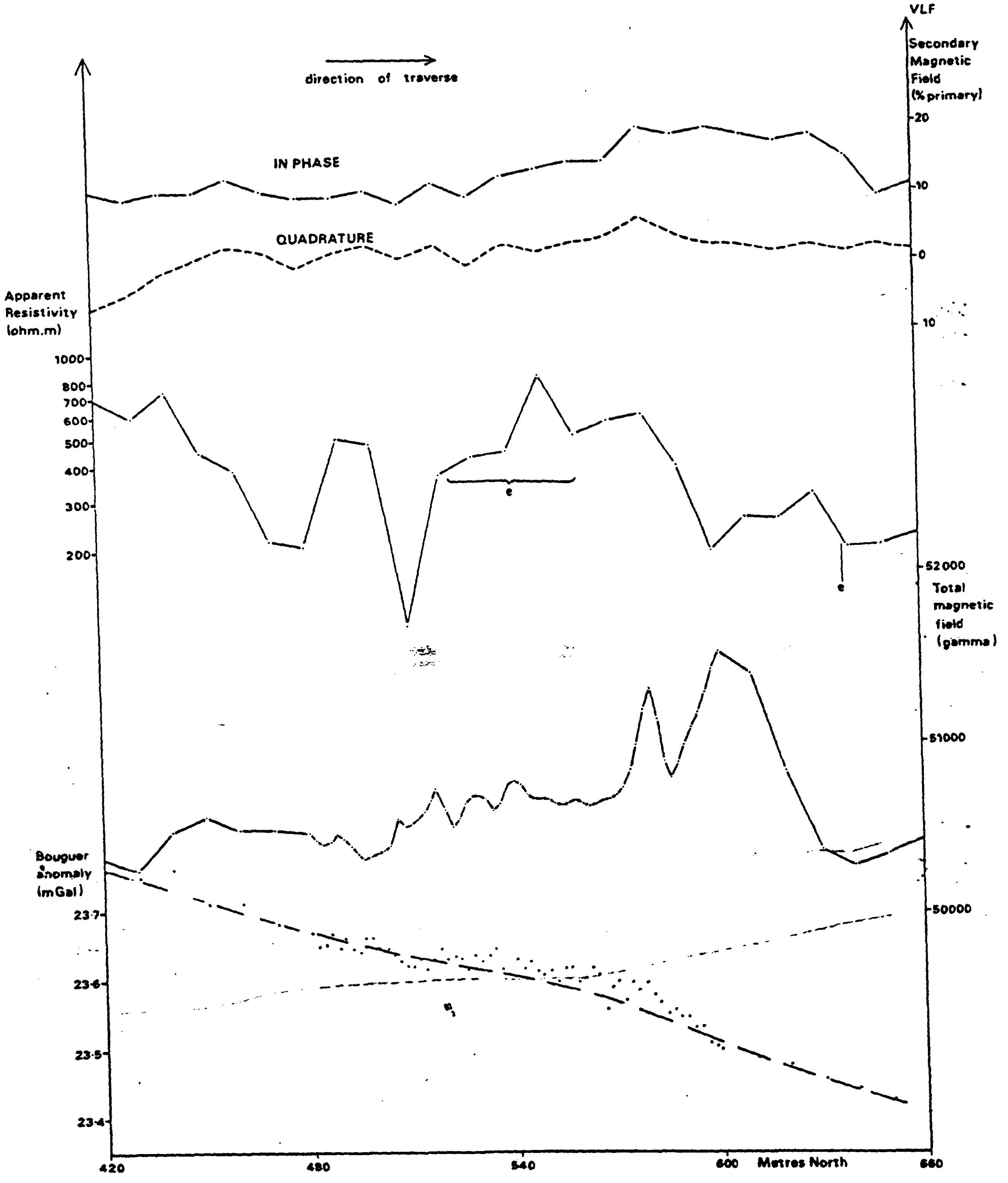

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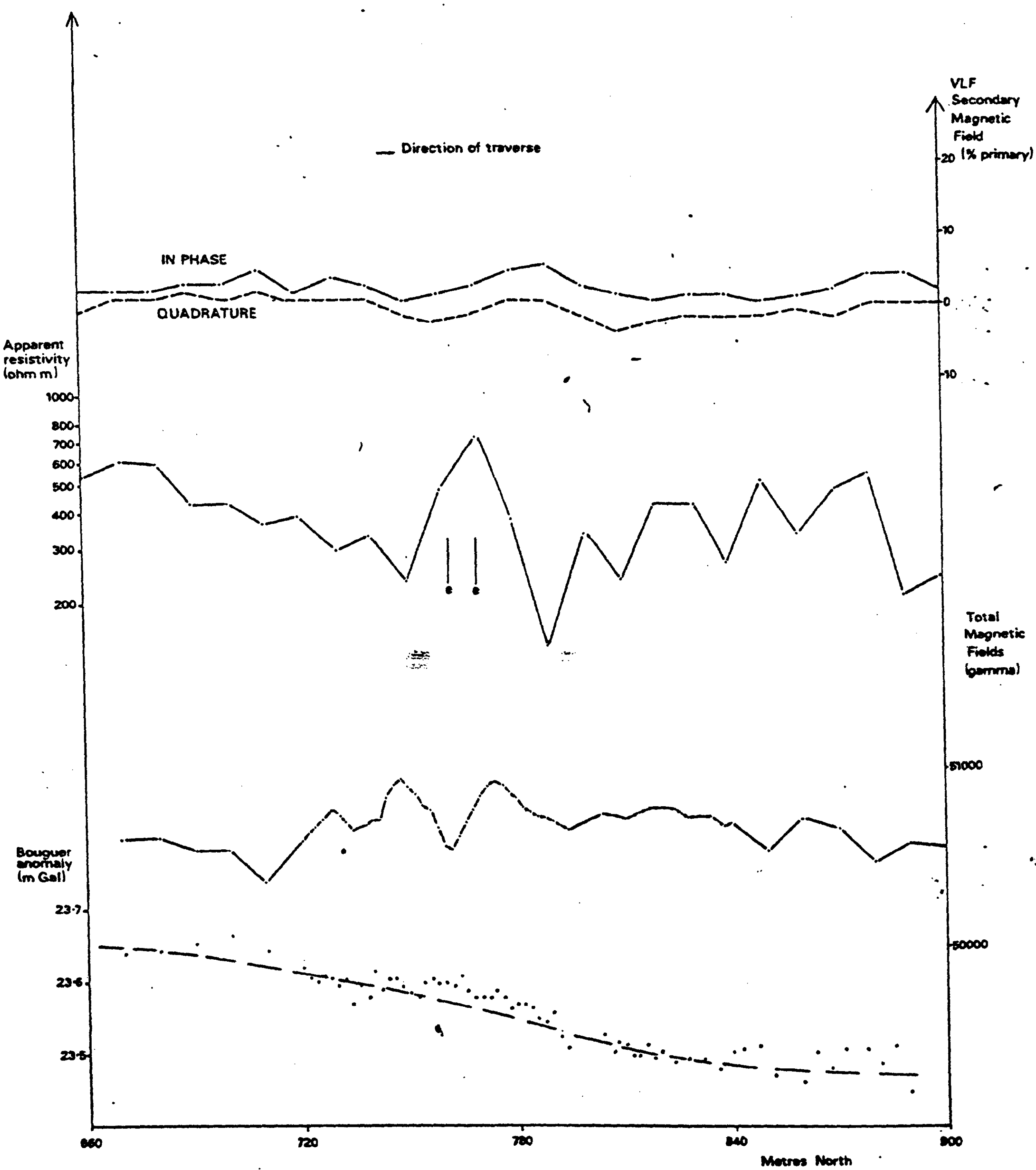

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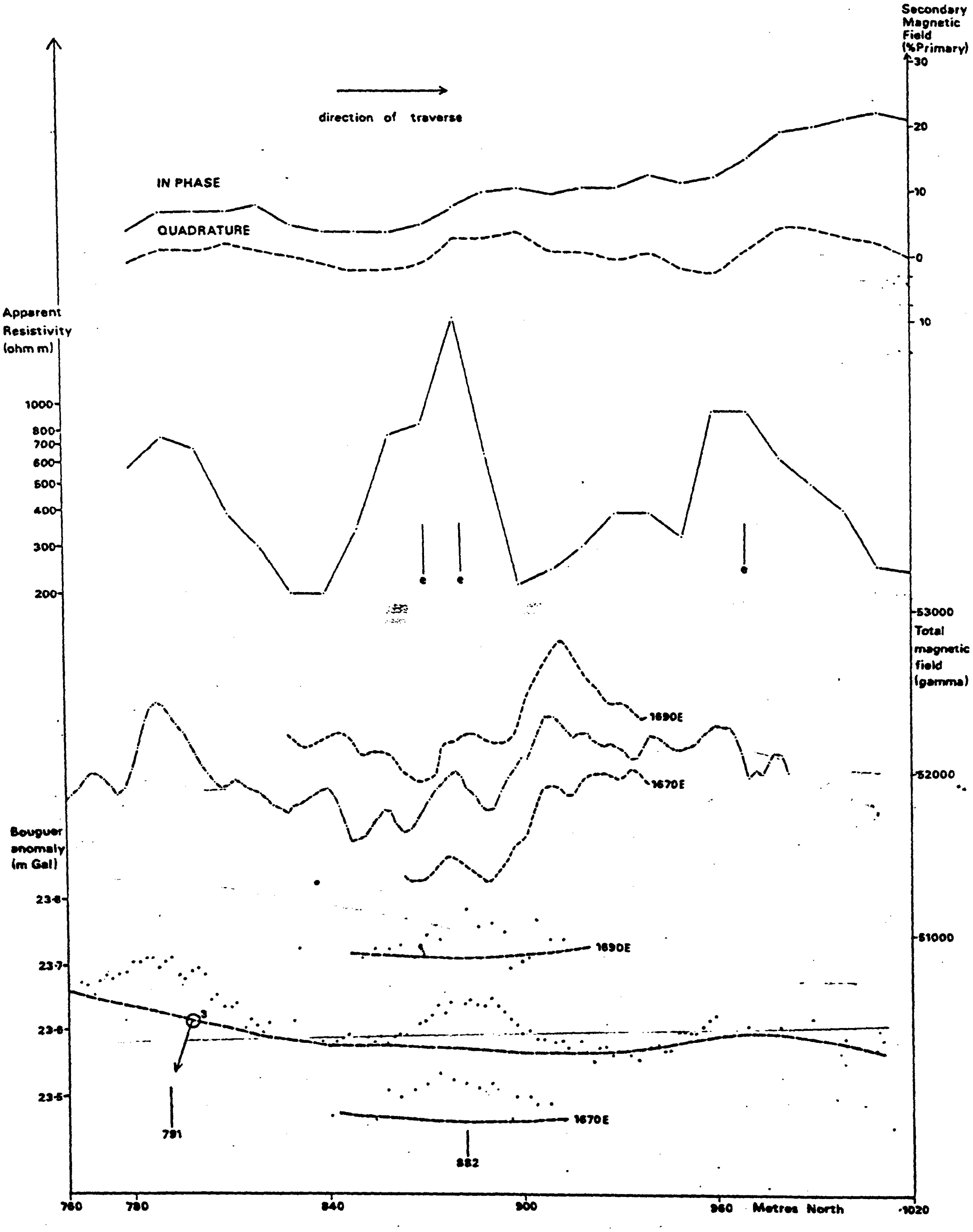

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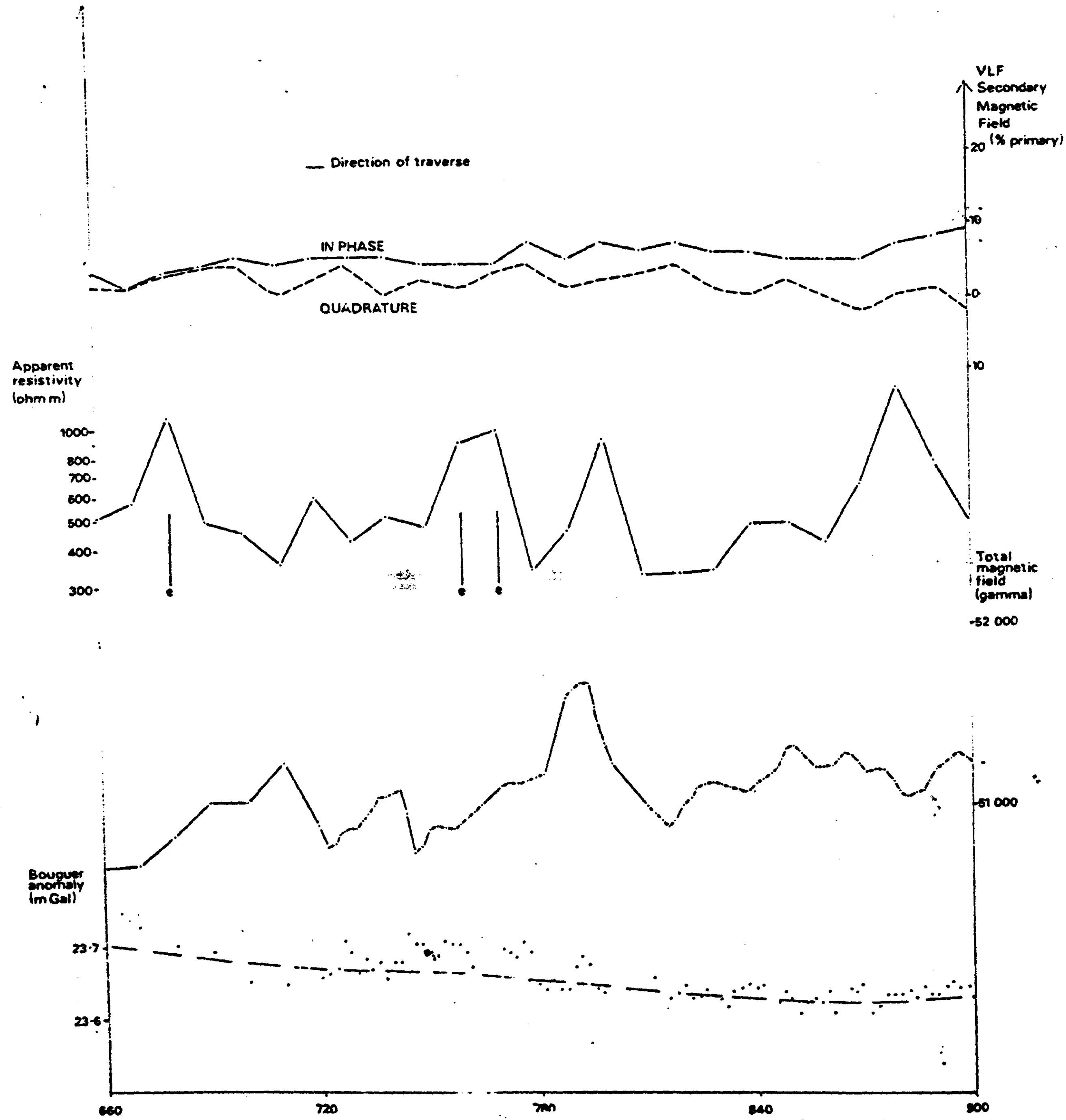

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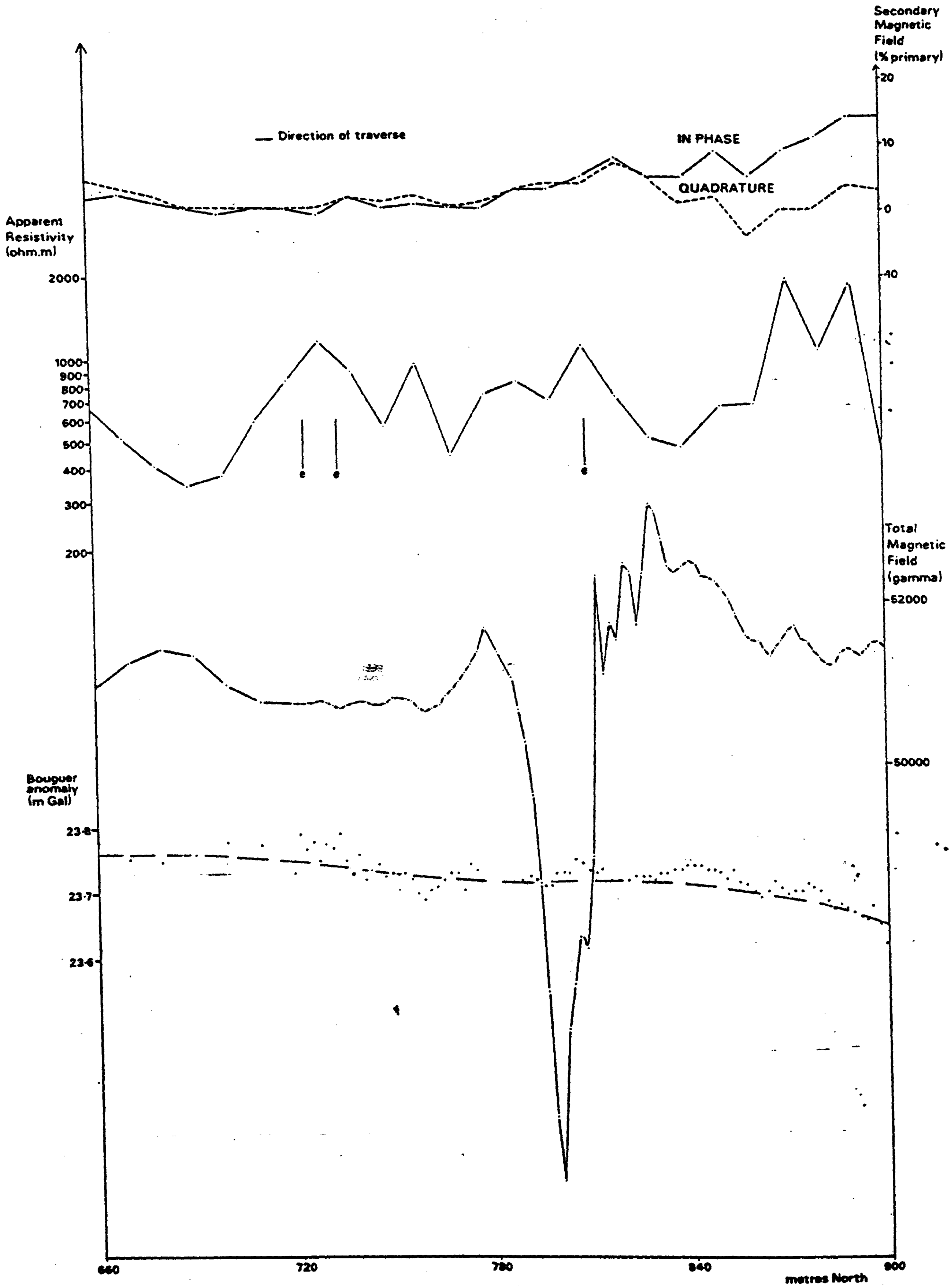

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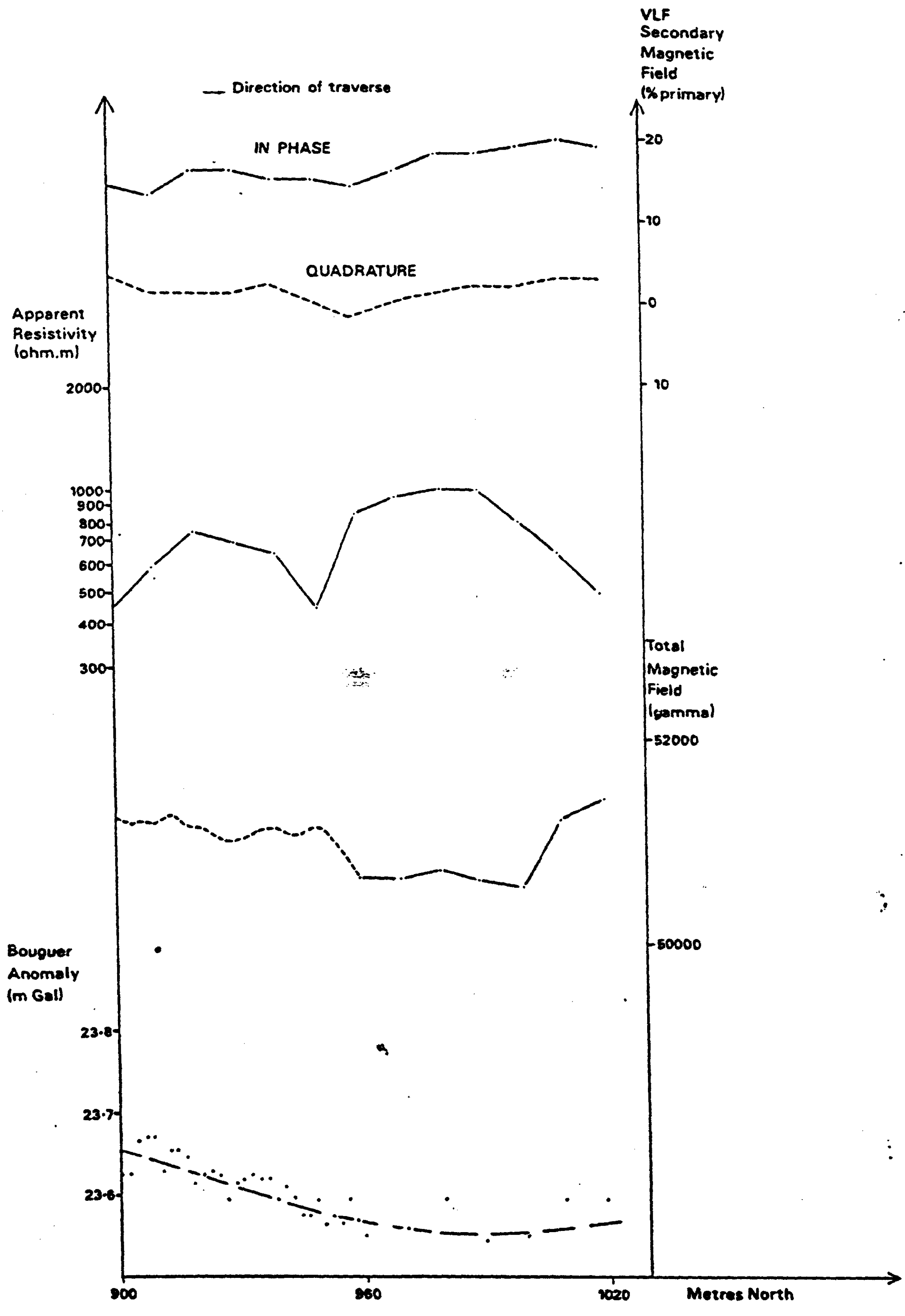

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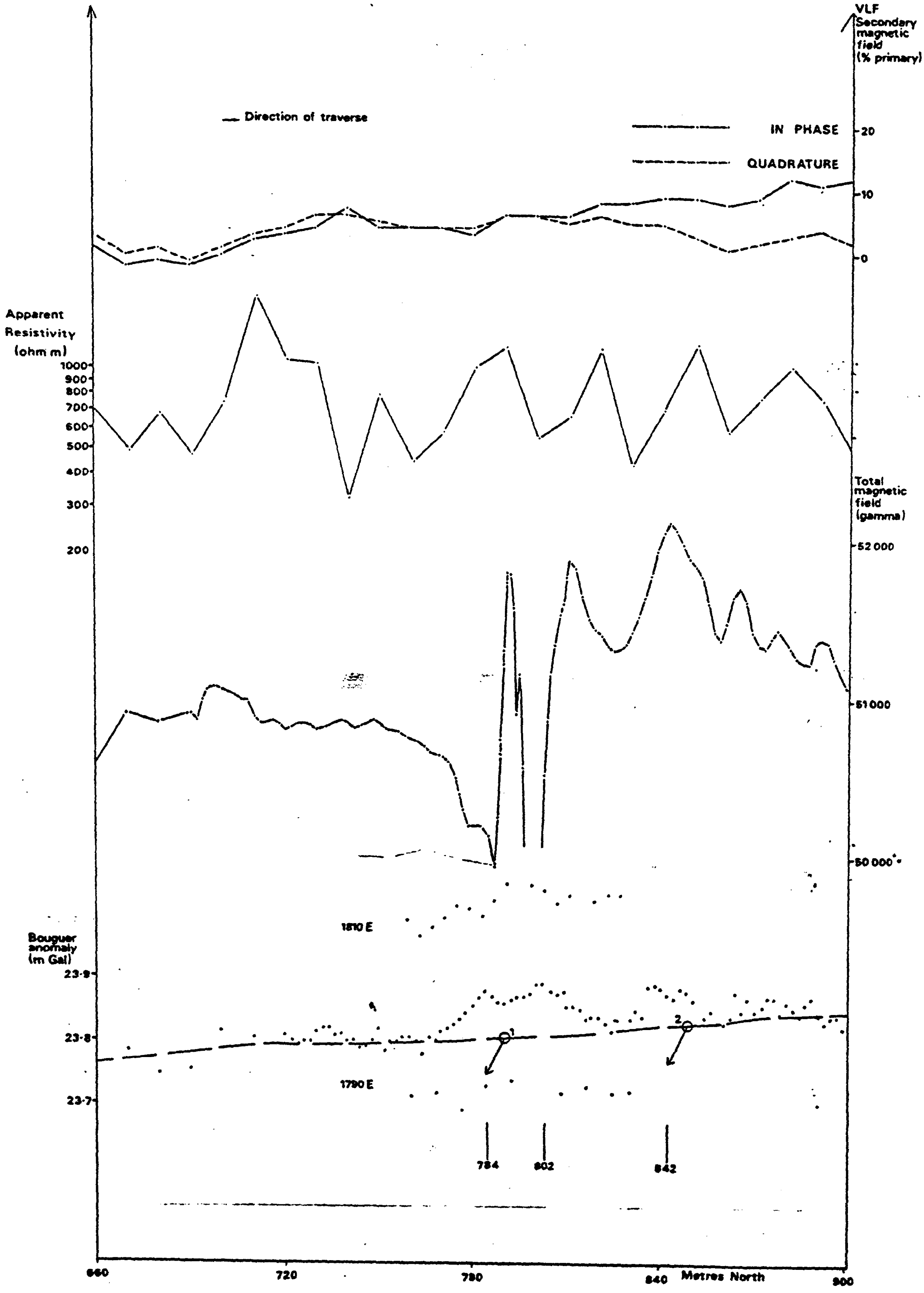

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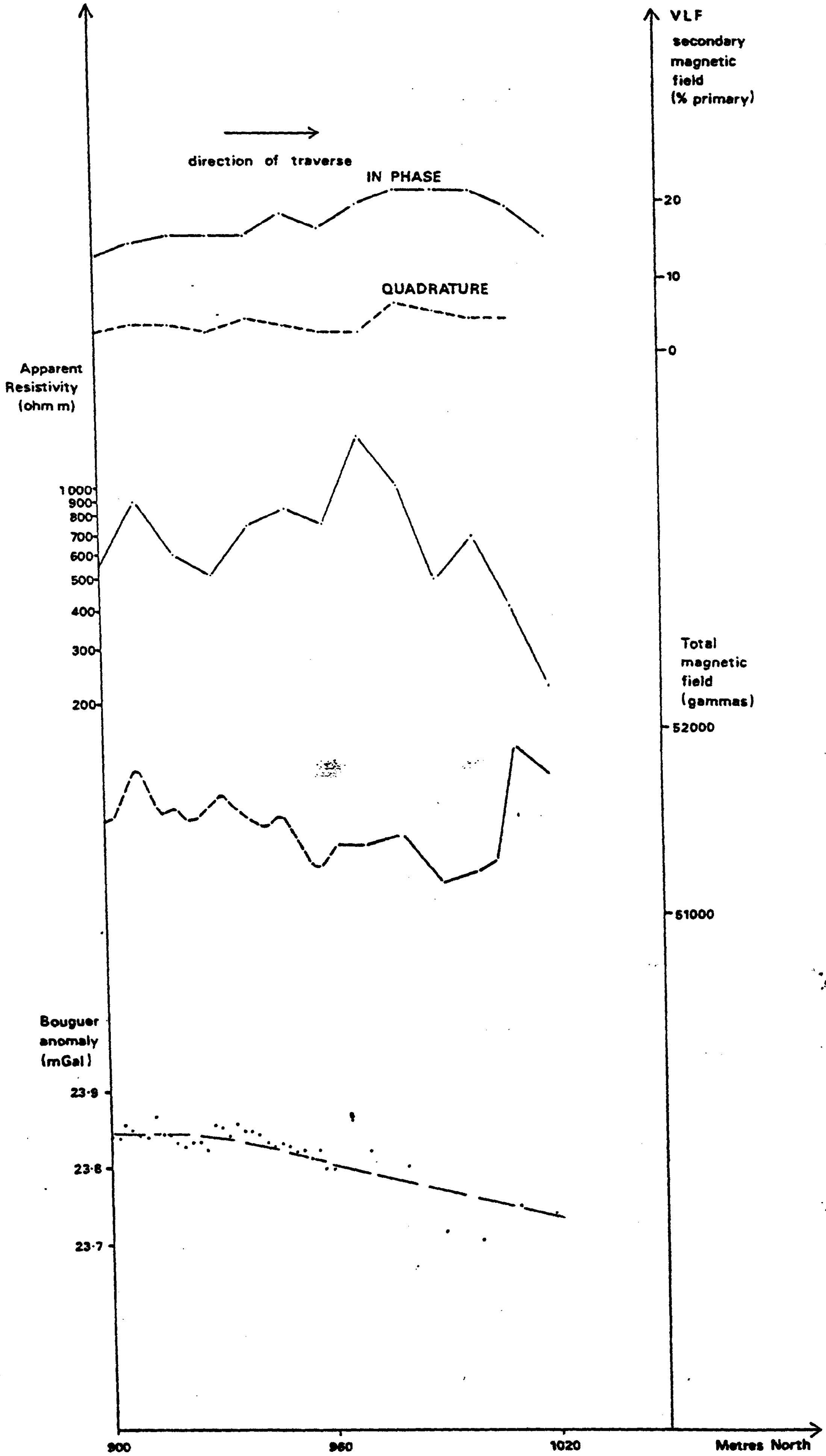

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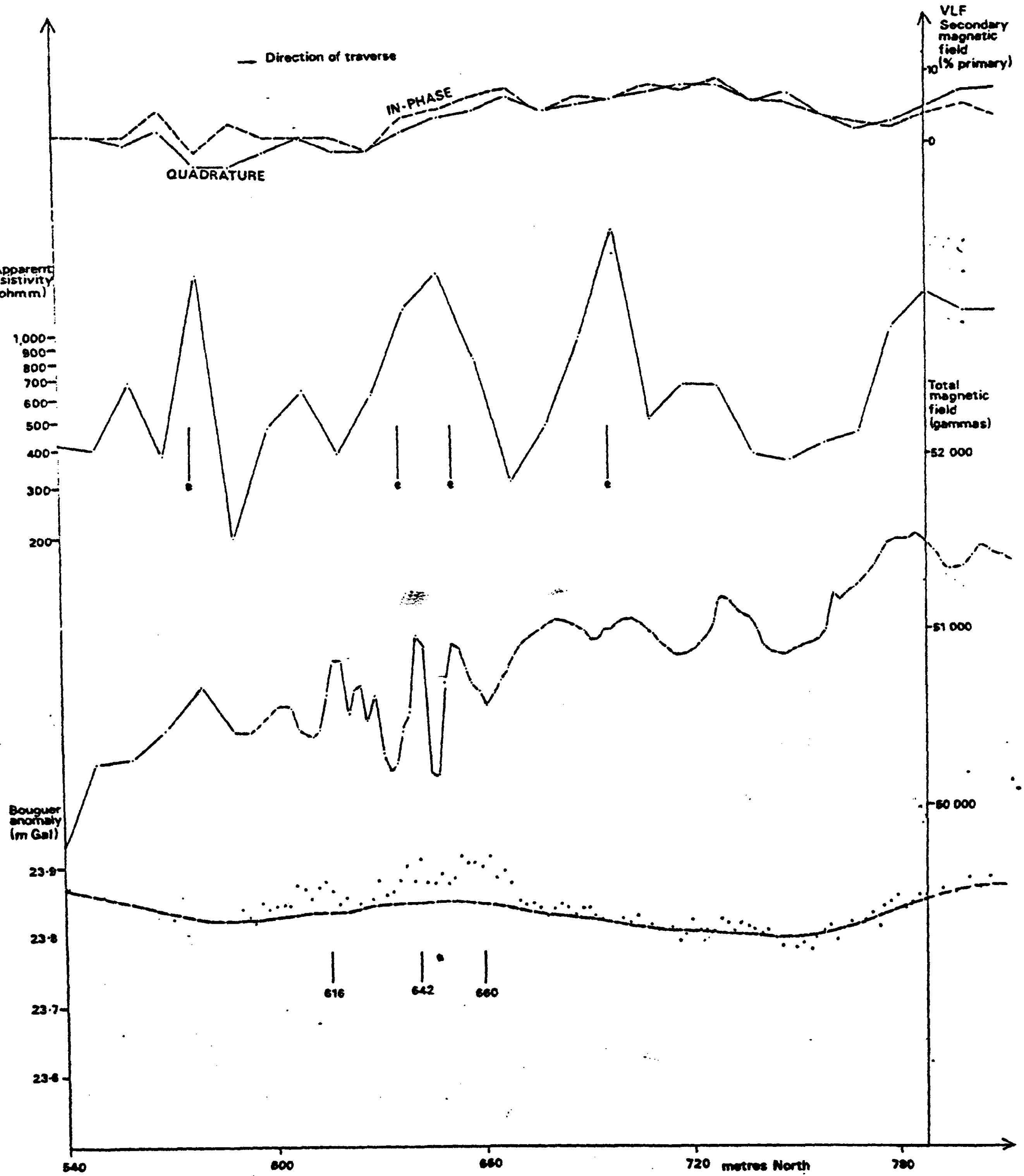

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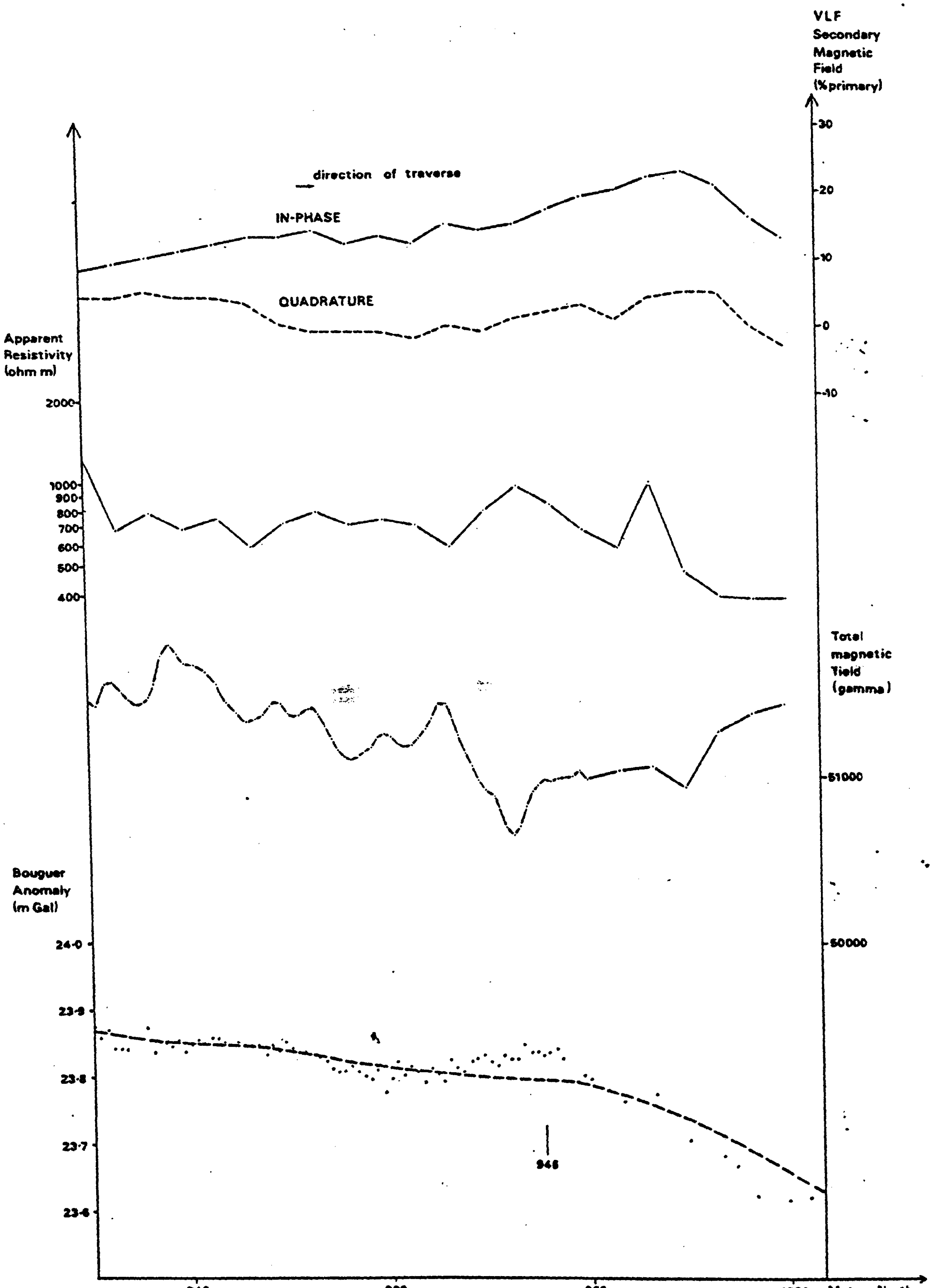

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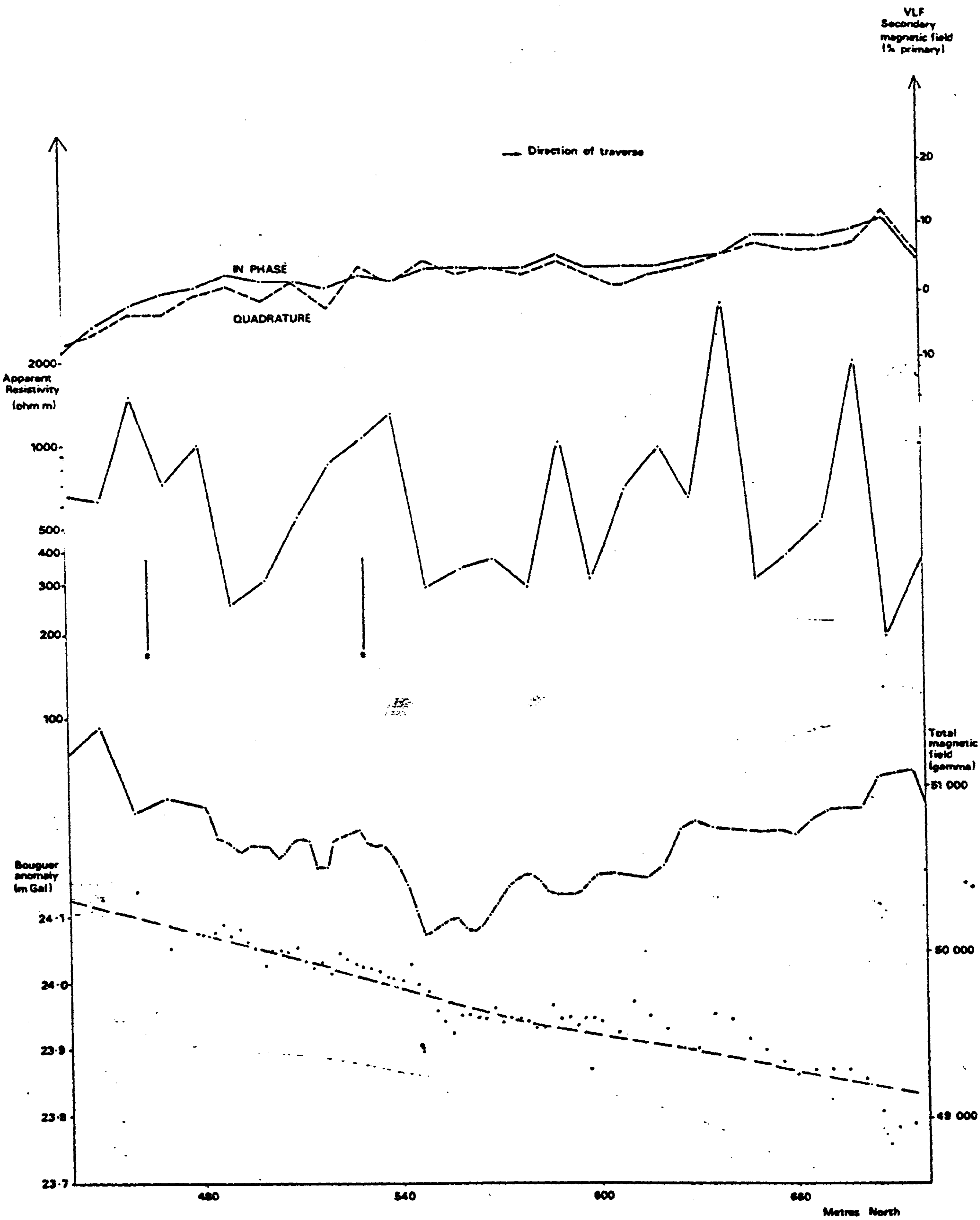

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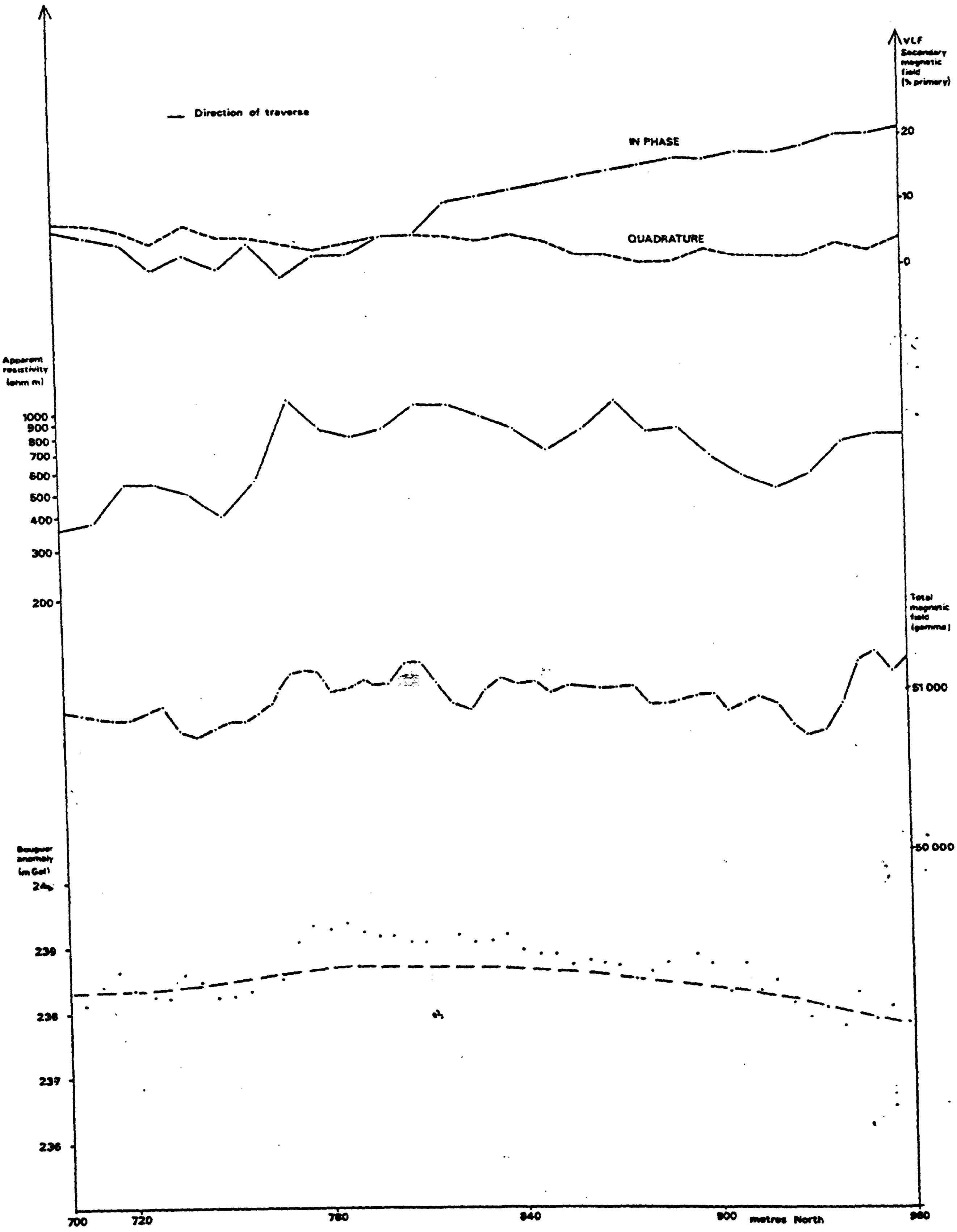
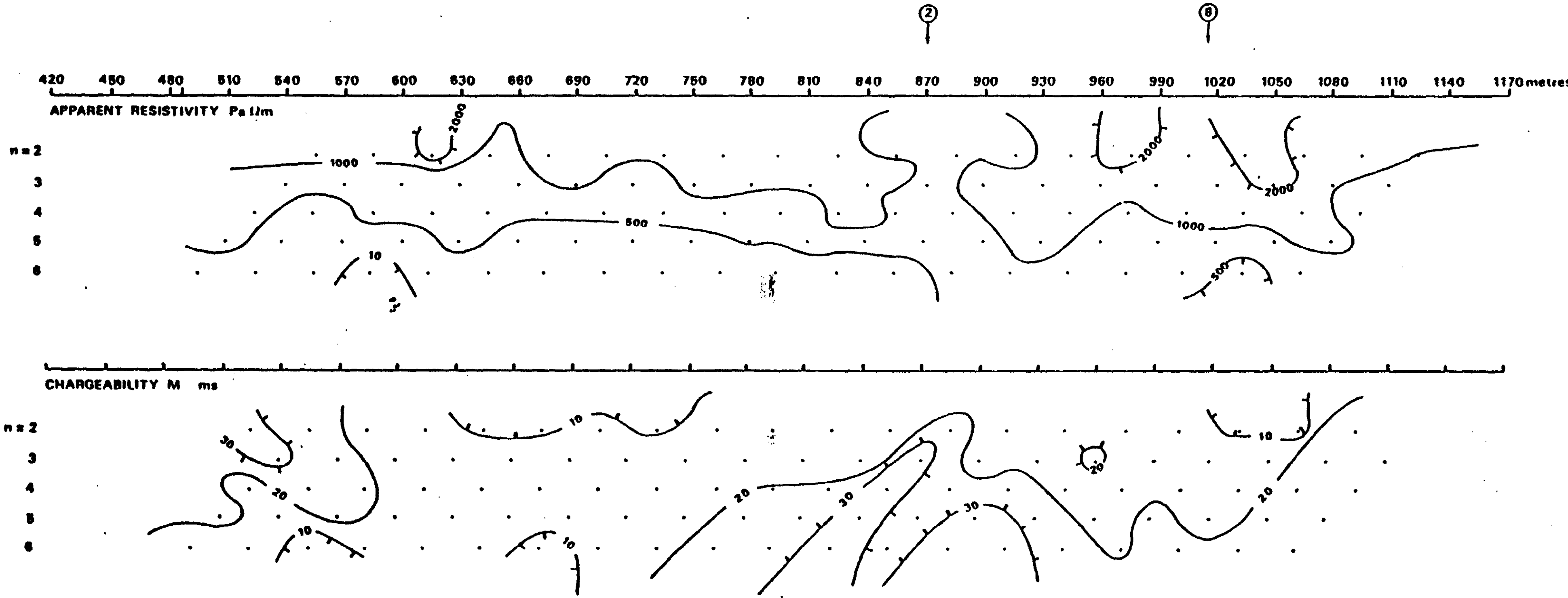


Appendix II Fig.18

APPENDIX III

IP PSEUDOSECTIONS

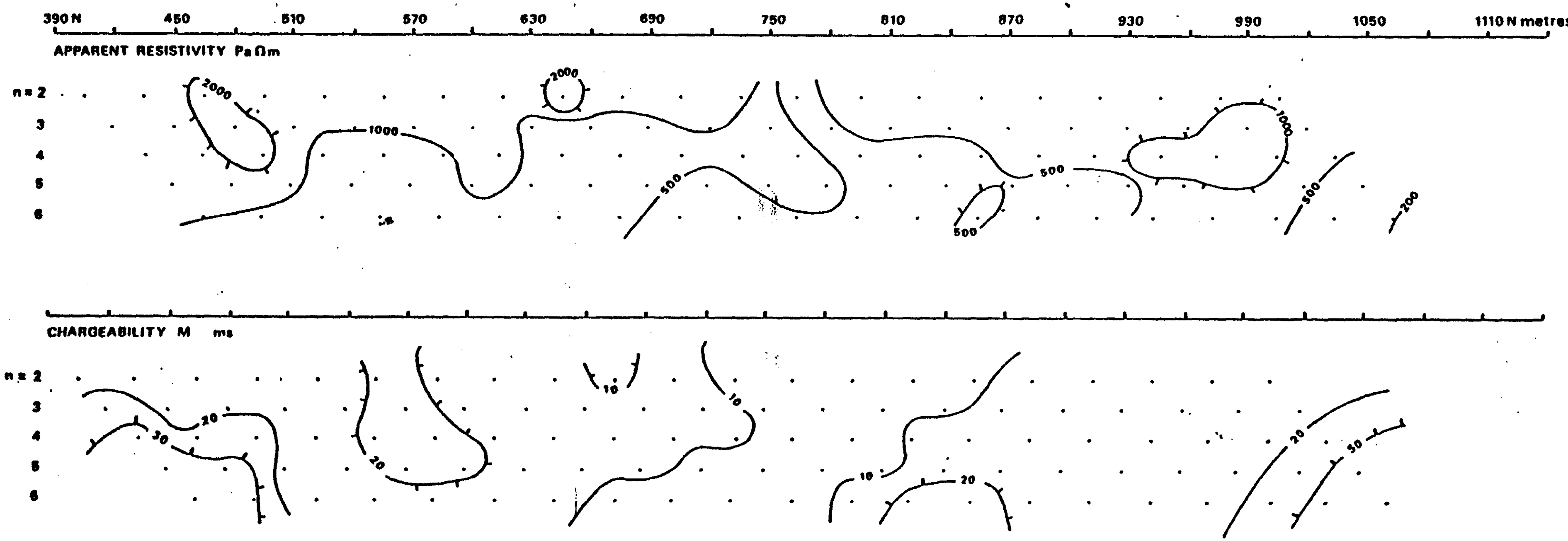
Fig 1	Line 1470E
Fig 2	Line 1590E
Fig 3	Line 1740E
Fig 4	Line 1890E



DIPOLE-DIPOLE ARRAY DIPOLE LENGTH 30m SAMPLING PERIOD 60ms SAMPLING DELAY 240ms

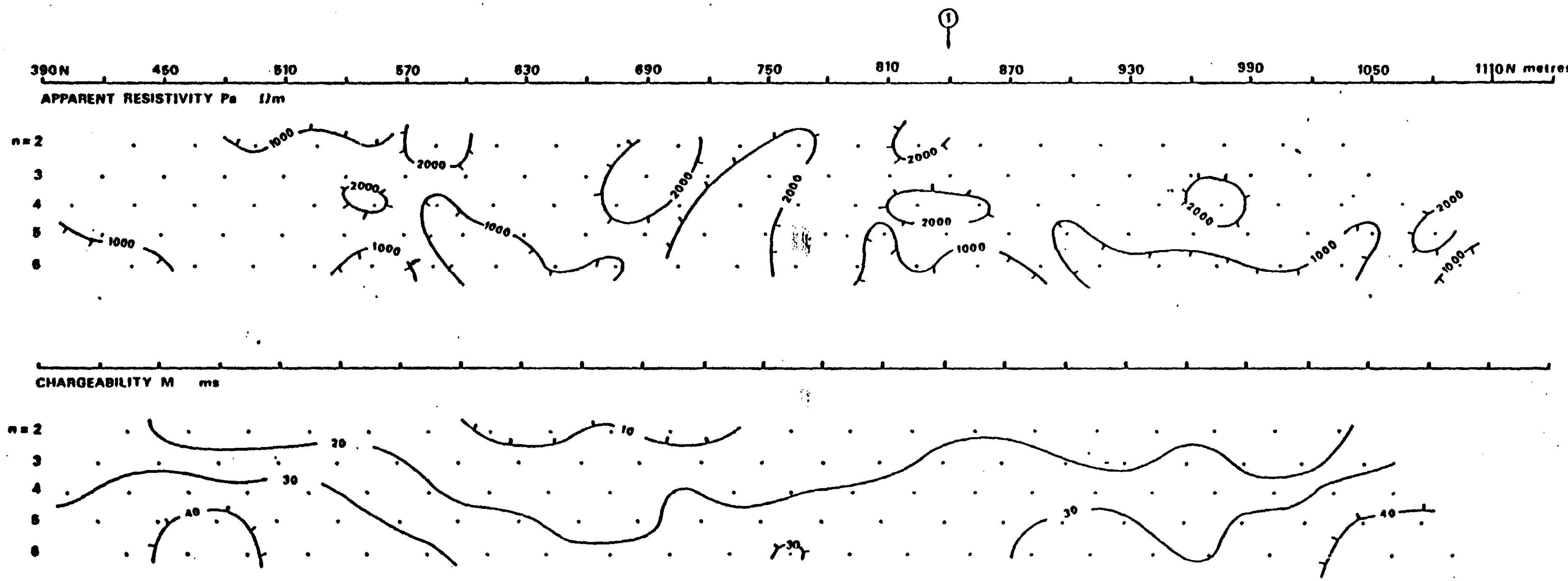
(2) position of 1976 gravity anomalies

Appendix III Fig.1



DIPOLE - DIPOLE ARRAY DIPOLE LENGTH 30m SAMPLING PERIOD 60ms SAMPLING DELAY 240ms

Appendix III Fig. 2



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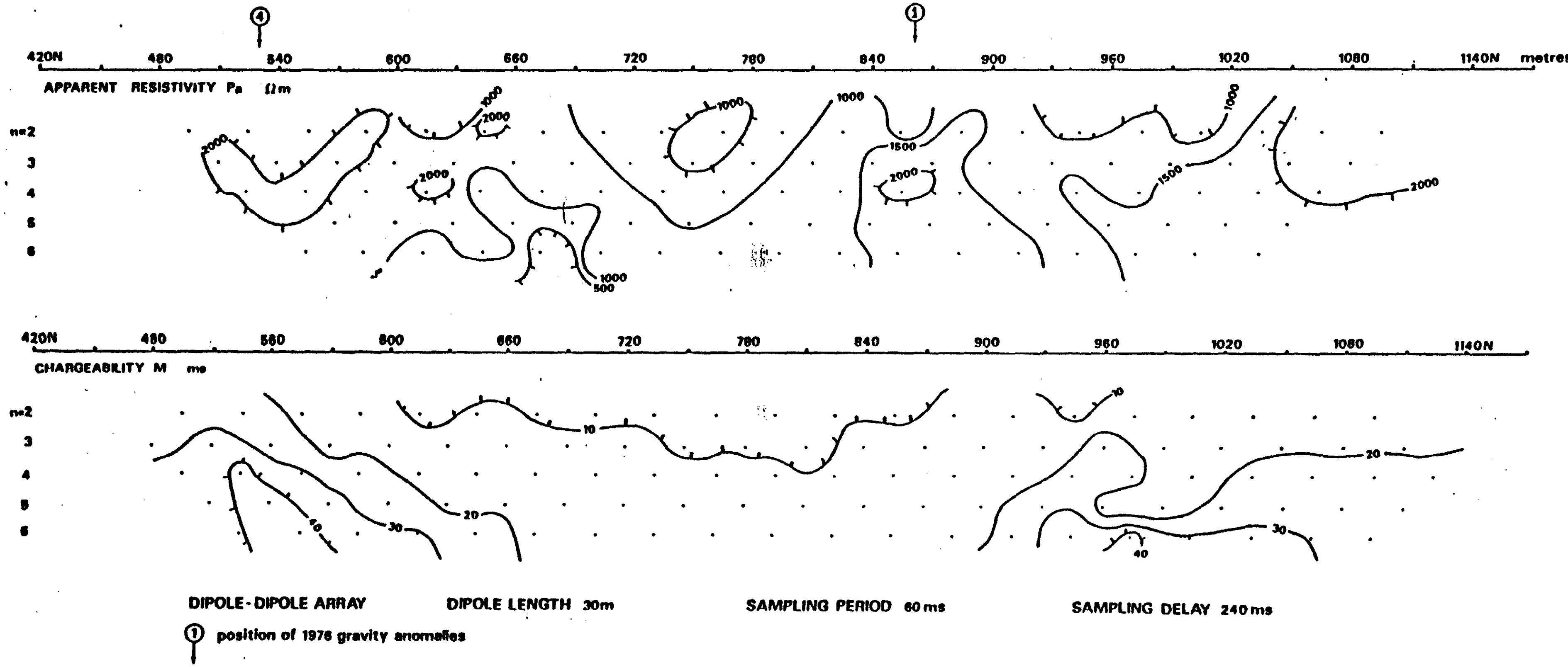
① position of 1976 gravity anomalies

Appendix III Fig.3



Appendix III Fig. 4

APPENDIX IV

BOREHOLE LOGS AND ESTIMATED CHROMIUM CONCENTRATIONS

BOREHOLE 1

Depth m	Inter-section m	Lithology	Mineralis-ation	Depth m	Inter-section m	Inferred Chromium %
0.00						
0.27	0.27	Superficial deposits				
		SERPENTINITE fairly uniform dark grey-green rock comprising tabular or lathlike (?) bastite pseudomorphs, up to 0.5cm across, and much finer pale green serpentine; latter appears to increase below 10.70m; pseudomorphs often sieved by serpentine; serpentinite commonly replaced by paler brown translucent mineral which emanates from cracks and joints; alteration, which is accompanied in places above 6.00m by limonite is particularly intense in following zones : 5.20 - 7.80m; 10.57 - 11.57m; 12.40 - 12.95m and 18.28 - 18.45m; cracks and joints in these zones often contain calcite ± serpentine from which thin calcite veinlets radiate in comb-like fashion	Disseminated chromite; traces of pyrite	1.42	1.02	0.40
				2.39	0.97	0.35
				3.40	1.01	0.40
				4.40	1.00	0.40
				5.40	1.00	0.45
				6.40	1.00	0.30
				7.40	1.00	0.40
				8.39	0.99	0.45
				9.40	1.01	0.50
				10.38	0.98	0.40
				11.39	1.01	0.45
				12.40	1.01	0.40
				13.38	0.98	0.30
				14.43	1.05	0.40
				15.40	0.97	0.35
				16.40	1.00	0.40
				17.41	1.01	0.30
				18.41	1.00	0.40
18.52	18.25			18.52	0.11	0.60

BOREHOLE 2

Depth m	Inter-section m	Lithology	Mineralis-ation	Depth m	Inter-section m	Inferred Chromium %
0.00						
0.40	0.40	Superficial deposits				
		SERPENTINITE; upper 20cm reduced to small fragments and partly limonitised; comprises blotchy brownish rock, similar to that forming the alteration zones in BH 1 with subordinate bands and patches of darker greenish grey serpentinite which below 10m (approx.) contain (?) bastite pseudomorphs; between 0.90 and 2.50m core is cut by vertical shears containing white (?) carbonate and, more rarely but more voluminously serpentine and talc; similarly infilled steeply inclined shear between 13.45 and 13.75m with prominent solution cavities; limonite which appears in the upper of these two shear zones is also common between 10.75 and 10.85, 11.20 and 11.40m and 14.40 - 15.00m; calcite veinlets are also present outwith the shear zones.	Disseminated chromite; native copper in serpentinite (9.91 - 9.96m) and in thin veinlet (8.65 - 8.85m)	1.52	1.12	0.50
				2.62	1.10	0.35
				3.52	0.90	0.50
				4.54	1.02	0.45
				5.52	0.98	0.45
				6.52	1.00	0.50
				7.52	1.00	0.45
				8.52	1.00	0.40
				9.52	1.00	0.40
				10.54	1.02	0.55
				11.52	0.98	0.60
				12.52	1.00	0.30
				13.50	0.98	0.50
14.32	13.92					
		SERPENTINITE, dark greenish grey with irregularly distributed bands and patches of brown serpentinite as above; (?) bastite pseudomorphs absent between 20.00 and 23.50m; veins which comprise calcite, serpentine and rare (?) asbestos occur principally in alteration zones.	Disseminated chromite; magnetite in veins; traces of pyrite and native copper in veinlet (15.43m)	14.52	1.02	0.55
				15.52	1.00	0.40
				16.52	1.00	0.35
				17.52	1.00	0.55
				18.52	1.00	0.35
				19.55	1.03	0.50
				20.52	0.97	0.40
				21.52	1.00	0.50
				22.52	1.00	0.55
				23.52	1.00	0.55
24.25	9.93			24.25	0.73	0.55

BOREHOLE 3

Depth m	Intersection m	Lithology	Mineralisation	Depth m	Inter-section m	Inferred Chromium %
0.00						
0.40	0.40	Superficial deposits				
4.50	4.10	SERPENTINITE, brownish with irregular patches of dark greenish grey unaltered serpentinite; strongly limonitised and core frequently reduced to small fragments above 1.60m; pale green serpentine present in veins which range in thickness from 1 mm to 35cm, the larger being present between 0.78 and 1.00m; 2.65 and 3.00m; and 3.56-3.80m; the latter is noticeably shattered and includes white (?) serpentine; serpentine veins are cut by irregular red and white carbonate veinlets	Disseminated chromite; trace of pyrite	1.71 2.76 3.80	1.30 1.05 1.04	0.50 0.40 0.30
15.72	11.22	SERPENTINITE, dark greyish green in which serpentine and fibrous amphibole appear to be main constituents; brownish alteration throughout with significant increase below zone of limonitisation and solution cavities at 11.44 - 11.57m; alteration most commonly encountered adjacent to calcite veins but from these frequently spreads out to occupy, on occasion most of core; both fresh and altered rocks cut by veins of greenish serpentine with comb-like calcite veinlets; core cut by steeply inclined 5 cm thick breccia zone between 13.46 and 13.62m with pale green calcite matrix	Sparsely disseminated chromite	4.76 5.77 6.77 7.78 8.76 9.77 10.77 11.77 12.75 13.78 14.77	0.96 1.01 1.00 1.01 0.98 1.01 1.00 1.00 0.98 1.03 0.99	0.45 0.60 0.40 0.40 0.50 0.60 0.50 0.40 0.40 0.45 0.50
24.35	8.63	SERPENTINITE, brownish with patches of dark serpentinite identical to above; three movement zones noted : (1) 17.63 - 17.90m, comprising pale green (?) serpentine traversed by network of haematite veinlets and quite soft in upper 5-6cm; (2) 23.37 - 23.35m, pale green and soft in lowest few cm with some brecciation and calcite veining; (3) 24.10 - 24.20m, similar to (2) but steeply inclined and only 3 cm thick; comprises pale green clay gouge; thin smear of asbestos on joints at 21.00 and 24.30m.	Sparsely disseminated chromite	15.78 16.76 17.73 18.79 19.77 20.77 21.76 23.02 24.00	1.01 0.98 0.97 1.06 0.98 1.00 0.91 1.26 0.98	0.45 0.50 0.50 0.45 0.45 0.50 0.45 0.40 0.55
37.38	13.03	SERPENTINITE, with probably a higher proportion of serpentine than previously; above 29.00m joints may be coated with calcite, green serpentine and, more rarely, (e.g. at 29.70m) asbestos; below 29.00m joint coatings rare but reappear between 31.15 and 31.65m where they comprise pale green serpentine with patches and smears of (?) chromite; between 34.73 and 34.83m, and 36.00 - 36.13m core is cut by veinlet carrying asbestos and bluish talc with grains of native copper in the latter; breccia zone, 30.95 and 31.03m, comprising angular fragments of serpentinite in soft pale clay gouge.	Disseminated chromite with local concentrations, finely divided pyrite; native copper in serpentinite (at 30.61m and sporadically below 36.13m) and in veins (34.73 - 34.83m; 36.00 - 36.13m)	25.04 26.01 27.02 28.00 29.00 30.02 31.04 32.03 33.03 34.00 35.02 36.02 37.38	1.04 0.97 1.01 0.98 1.00 1.02 1.02 0.99 1.00 0.97 1.02 1.00 1.36	0.50 0.45 0.40 0.40 0.45 0.50 0.45 0.45 0.60 0.50 0.40 0.40 0.50
37.38		End of borehole				

BOREHOLE 4

Depth m	Inter-section m	Lithology	Mineralisation	Depth m	Inter-section m	Inferred Chromium %
0.00						
1.00	1.00	Superficial deposits				
		SERPENTINITE, completely replaced by brownish alteration product in uppermost 2 cm; below this consists of fairly coarse-grained grey rock which, on the external surface displays a characteristic blotchy texture - the result of pervasive brown alteration; the serpentinite, also includes zones of paler brown (?) breunnerite, notably between 1.98 and 2.17m, 2.37m, and 3.29 - 3.33m; prominent veinlets of pale green asbestiform serpentine accompany the uppermost of these zones; between 3.33 and 3.50m core comprises much paler grey and more brittle rock with solution cavities; a foliation which is frequently affected by monoclinal folding appears at 7.90m and dies out below 9.70m; veinlets of pale green serpentine present at 3.00 - 3.10m, 4.20 - 4.48m (with marginal brown alteration) and below 11.85m	Rare chromite; trace of native copper (5.58m)	2.02	1.02	0.25
				3.02	1.00	0.30
				4.02	1.02	0.30
				5.00	0.98	0.20
				6.02	1.02	0.25
				7.02	1.00	0.30
				8.04	1.02	0.30
				9.02	0.98	0.30
				10.07	1.05	0.30
				11.03	0.96	0.30
				12.02	0.99	0.20
				13.02	1.00	0.25
				14.02	1.00	0.25
15.13	14.13			15.13	1.11	0.30
15.13		End of borehole				

BOREHOLE 5

Depth m	Inter-section m	Lithology	Mineralisation	Depth m	Inter-section m	Inferred Chromium %
0.00						
0.51	0.51	Superficial deposits				
		SERPENTINITE, considerably fresher than in BH4, comprising somewhat finer grained and more homogeneous dark grey-green rock devoid of blotchy texture; patchy dark brown alteration which figured so prominently in BH 1-3 again in evidence and above 3.20m is accompanied by pale yellow-brown limonite; alteration decreases below 5.06m and is absent below 10.00m; alteration in many places mantles zones (up to 15cm thick) of pale greenish serpentine with subordinate haematite and strong shearing.	Isolated chromite crystals with occasional clusters	1.53	1.02	0.25
				2.52	0.99	0.50
				3.52	1.00	0.50
				4.52	1.00	0.45
				5.54	1.02	0.30
				6.49	0.95	0.35
				7.50	1.01	0.35
				8.52	1.02	0.45
				9.50	0.98	0.35
				10.51	1.01	0.50
				11.52	1.01	0.35
				12.52	1.00	0.50
				13.52	1.00	0.30
				14.52	1.00	0.55
15.05	4.54			15.05	0.53	0.40
15.05		End of borehole				

BOREHOLE 6

Depth m	Inter-section m	Lithology	Mineralis-ation	Depth m	Inter-section m	Inferred Chromium %
0.00						
0.52	0.52	Superficial deposits				
0.73	0.21	SERPENTINITE dark grey with pronounced blotchy texture - resembling dominant rock in BH4; strongly limonitised in uppermost 3 cm and lowermost 1 cm.		0.52	1.15	0.45
6.60	5.87	SERPENTINITE, pale green with conspicuous bands of dark serpentinite; below 5.25m (approx) passes gradually into pale to mid grey serpentinite which is transitional with the underlying unit; banding mostly vertical or steeply inclined (60°+) though locally more gentle as a result of open folding; also disrupted in many places by shearing with some incipient brecciation; shears and joints infilled with pale buff to ochreous (?) carbonate	Chromite ranging from isolated crystals to bands of massive ore 20cm	2.67	1.00	5.60
				3.67	1.00	2.00
				4.77	1.10	0.40
				5.80	1.03	0.30
				6.77	0.97	0.20
5.43	8.83	SERPENTINITE mid grey with dark grey bands; banding not as conspicuous as in above unit, possibly because of the diminished colour contrasts and the restriction of the darker unit in places to thin partings; area characterised by thin partings have, in addition, a closely spaced schistosity; band of pale green serpentinite occupies most of core, between 8.00 and 8.50m; irregular veinlets of pale buff to ochre carbonate occur throughout and in places contain pale grey mineral; latter mineral dominant between 7.55 and 8.30m where the net vein complex encloses angular fragments of serpentinite	Disseminated chromite	7.77	1.00	0.30
				8.75	0.98	0.35
				9.77	1.02	0.60
				10.77	1.00	0.40
				11.78	1.01	0.40
				12.77	0.99	0.45
				13.79	1.02	0.75
				14.77	0.98	0.65
				15.43	0.66	0.45
15.43		End of borehole				

BOREHOLE 7

Depth m	Inter section m	Lithology	Mineralis-ation	Depth m	Inter-section m	Inferred Chromium %
0.00						
0.90	0.90	Superficial deposits				
18.82	17.92	SERPENTINITE, dominantly dark grey with occasional pale grey bands and rare greenish patches; schistosity/closely spaced shears present throughout much of length; principally vertical to steeply dipping with local variations resulting from folding; core in general quite broken and above 3.20m mostly reduced to small fragments; core lost between 1.12 and 1.40m; evidence of small scale faulting between 10.50 and 11.00m in disruption of banding and incipient brecciation; serpentinite cut by innumerable veins and veinlets of pale buff to white carbonate with, in places subordinate pale green asbestiform (?) serpentine; may be mantled or, more rarely cut, by an ochreous mineral; veins generally up to 3cm in thickness but between 2.64 and 2.84m core is dominated by patchy carbonate with only minor fragments of country rock	Disseminated chromite with some enriched bands	2.88	1.39	0.15
				4.02	1.14	0.50
				5.04	1.02	0.30
				6.00	0.96	-
				7.02	1.02	0.60
				8.00	0.98	0.35
				9.02	1.02	1.70
				10.00	0.98	0.35
				11.02	1.02	1.50
				12.02	1.00	0.20
				13.00	0.98	0.30
				14.01	1.01	0.40
				15.02	1.01	0.10
				16.02	1.00	0.50
				17.02	1.00	0.60
				18.05	1.03	0.75
				18.82	0.77	0.35
18.82		End of borehole				

Fig 2 Topography and geology of the survey area with locations of geophysical surveys and borehole sites