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OUTOKUMPU OY

EXPLORATION

195

T Katajarinne/km

17.5.1985

LØKKEN GRUBER A/S

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ENVIRONMENT OF THE LØKKEN MINE
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OF THE LØKKEN MINE 26.8. - 7.9.1984

The report deals with the results and interpretations of the AMT and gravimetric surveys undertaken at three targets, Løkken, Høydal and Svinsås, in the environments of the Løkken mine.

The report also includes the results of the petrophysical measurement performed at the targets.

Report of the investigations was carried out for the Løkken Gruber A/S, Norway

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AMT AND GRAVIMETRIC SURVEYS IN THE ENVIRONMENT OF THE LØKKEN MINE 26.8.
- 7.9.1984

SUMMARY

Three AMT and four gravimetric profiles were surveyed at three targets close to the Løkken mine to test the applicability of the methods to deep exploration in this area. The survey targets were the deep portions of the Løkken ore deposit, the Svinsås target and the Høydal ore deposit (appendices 1 - 9).

In addition, the majority of the drill holes still open at the targets were measured with a Norma resistance meter, and a number of determinations of the petrophysical parameters were undertaken on the drill core samples at the petrophysical laboratory of Outokumpu Oy Exploration in Espoo.

A power line and another man-made source interfered with the AMT surveys at Løkken; elsewhere no technical difficulties were encountered. Altogether 41 soundings were done along three profiles. There were no great surprises and the results are considered positive. In spite of the disturbances, the Løkken orebody was localized at the right depth. Indications of massive conductors were not encountered at the other targets. The established vasskis horizons do not mask so much as to prevent the discovery with AMT of a massive highly conductive sulphide body at fairly great depth (1000 m), e.g. at Svinsås. Reasonable depth penetration (500 m) could also be obtained with other electromagnetic sounding methods, e.g. the transient method.

According to the petrophysical determinations, host rocks heavier than the country rocks are not associated with either the Løkken or Høydal orebodies or with the Svinsås ore showing. Use of the gravimetric method is further hampered by the rough topography, which has a dominating effect on the survey data. The data can be interpreted reliably only after careful terrain correction has been done. No gravity anomalies are associated with the profiles surveyed.

Norma resistance measurements were conducted in 24 drill holes. Susceptibility, density and resistivity were measured from drill core samples of five holes, and the IP effect for the samples of three holes. Remanence was determined for 15 drill core samples. No continuous zones of high conductivity were encountered. Host rocks heavier than the country rocks do not appear to be associated with the ores in the

area. There are numerous zones of magnetic rocks, generally with magnetite as the magnetic mineral, in the environment of Løkken. The ore and S-bearing rocks are only weakly, if at all, magnetic. More petrophysical measurements must be made before a reliable picture is obtained of the Løkken formation. Clear IP anomaly effects were noted in places in the holes measured. The Q values from the remanence measurements are distributed as follows: Q = 0.1 - 0.4, 9 samples, Q = 1.2 - 6.9, 5 samples, Q = 20, one sample.

Ensio Lakanen undertook the AMT surveying and wrote the corresponding part of the report; Tapani Katajarinne was responsible for the rest. Both geophysicists participated in the surveying in Norway.

DETERMINATION OF THE PETROPHYSICAL PARAMETERS

Since the application of geophysical methods, in the present case AMT and gravimetry, is based on physical properties of the various rock types, the results of the petrophysical measurements will be discussed first.

Measuring equipment

Drill hole logging	
apparent resistance	Norma resistance meter range: 1 - 5000 Ω 1-point method
Laboratory measurements	
susceptibility	TH-1, Geoinstruments range 5 - 1000000x10 ⁻⁵ SI
resistivity	VTT resistivity meter (VTT = Technical Research Centre of Finland) range: 10 ⁻³ - 10 ⁶ Ω m
density	Mettler balance
IP effect	McPHAR IP Core Tester
remanence	Förster remanence meter

Logging and measurements on core samples (table 1)

Resistance was measured in the drill holes at intervals of 1 m. On account of the fracture zones, few of the holes could be logged to the bottom. Density, susceptibility and resistivity were measured on the drill core samples at intervals of 1 - 5 m.

FE % (Frequency effect) was determined at intervals of 5 m. Remanence was measured for 15 samples from three holes at various depths.

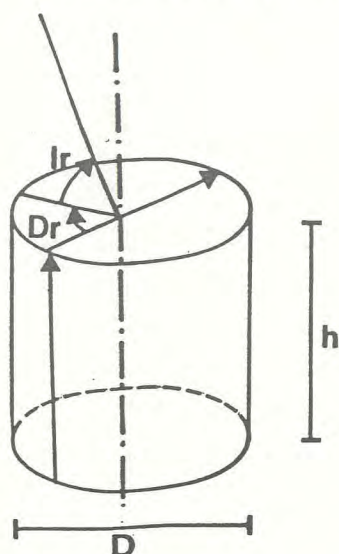
Moreover, susceptibility, density and resistivity were measured for nine rock types typical of the Løkken formation and for 10 gabbro samples.

Table 1. Petrophysical data.

Hole	depth/m		drill hole samples				
	drilled	Norma meas.	susc	density	resist.	IP	remanence
Interval →	1 m		1-5 m		5 m		
Lø-1		79	235	235	235	230	40, 179, 180, 181
-2		457					
Sv-3	360	337	355	355	355		
4	432	432	432	432	432	150-180	256, 275, 315
5	275	263	275	275	275		
6		216					
Hø-31	353	349					
43	269	33					
45	357	21					
46	262	148					
47	239	169					
49	290	287					
50	217	210					
52	268	223					
53	240	234					
55	203	202	203	203	203	31-140	49.5, 58.7, 70, 109.5
57	139	103					
62	373	50					
85	144	135					
87	292	42					
89	361	49					
93	106	96					
95	361.2	350					
45A		145	(two holes measured with code Hø-45)				

The numbers in table 1. show to what depth from the collar of the hole or over what interval (IP) the determinations were made. For the remanence, the numbers indicate the depth from which the sample was taken.

Remanence determinations



The absolute value of remanence and the Q value (= the ratio of remanent magnetization to induced magnetization) were measured on 15 unoriented samples from three drill holes. Hence it is not possible to determine the direction of the remanence. The reference directions for the measurement were marked as shown in Fig. 1 on cylindrical pieces cut from the drill core. The arrow parallel to the axis of the cylinder points upwards in the drill hole.

Some of the samples were tapped with a hammer and remeasured to test how stable the remanence was. No demagnetization tests were performed.

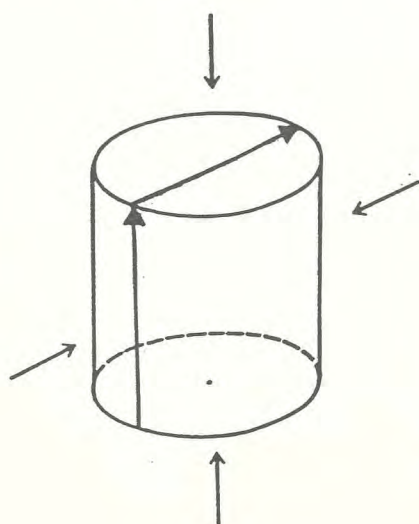
Fig. 1.

From the measuring data it can be concluded (Table 2) that:

- Excluding two data, $Q = 6.9$ and $Q = 20$, Q is less than 4. In 9 out of 15 samples Q is less than 0.4
- In a certain hole (Hø-55) the Q value may vary between 0.1 and 20.
- Q seems to be independent of susceptibility.
- For the magnetic interpretation it is important to know whether the direction of remanence is parallel to the Earth's magnetic field. Unoriented samples cannot answer this question.
- Tapping tests suggest that drilling has not significantly changed the magnitude and direction of remanence. The tapping seems only slightly to reduce the Q values.

Table 2. Remanence data from Lökken. Unoriented samples.

SAMPLE	SUSCEPT.	Jr	Dr	Ir	Q	REMARKS
BH-1/40 m	3500	970	313	3	6.9	
" "	"	967	314	3	6.8	tap ↓
" "	"	955	317	2	6.7	tap ↙
" 179 m	10780	110	17	-79	0.3	
" 180 m	47200	460	354	-72	0.3	
" 181 m	20400	301	90	74	0.4	
Hø-55/49,5 m	12000	1784	14	40	3.8	
" "	"	1767	4	42	3.7	tap ↓
" "	"	1707	4	44	3.6	tap ↙
" "	"	1402	340	33	3.1	tap ↑
" "	"	1402	358	35	3.1	tap ↗
" 58,7 m	900	2	243	42	0.1	
" 70 m A	11200	1189	240	-72	2.7	
" "	"	1067	234	-72	2.4	tap ↓
" "	"	712	0	-68	1.6	tap ↙
" "	"	1141	238	-73	2.6	tap ↑
" "	"	1119	246	-67	2.6	tap ↗
" 70 m B	11500	9109	187	2	20	
" "	"	8135	187	3	17.8	tap ↓
" "	"	7500	184	8	16.4	tap ↙
" "	"	7160	185	6	17	tap ↑
" "	"	7000	190	8	17	tap ↗
" 109,5 m	10100	162	150	23	0.4	
SV-4/255,9 m A	5000	52	177	73	0.3	
" 255,9 m B	7000	58	165	71	0.2	
" 275,3 m A	14000	1961	7	-24	3.6	
" "	"	1786	9	-25	3.2	tap ↓
" "	"	1395	9	-34	2.5	tap ↙
" "	"	1459	19	-35	2.6	tap ↑
" "	"	1418	12	-36	2.5	tap ↗
" 275,3 m B	10920	514	333	-82	1.2	
" "	"	493	325	-85	1.1	tap ↓
" "	"	367	336	-82	0.8	tap ↙
" 315 m A	11480	94	207	65	0.2	
" 315 m B	5460	29	203	66	0.1	



Dr declination of remanence in degrees from the reference direction.

Ir inclination of remanence in degrees from the reference direction.

Tapping directions

The Løkken formation

It was not possible either to measure any of the drill holes that intersected the Løkken ore or to get a continuous set of drill core samples for laboratory determinations. Hence a petrophysical model section cannot be constructed for the formation. A preliminary concept of the petrophysical properties of the rocks of the formation can, however, be obtained from drill holes Lø-1 and Lø-2 (appendices 10 - 11), which intersect the country rocks, and from the type samples (Table 3). At a depth of 145 m Lø-1 intersects a conductive S-bearing horizon whose lowest resistivity values measured on the core samples are 0.01 - 1 Ω m. The Norma measurement in Lø-1 had to be stopped at a fracture at 79 m. A zone as conductive as that has not been encountered in the other holes measured. Lø-2 intersects several zones with low resistance (300 - 800 Ω). Similar zones are met with in the holes at Høydal and Svinsås. Apart from the narrow magnetite-bearing jasper layers at 40 m and 179 - 181 m Lø-1 is not magnetic. It is noteworthy that the S-bearing conductive horizon at 115 - 145 mentioned above is completely non-magnetic. Lø-1 shows several layers that differ in density. Thus, for instance, $\rho = 2.96 \text{ g/cm}^3$ at 53 - 25 m, $\rho = 2.8 \text{ g/cm}^3$ at 40 - 55 m, $\rho = 3.00 \text{ g/cm}^3$ at 60 - 120 m and $\rho = 3.82 \text{ g/cm}^3$ at 125 - 145 m. IP determinations were done in Lø-1 at intervals of 5 m. At a depth of 60 - 145 m there is a layer that becomes clearly polarized.

Table 3. Petrophysical data on the type samples from the Løkken formation.

Sample	density suscept. resistivity		
	g/cm ³	x10 ⁻⁵ SI	Ωm
Svartfjell, H-71 155 m	3.58	40	8 x 10 ⁻²
Urenkis	4.14	80	2 x 10 ⁰
Vasskis	3.39	1100	1 x 10 ⁻¹
Massiv malm A	4.66	520	1 x 10 ⁻¹
Massiv malm B	4.57	570	1 x 10 ⁻²
Vesicular putelava	2.97	90	2 x 10 ⁵
Puterbreksje	2.87	110	1 x 10 ⁵
Massiv grönsten	2.82	2360	3 x 10 ⁵
Putelava	2.89	610	7 x 10 ⁴
SU-1 125 m Gabbro	3.05	120	7 x 10 ⁵
" 159 m "	3.08	140	1 x 10 ⁶
" 263.5 m "	3.03	150	5 x 10 ⁵
" 303 m "	3.10	170	8 x 10 ⁵
" 311.5 m "	3.01	140	4 x 10 ⁵
" 314.5 m "	2.98	130	1 x 10 ⁶
" 315 m "	3.10	170	3 x 10 ⁵
" 560 m "	3.04	120	8 x 10 ⁵
" 698 m "	3.02	110	1 x 10 ⁷
" 816 m "	2.91	190	1 x 10 ⁶

The result from the type samples (Table 3) is clear. The ore and sulphide-bearing rocks differ from the country rocks very distinctly in density and conductivity but not in magnetic properties.

The ore does not differ from the sulphide-predominant rocks (vasskis) in petrophysical properties.

The measurements on the gabbro samples from drill hole Su-1 indicate that the density of the gabbro is anomalously high ($2.91 - 3.10 \text{ g/cm}^3$), that the samples are only slightly magnetized ($110 - 190 \times 10^{-5} \text{ SI}$) and that they are insulators (ρ more than $5 \times 10^5 \text{ } \Omega\text{m}$).

The number of samples was too small to permit the differences in petrophysical parameters between the country rocks to be evaluated.

Svinsås

The laboratory measurements demonstrate that drill hole SV-5 (appendix 14) intersected several thin zones that are intermediate ($10 - 100 \text{ } \Omega\text{m}$) or moderate ($0.1 - 10 \text{ } \Omega\text{m}$) conductors. The three lowest values of resistivity are: $0.1 \text{ } \Omega\text{m}$ at 233 m, $4 \text{ } \Omega\text{m}$ at 235 m and $6 \text{ } \Omega\text{m}$ at 211 m; pyrite seems to be the conductive mineral in all of them. Magnetite makes the first two highly magnetic as well.

This discontinuous layer composed of several thin conductive zones (appendix 17) crops out on profile $y = 0.3$ at $x = 0.9$ as suggested by the Genie measurement (appendices 54 - 56). The conductive zone shows a distinct improvement eastwards.

The lowest resistivity values measured from the cores of drill holes SV-3 and SV-4 (appendices 12 - 13) are 1000 and 3000 Ωm . The lowest resistance values measured from holes are 50 - 100 Ω .

All three holes SV-3, 4 and 5 intersected a discontinuous zone, 7 - 15 m thick, that is intensely magnetized in places (appendix 18). This layer may crop out at $x = 0.8 - 1.0$ (appendices 49 and 58). The magnetized mineral seems to be invariably magnetite.

Holes SV-3, 4 and 5 start with a 20 - 30 m thick layer that has a density exceeding 2.9 g/cm^3 . Below it the density is reduced. In drill holes SV-3 and 4 the density increases again below the magnetized layer (appendix 19). The high densities in the holes (density exceeding 3.5) were measured on the vasskis intersections. Drill hole SV-5 is bottomed (at a depth of 260 - 275 m) in quartz porphyry with a low density of ca. 2.65 g/cm^3 .

Høydal

Most of the open holes in area were measured with Norma (appendices 20 - 23). In drilling profile 121, which was surveyed with AMT and gravimetry, only holes Hø-31 and 51 were open down to the bottom (appendices 24 - 25). Drill hole Hø-31 intersects a thin layer with disseminated chalcopyrite at 193 - 198 m. Holes Hø-43, 44 and 45 intersect a thicker Cu-bearing

zone that could not be measured because of blocking in the holes. The lowest resistance of all the holes at Høydal, 20 Ω , was encountered at 194 m in Hø-50. The conductive mineral is pyrite.

Elsewhere the resistance is 150 Ω or higher. Thus, highly conductive zones were not encountered. Felsite, however, differs from its environment owing to its distinctly lower resistivity (appendices 24 - 25). The contact between the upper surface of the felsite with disseminated chalcopyrite and greenstone is manifest as a marked boundary surface of resistivity. The resistivity contact between the felsite and the underlying agglomerate is even more distinct. The layer with the disseminated chalcopyrite at 193 - 198 m in Hø-31 does not differ in conductivity from the felsite.

The same lithological association, albeit without mineralized portions, was, however, intersected in profile 117 (appendices 25 - 26) west of drilling profile 121. Susceptibility, density and resistivity were measured for the core samples from Hø-55 drilled in this profile.

Felsite also differs from the environment in being more conductive in the Norma measurements. Laboratory measurements do not indicate a difference in resistivity. The higher in situ conductivity is due to the ionic conductivity. The felsite at a depth of 100 - 110 m as well as the overlying greenstone at 40 - 100 m are fairly intensely magnetized (ca. $10\,000 \times 10^{-5}$ SI) (appendices 25 and 27). The magnetized zone is also manifest as slightly elevated density values. The same magnetized zone is probably encountered on drilling profile 121.

AMT MEASUREMENTS

General

Audiomagnetotellurics, or AMT for short, is a little brother of magnetotellurics, differing from the latter only in its limited frequency range. Both are passive electromagnetic sounding methods, i.e. Nature herself acts as transmitter. The frequency range used in AMT exceeds 1 Hz, i.e. it comprises ELF (3 - 3000 Hz) and the lower part of VLF (max. 20 kHz), with thunder storms, which can be at a distance of thousands of kilometres, as a source of energy. The electric field is measured with oriented electrodes and the magnetic field with coils tuned for the appropriate frequency band. The square of the ratio of the voltages measured with electrodes and coil multiplied by a natural constant gives the

apparent resistivity, R_a , which is an absolute value when the ground is homogeneous. The scalar equipment, French ECA-541 used by Outokumpu Oy Exploration, measures directly the R_a of the frequency desired, thus speeding up the measurements. On account of the random nature of the source, the result is the mean of several pulses, and attempts are made to eliminate fast variations and man-made disturbances. Over 10 soundings can be done with the scalar AMT in one working day; the corresponding figure for magnetotellurics is one at most.

As an electromagnetic method the AMT hunts for conductors. The more the conductor differs from its environment the more unambiguously the technique localizes it. It is even sensitive to conductors that are poor in absolute values provided the channelling of the electric currents results in significant enhancement. The depth penetration of the method is good, even up to 2000 m, owing to the intensity of the natural fields and the great distance from the source. The location of the surficial conductors must be known if the aim is to reach great depths, and they must not be so conductive as to mask the information coming from deeper levels. Little has been written about the positive and negative features of the method, and this cannot be done briefly. The measuring philosophy developed by Outokumpu Oy has been described by Lakanen (1985, submitted for publication in Geophysics).

Measurements and data processing

The profile over the Løkken ore deposit comprised 11 soundings over a distance of 600 m. At Svinsås 20 soundings were made over a distance of 1150 m and at Høydal 10 soundings over a distance of 500 m. For the intensity of the natural fields the time was not the best possible. Nevertheless the fields were strong enough to exceed the sensitivity of the equipment at each site for all the frequencies except at 8 and 3700 Hz a couple of times. To eliminate the short-lasting variations each frequency was measured at least three times at suitable intervals. One site along each profile was chosen as a reference station, which was measured when starting the day's survey of the profile. The minimum azimuth was determined at each station, as described by Lakanen (1985). The reference station showed that the variation in the distance of the source fields was so small that no corrections were needed.

The data were processed with a HP9845 into profiles as sets of three frequencies. The layered earth model interpretation, 1D, was accomplished with an interactive program first as a routine for all the profiles, then with integration of all the relevant factors. The Bostick inversion, a rough multi-layer interpretation, which considers even the slightest variations in the data, was performed on the manually smoothed results. The depth contours are shown with static correction and automatic gain, which means that the results were normalized in relation to each other, thus improving their readability. The mean of each sounding, R_a , is given in ohm-metres. The results of the 1D interpretation are given as cross-sections, in which a short line indicates the upper surface of the conductive layer, and the number next to it the interpreted resistivity. The bar extending downwards means that the lower surface of the conductor was not reached. The azimuth of the measurement in relation to the profile is indicated by an arrow clockwise from the north and numbers are in gones ($90^\circ = 100$ g).

Løkken

The orebody is located on the survey profile at a depth of about 800 m. Unfortunately a new power line had been erected about 200 m south of the orebody and running parallel to it. This still interferes with the readings at a distance of 300 m, and a station (100 m) close to it could not be surveyed at all. An unknown, intense peak occurred in the electric field at regular intervals of about one second making integration impossible and hampering reading of the instrument. Only one sounding, 300 m north of the orebody, could be done in the normal way. The ventilation machine of the mine a few hundred meters below the profile was suspected of causing the disturbance. The interference was weaker at a supplementary site measured 100 m higher up the hill. Tests done early on Saturday and Sunday morning did not help; the disturbance existed all the time.

The reliability of the sounding data suffered severely because of the interferences, see appendices 28 - 32. Nevertheless the more detailed examination indicated the anomalous behaviour over the orebody at low frequencies. The interpretation also gave the correct depth, 800 m, fairly accurately (appendix 60). The anomaly is weaker at the next station 100 m northwards, and still weaker at the station 150 m

northwards. A spacing of 100 m between the first three sounding stations was chosen in order to get rid of the interference caused by the power line. The remaining soundings indicate a weak conductivity contrast at great depth, but it has no significance and may just be due to lateral changes. The anisotropy is small, i.e. the readings in minimum and maximum azimuths do not differ much. The results corroborate those from previous AMT measurements performed by Sulitjelma AS before the construction of the power line.

Svinsås

A profile with four drill holes and a known vasskis horizon with a gentle dip was selected here. Measuring was easy in the area, and there were none of the interferences encountered at Løkken. A distinct minimum azimuth, 100 - 140 g, was established at intermediate frequencies. At lower frequencies, however, a different azimuth, 60 g, with weak anisotropy was obtained. The results indicate weak conductivity contrasts, see appendices 33 - 37. Only a few indications of higher conductivity were noted in the southern portion of the profile, but they are at depths on which there are no drilling data (appendix 36). The known vasskis horizon is not conductive, continuous or thick enough, because even the high frequencies penetrate it. Rather, the data suggest that another more uniform zone exists beneath the vasskis, in which case it should crop out farther south. The phenomenon could also be attributed to a change in the strike of the vasskis horizon, to its edge, a break in it or to a strong bend close to the profile. At any rate the observed conductive layer is as gently dipping as the vasskis horizon. The strongest indication of the conductor was measured at 250 S (-0.25). At about the same site drill hole No. 5 intersected a narrow but conductive zone, 0.1 ohm-metres. It may be cut by a fault to the north, where five soundings indicate a shallower conductor with lower conductivity correlating with the zone of disseminated sulphides intersected by the drill holes. The point close to the road gives abnormally high resistivities. North of the road there are only low conductivity contrasts. Notice that rather low resistivity of 1 ohm-meter was used to determine depth. This is needed, because Bostick-inversion indicates only narrow zones.

Høydal

The known orebody gave a straightforward result, appendices 38 - 42. At the outcrop there is a strong minimum but the orebody seems to lack depth extension. Two smaller minima, which may be due to outcropping greenstone zones rich in magnetite, were detected at 50 and 200 S (0.05, 0.2). The other indications may be due to pseudoeffects, though they do correlate with the bottom of the formation. No big massive conductors were encountered here.

GRAVITY MEASUREMENTS

General

Sulphide ores are often associated with skarn rocks, mafic formations or other rocks that are heavier than the country rocks and show up on the gravity map as positive anomalies. The anomaly caused by the ore cannot usually be distinguished from the anomaly of the host rock.

According to petrophysical measurements, host rocks heavier than the country rocks occur in neither the ore deposits at Løkken and Høydal nor in the showing at Svinsås. Thus a gravity anomaly, if present, is due to the ore alone and small orebodies cannot be located at great depths. This was demonstrated by calculating a few examples for each target.

The rough topography in the environment of Løkken is another factor hampering application of gravity survey. Its influence dominates the anomaly pattern as is demonstrated by the two rough terrain corrections calculated for the Løkken profile.

Apart from localizing ore, gravity measurements can also be used to develop and test a regional geological model; for that purpose a regional gravimetric survey on a sparse grid is sufficient. This, however, requires that comprehensive and representative density measurements be made on the rocks in the area.

All the profiles measured exhibit a distinct and rather linear gradient to the north, 1.0 - 4.5 mGal/km.

Execution of the measurements

The measurements were made with a Worden Master gravimeter No. 1207 owned by Outokumpu Oy Exploration. The reading accuracy of the equipment is 1×10^{-2} mGal.

After a training period of one day Mr. Tor Walseth was ready to be our surveyor. The three helpers required were from the mine. Mr. T Katajarinne did the book-keeping and supervised the survey on the Løkken 1 and Svinsås profiles. The Høydal and Løkken 2 profiles were surveyed under the supervision of Mr. Tor Walseth. The elevation was measured with a RRKM-20 elevation difference meter manufactured by Rautaruukki Oy. It has an accuracy of ± 20 cm/km.

The survey data were calculated to Bouguer values, i.e. drift, latitude, relative elevation and Bouguer corrections were applied to the data.

Terrain correction

The influence on the survey data caused by the rough topography in the Løkken area was evaluated by calculating a rough terrain correction for the Løkken-1 profile with both a prism model and a sector method (appendix 43).

For the prism method the elevation data were collected for each survey point parallel to the slope from an economy map (ekonomisk kartverk) at a scale of 1:5000. In this example the shape of the terrain was outlined with four prisms.

In the sector method the environment of a point was divided into four sectors. The terrain correction was calculated with the following equation (P Kearey & M Brooks: An Introduction to Geophysical Exploration, p. 153).

$$T = 0.491 \times 10^{-3} \frac{\rho}{n} (r_2 - r_1 + \sqrt{r_1^2 + z^2} - \sqrt{r_2^2 + z^2})$$

T = terrain correction of a sector

ρ = density (kg/m^3)

n = number of sectors

r_1 = inner radius (m) of the sector

r_2 = outer radius of the sector

z = elevation of the calculation sector (= difference in elevation between the survey point and the centre of the sector).

In both models of calculation only the influence of the nearby topography, which causes sharp variation in the anomaly curve, was taken into consideration, i.e. over a distance of 0 - 200 m from the survey point. The variation in topography in the terrain farther away may induce large changes in the anomaly curve, but these changes are gently sloping.

Topography has a marked effect on the anomaly pattern. The sharp changes in the anomaly curves of the four profiles measured may be attributed almost wholly to the variation in topography (appendix 44).

Løkken

Profile 1 was measured across the orebody at a site where the orebody is at a depth of 800 m. An anomaly caused by an orebody 50 m high, 100 m wide and 1000 m long at a depth of 800 m and with a vasskis horizon 30 m high, 200 m wide and 1000 m long 20 m beneath it was calculated on the ground surface. The densities measured, 4.5 g/cm^3 for ore, 3.5 g/cm^3 for vasskis and 2.8 g/cm^3 for country rock, were used. The interpretation profiles were calculated to pass through the middle of the prisms (appendix 45).

The ore and vasskis at this depth produce an anomaly of about 0.1 mGal, which cannot be distinguished from the Bouguer curve. According to the example calculated the upper surface of the orebody should be at a depth of about 200 m before the anomaly attributed to its manifest in profile surveying. In systematic measurements the orebody in the example manifests itself at somewhat greater depth in the anomaly pattern.

The gradient rising northwards is 1.5 mGal/km on the Løkken 1 profile. A shorter profile (appendix 46) was measured east of the above profile. No clear gravity anomaly could be observed here either. The northward gradient is 1 mGal/km.

Svinsås

No anomaly caused by ore or any other rock heavier than the country rocks was encountered in the measurements.

On account of the smoother terrain the anomaly curve is more tranquil than at Løkken.

The gradient rising northwards is linear and 4 mGal/km in magnitude. A thin vasskis horizon has been intersected at Svinsås by drill holes at a depth of 200 - 300 m (appendix 16). In the interpretation example the ore is positioned at depths of 150 m and 400 m. The ore is represented by a prism 200 m wide, 300 m long and 20 m thick. A prism measuring 20 x 400 x 300 m has been positioned 30 m below the ore to correspond to a vasskis horizon.

The ore can be observed at a depth of 150, 200 m but not at 400 m (appendix 47). The size of the orebody in the example is 5.4 million tonnes, that of the vasskis horizon 8.4 million tonnes.

Høydal

No gravity anomaly due to the ore or any other rock heavier than the country rocks is known here either. The linear gradient, 4.5 mGal/km, increases northwards. In the interpretation model the low-grade

Cu mineralization intersected by drill holes was replaced by prisms 100 m long with cross-sections the same size as the cross-section of the Cu mineralization.

The model does not produce on the ground surface an anomaly detectable in measurements (appendix 48). An orebody like the one described (ca. 2.4 mill. t) might respond to the gravity measurements if its upper surface is at a depth of 0 - 50 m.

ADP DRAWING OF THE GEOPHYSICAL MAPS OF SVINSÅS

As agreed upon in the status by K Mäkelä (5.7.1984), the results of the magnetic, VLF, Genie and IP (n = 4) measurements undertaken at the Svinsås target were stored and drawn as maps by computer (appendices 49 - 57). Two prism interpretations were done on the data of the magnetic survey.

The trend of the magnetized conductive zones could have been established more reliably had the line spacing been shorter. If the lines are diagonal to the anomaly zones and the line spacing is long the interpolation technique used in drawing the maps does not always connect the zones correctly. According to the interpretation, the magnetized zone in the southern margin of the survey area dips northwards (appendices 58 - 59), which is consistent with the results of the drilling. As indicated by the interpretation, the width of the outcrop in the zone is greater than that of the outcrop intersected by drill holes. The magnetized zone may consist of several narrow layers. To establish whether this is the case, the spacing between the survey points should be 5 or 10 m. A survey done on a denser grid would also permit more detailed interpretation.

CONCLUSIONS AND RECOMMENDATIONS

In spite of the interfering power line close to the survey site the AMT measurement gave a weak but distinct response for the Løkken ore at a depth of 800 m. Highly conductive continuous zones were not encountered along the survey profiles at Svinsås and Høydal (poorly conductive zones were though). According to the resistivity measurements, the drill holes have not intersected such zones either. As shown by the measurements on the type samples the Løkken ore is highly conductive as was expected. AMT is a suitable method when searching for blind ores in the extensions of the known feeder zones. It is useful particularly because of its cheapness and because the data can be interpreted fairly reliably when extending the survey below 500 m.

The results of the gravity survey, the prism interpretations, the examples of the terrain corrections and the density determinations have revealed two factors that hamper application of the gravity survey in the area: 1. The Løkken ore deposit does not seem to have a host rock heavier than the country rocks, 2. the rough topography in the area dominates the anomaly pattern.

It is difficult to discover small blind orebodies by gravity methods. Interpretation succeeds only after a detailed terrain correction has been done.

For future geophysical measurements and interpretations it is recommended that, if possible, a reliable and representative petrophysical model cross section be constructed for the Løkken formation to establish the electric (conductivity, FE), magnetic and density properties of the rocks. This is important for the planning of survey methods and the interpretation of data.

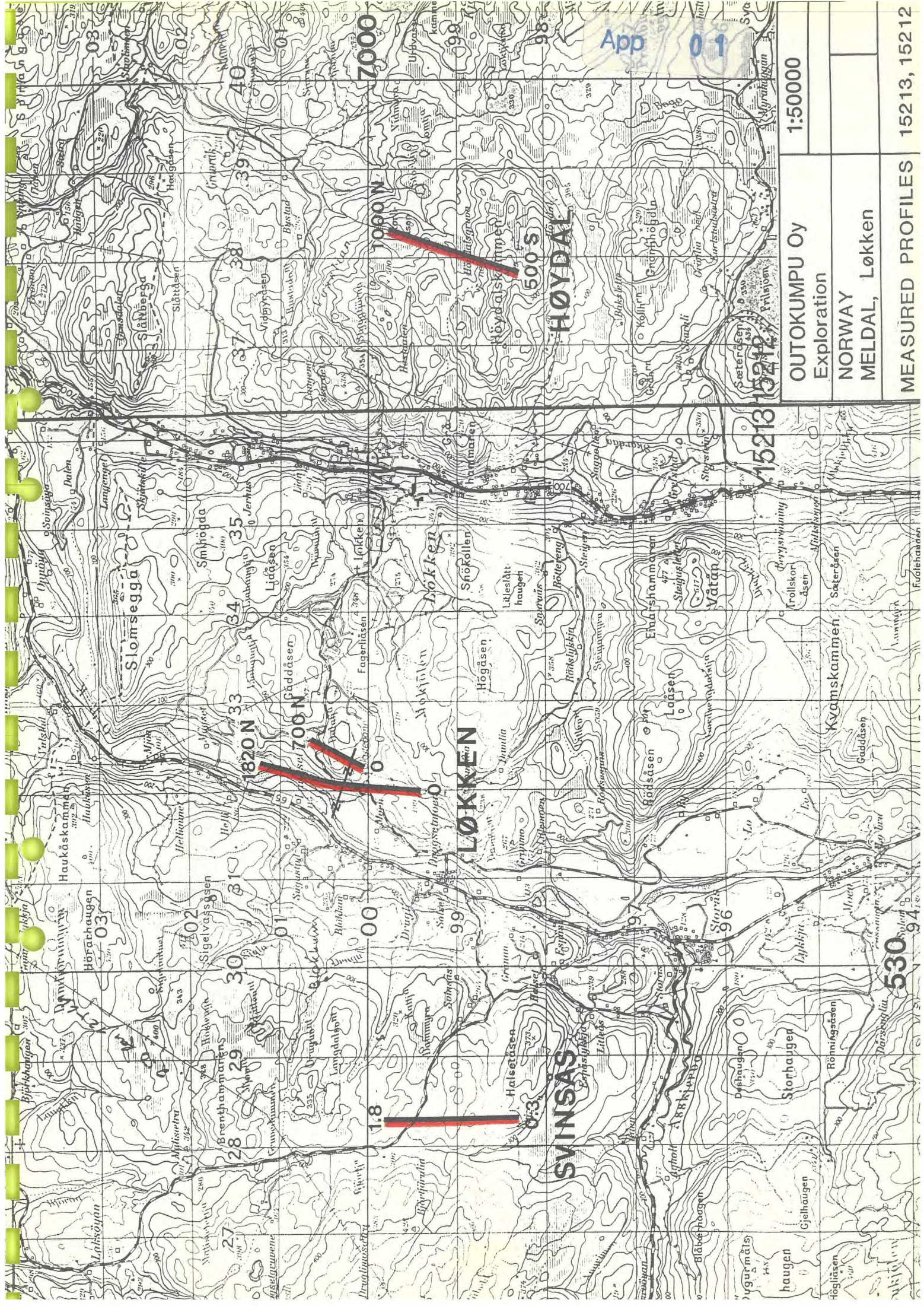
It is proposed that the following instruments of reasonable price be acquired to measure the petrophysical parameters:

- A resistance meter (Norma or similar) and a cable winch ca. 10,000 - 15,000 Nok.
- A field susceptibility meter (e.g. JH-8/Geo-instruments) ca. 8,000 - 10,000 Nok.
- A device to measure chargeability (IP).
- An ordinary balance for determining density.

It is proposed that a desk top calculator be acquired with the necessary interpretative programs to process and interpret the survey data. The price of a package that could accomplish these tasks is likely to be from 100,000 Nok upwards.

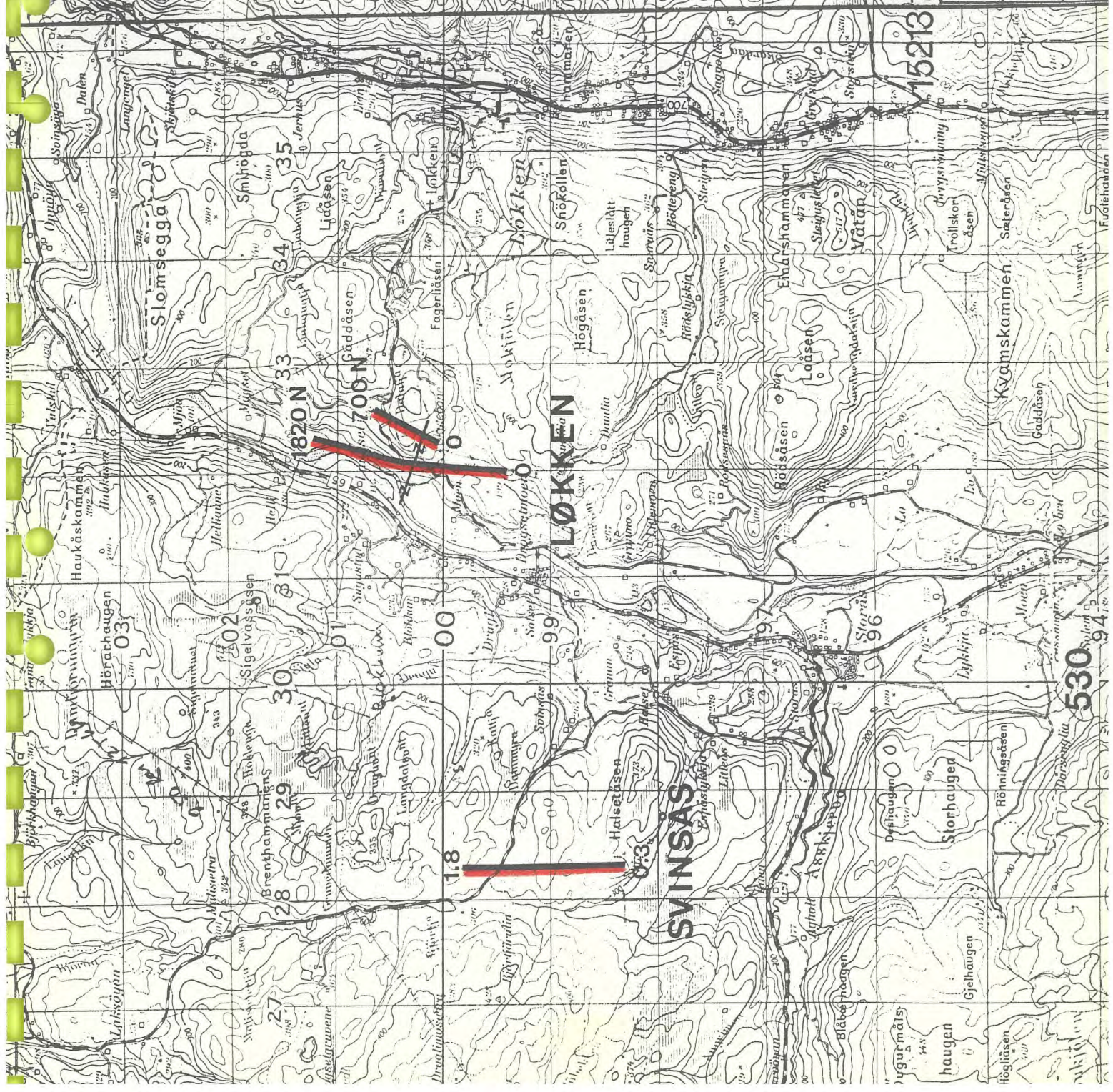
APPENDICES

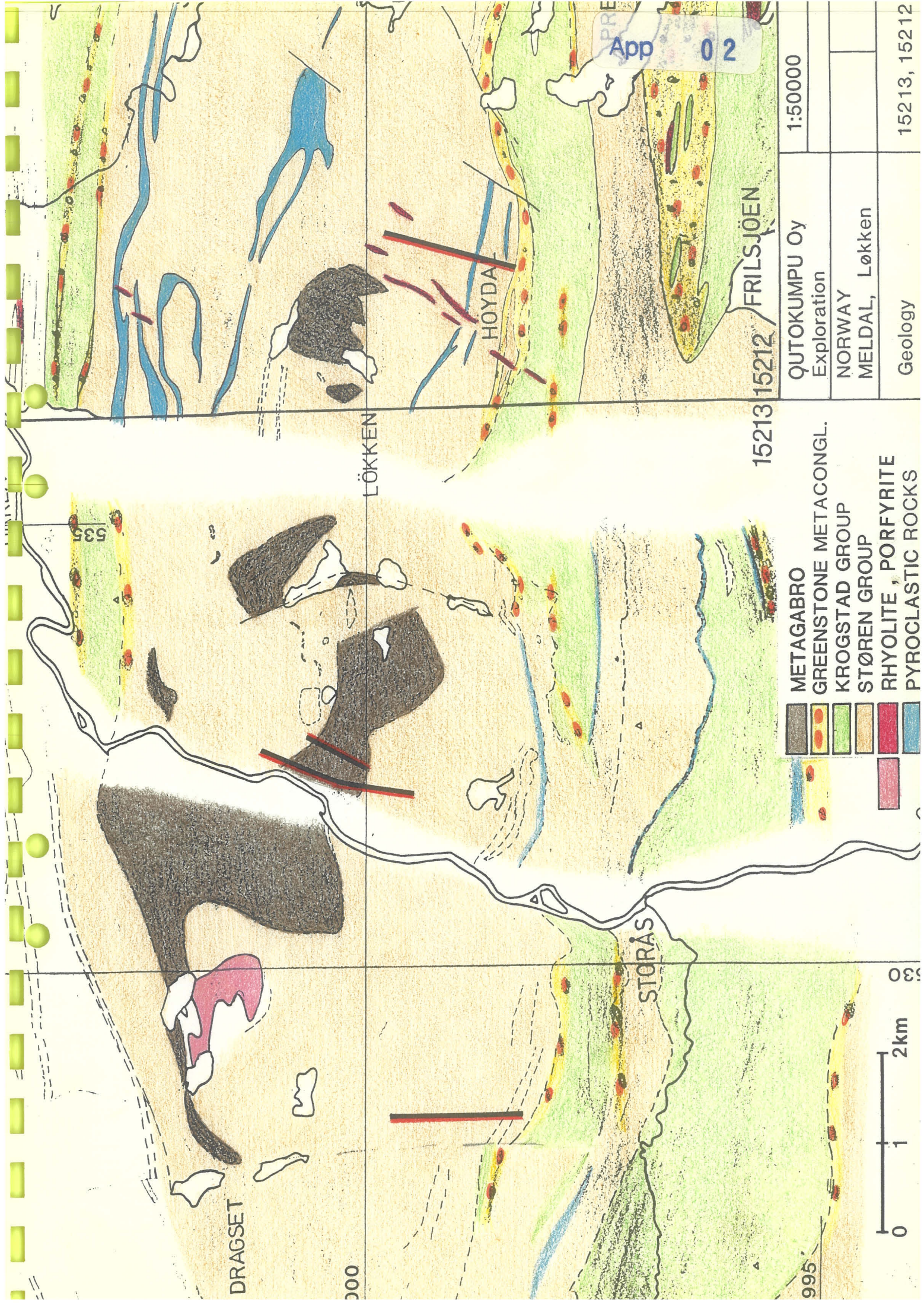
1	Profiles measured, topographic map	1:50000
2	" geological map	1:50000
3	" aeromagn. map (Dighem)	1:50000
4 - 6	" geological maps	
7	" Løkken, economic map	1:5000
8	" Svinsås " "	1:5000
9	" Høydal " "	1:5000
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17 - 19	Petroph. cross-section, Svinsås y = 0.3	1:5000
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58	Magnetic interpretation, Svinsås y = 0.3	1:5000
59	" y = 0.6	1:5000
60	AMT " , Løkken station 0	



App 01

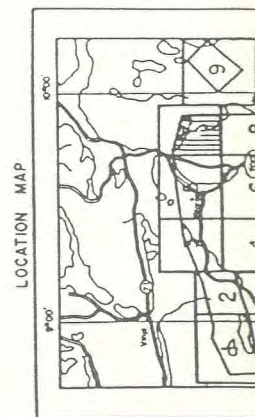
OUTOKUMPU Oy	1:50000
Exploration	
NORWAY	
MELDAL, Løkken	
MEASURED PROFILES	15213, 15212





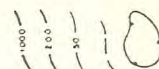
- METAGABRO
- GREENSTONE METACONGL.
- KROGSTAD GROUP
- STØREN GROUP
- RHYOLITE, PORPHYRITE
- PYROCLASTIC ROCKS

QUTOKUMPU Oy	1:50000
Exploration	
NORWAY	
MELDAL, Løkken	
Geology	15213, 15212



ISOMAGNETIC LINES
(total field)

1000	gauss
200	gauss
50	gauss
25	gauss
magnetic disturbance	



1:100,000

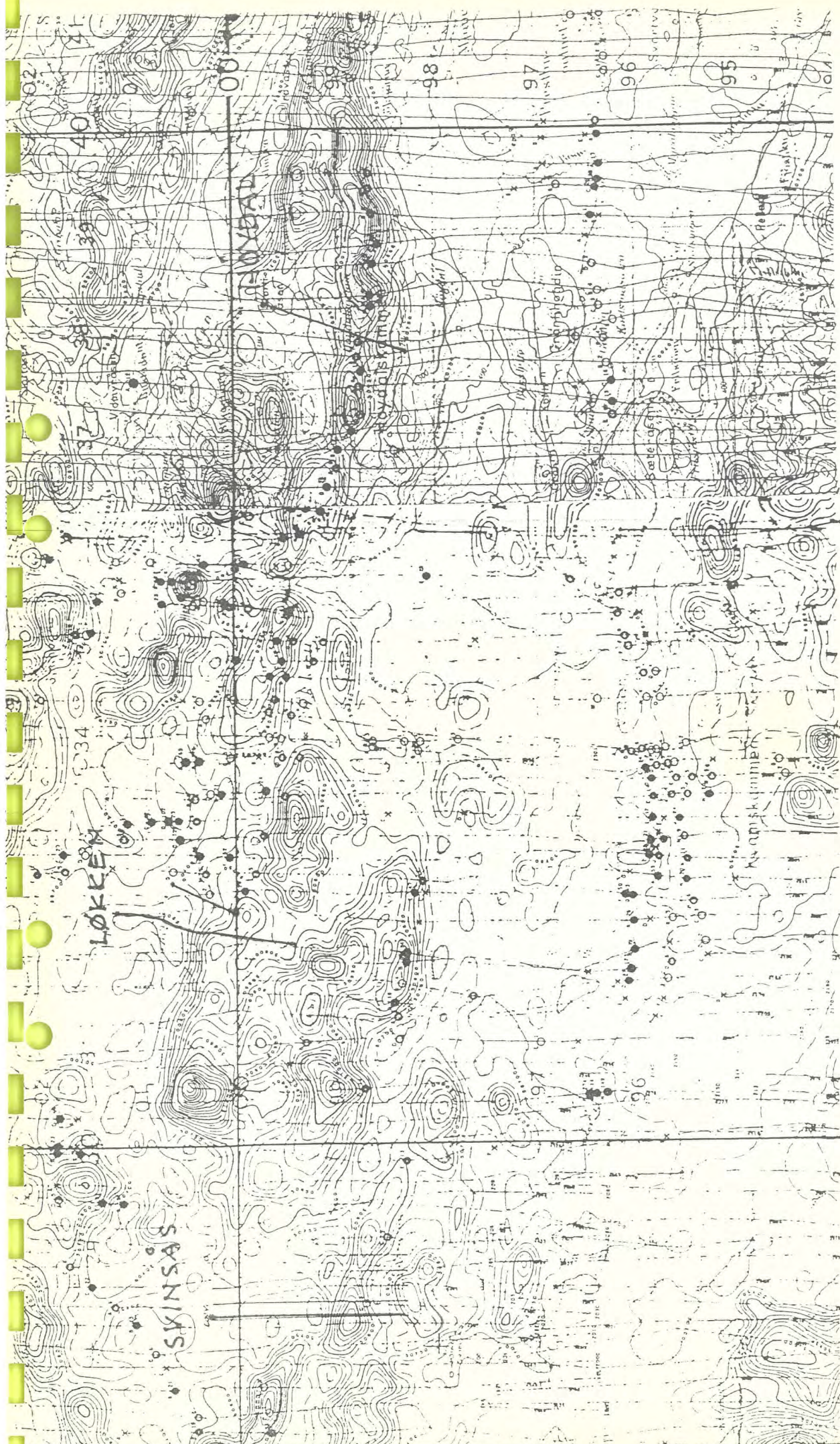
1:100,000

DIGHEM^{II} SURVEY

LOKKEN AREA, NORWAY

MAGNETICS

FOR





Bergvesenet

Postboks 3021, 7002 Trondheim

Rapportarkivet

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OUTOKUMPU OY

EXPLORATION

195

T Katajarinne/km

17.5.1985

LØKKEN GRUBER A/S

AMT AND GRAVIMETRIC SURVEYS IN THE
ENVIRONMENT OF THE LØKKEN MINE
26.8. - 7.9.1984

1984



AMT AND GRAVIMETRIC SURVEYS IN THE ENVIRONMENT
OF THE LØKKEN MINE 26.8. - 7.9.1984

The report deals with the results and interpretations of the AMT and gravimetric surveys undertaken at three targets, Løkken, Høydal and Svinsås, in the environments of the Løkken mine.

The report also includes the results of the petrophysical measurement performed at the targets.

Report of the investigations was carried out for the Løkken Gruber A/S, Norway

by Tapani Katajarinne and Ensio Lakanen
Geophysicist Research Geophysicist

O U T O K U M P U Oy
Exploration

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AMT AND GRAVIMETRIC SURVEYS IN THE ENVIRONMENT OF THE LØKKEN MINE 26.8.
- 7.9.1984

SUMMARY

Three AMT and four gravimetric profiles were surveyed at three targets close to the Løkken mine to test the applicability of the methods to deep exploration in this area. The survey targets were the deep portions of the Løkken ore deposit, the Svinsås target and the Høydal ore deposit (appendices 1 - 9).

In addition, the majority of the drill holes still open at the targets were measured with a Norma resistance meter, and a number of determinations of the petrophysical parameters were undertaken on the drill core samples at the petrophysical laboratory of Outokumpu Oy Exploration in Espoo.

A power line and another man-made source interfered with the AMT surveys at Løkken; elsewhere no technical difficulties were encountered. Altogether 41 soundings were done along three profiles. There were no great surprises and the results are considered positive. In spite of the disturbances, the Løkken orebody was localized at the right depth. Indications of massive conductors were not encountered at the other targets. The established vasskis horizons do not mask so much as to prevent the discovery with AMT of a massive highly conductive sulphide body at fairly great depth (1000 m), e.g. at Svinsås. Reasonable depth penetration (500 m) could also be obtained with other electromagnetic sounding methods, e.g. the transient method.

According to the petrophysical determinations, host rocks heavier than the country rocks are not associated with either the Løkken or Høydal orebodies or with the Svinsås ore showing. Use of the gravimetric method is further hampered by the rough topography, which has a dominating effect on the survey data. The data can be interpreted reliably only after careful terrain correction has been done. No gravity anomalies are associated with the profiles surveyed.

Norma resistance measurements were conducted in 24 drill holes. Susceptibility, density and resistivity were measured from drill core samples of five holes, and the IP effect for the samples of three holes. Remanence was determined for 15 drill core samples. No continuous zones of high conductivity were encountered. Host rocks heavier than the country rocks do not appear to be associated with the ores in the

area. There are numerous zones of magnetic rocks, generally with magnetite as the magnetic mineral, in the environment of Løkken. The ore and S-bearing rocks are only weakly, if at all, magnetic. More petrophysical measurements must be made before a reliable picture is obtained of the Løkken formation. Clear IP anomaly effects were noted in places in the holes measured. The Q values from the remanence measurements are distributed as follows: Q = 0.1 - 0.4, 9 samples, Q = 1.2 - 6.9, 5 samples, Q = 20, one sample.

Ensio Lakanen undertook the AMT surveying and wrote the corresponding part of the report; Tapani Katajarinne was responsible for the rest. Both geophysicists participated in the surveying in Norway.

DETERMINATION OF THE PETROPHYSICAL PARAMETERS

Since the application of geophysical methods, in the present case AMT and gravimetry, is based on physical properties of the various rock types, the results of the petrophysical measurements will be discussed first.

Measuring equipment

Drill hole logging	
apparent resistance	Norma resistance meter range: 1 - 5000 Ω 1-point method
Laboratory measurements	
susceptibility	TH-1, Geoinstruments range 5 - 1000000x10 ⁻⁵ SI
resistivity	VTT resistivity meter (VTT = Technical Research Centre of Finland) range: 10 ⁻³ - 10 ⁶ Ω m
density	Mettler balance
IP effect	McPHAR IP Core Tester
remanence	Förster remanence meter

Logging and measurements on core samples (table 1)

Resistance was measured in the drill holes at intervals of 1 m. On account of the fracture zones, few of the holes could be logged to the bottom. Density, susceptibility and resistivity were measured on the drill core samples at intervals of 1 - 5 m.

FE % (Frequency effect) was determined at intervals of 5 m. Remanence was measured for 15 samples from three holes at various depths.

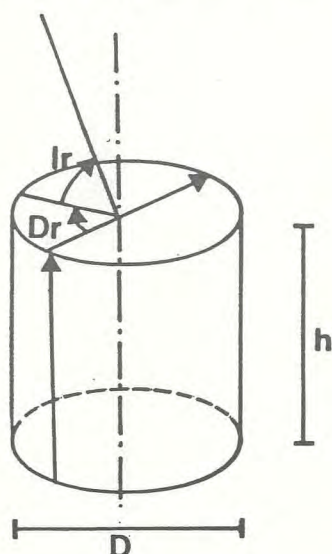
Moreover, susceptibility, density and resistivity were measured for nine rock types typical of the Løkken formation and for 10 gabbro samples.

Table 1. Petrophysical data.

Hole	depth/m		drill hole samples				
	drilled	Norma meas.	susc	density	resist.	IP	remanence
Interval →	1 m		1-5 m		5 m		
Lø-1		79	235	235	235	230	40, 179, 180, 181
-2		457					
Sv-3	360	337	355	355	355		
4	432	432	432	432	432	150-180	256, 275, 315
5	275	263	275	275	275		
6		216					
Hø-31	353	349					
43	269	33					
45	357	21					
46	262	148					
47	239	169					
49	290	287					
50	217	210					
52	268	223					
53	240	234					
55	203	202	203	203	203	31-140	49.5, 58.7, 70, 109.5
57	139	103					
62	373	50					
85	144	135					
87	292	42					
89	361	49					
93	106	96					
95	361.2	350					
45A		145	(two holes measured with code Hø-45)				

The numbers in table 1. show to what depth from the collar of the hole or over what interval (IP) the determinations were made. For the remanence, the numbers indicate the depth from which the sample was taken.

Remanence determinations



The absolute value of remanence and the Q value (= the ratio of remanent magnetization to induced magnetization) were measured on 15 unoriented samples from three drill holes. Hence it is not possible to determine the direction of the remanence. The reference directions for the measurement were marked as shown in Fig. 1 on cylindrical pieces cut from the drill core. The arrow parallel to the axis of the cylinder points upwards in the drill hole.

Some of the samples were tapped with a hammer and remeasured to test how stable the remanence was. No demagnetization tests were performed.

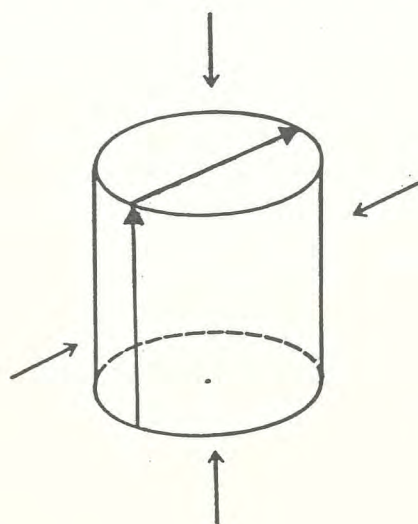
Fig. 1.

From the measuring data it can be concluded (Table 2) that:

- Excluding two data, $Q = 6.9$ and $Q = 20$, Q is less than 4. In 9 out of 15 samples Q is less than 0.4
- In a certain hole (Hø-55) the Q value may vary between 0.1 and 20.
- Q seems to be independent of susceptibility.
- For the magnetic interpretation it is important to know whether the direction of remanence is parallel to the Earth's magnetic field. Unoriented samples cannot answer this question.
- Tapping tests suggest that drilling has not significantly changed the magnitude and direction of remanence. The tapping seems only slightly to reduce the Q values.

Table 2. Remanence data from Løkken. Unoriented samples.

SAMPLE	SUSCEPT.	Jr	Dr	Ir	Q	REMARKS
BH-1/40 m	3500	970	313	3	6.9	
" "	"	967	314	3	6.8	tap ↓
" "	"	955	317	2	6.7	tap ↙
" 179 m	10780	110	17	-79	0.3	
" 180 m	47200	460	354	-72	0.3	
" 181 m	20400	301	90	74	0.4	
Hø-55/49,5 m	12000	1784	14	40	3.8	
" "	"	1767	4	42	3.7	tap ↓
" "	"	1707	4	44	3.6	tap ↙
" "	"	1402	340	33	3.1	tap ↑
" "	"	1402	358	35	3.1	tap ↗
" 58,7 m	900	2	243	42	0.1	
" 70 m A	11200	1189	240	-72	2.7	
" "	"	1067	234	-72	2.4	tap ↓
" "	"	712	0	-68	1.6	tap ↙
" "	"	1141	238	-73	2.6	tap ↑
" "	"	1119	246	-67	2.6	tap ↗
" 70 m B	11500	9109	187	2	20	
" "	"	8135	187	3	17.8	tap ↓
" "	"	7500	184	8	16.4	tap ↙
" "	"	7160	185	6	17	tap ↑
" "	"	7000	190	8	17	tap ↗
" 109,5 m	10100	162	150	23	0.4	
SV-4/255,9 m A	5000	52	177	73	0.3	
" 255,9 m B	7000	58	165	71	0.2	
" 275,3 m A	14000	1961	7	-24	3.6	
" "	"	1786	9	-25	3.2	tap ↓
" "	"	1395	9	-34	2.5	tap ↙
" "	"	1459	19	-35	2.6	tap ↑
" "	"	1418	12	-36	2.5	tap ↗
" 275,3 m B	10920	514	333	-82	1.2	
" "	"	493	325	-85	1.1	tap ↓
" "	"	367	336	-82	0.8	tap ↙
" 315 m A	11480	94	207	65	0.2	
" 315 m B	5460	29	203	66	0.1	



Tapping directions

Dr declination of remanence in degrees from the reference direction.

Ir inclination of remanence in degrees from the reference direction.

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The Løkken formation

It was not possible either to measure any of the drill holes that intersected the Løkken ore or to get a continuous set of drill core samples for laboratory determinations. Hence a petrophysical model section cannot be constructed for the formation. A preliminary concept of the petrophysical properties of the rocks of the formation can, however, be obtained from drill holes Lø-1 and Lø-2 (appendices 10 - 11), which intersect the country rocks, and from the type samples (Table 3). At a depth of 145 m Lø-1 intersects a conductive S-bearing horizon whose lowest resistivity values measured on the core samples are $0.01 - 1 \Omega\text{m}$. The Norma measurement in Lø-1 had to be stopped at a fracture at 79 m. A zone as conductive as that has not been encountered in the other holes measured. Lø-2 intersects several zones with low resistance ($300 - 800 \Omega$). Similar zones are met with in the holes at Høydal and Svinsås. Apart from the narrow magnetite-bearing jasper layers at 40 m and 179 - 181 m Lø-1 is not magnetic. It is noteworthy that the S-bearing conductive horizon at 115 - 145 mentioned above is completely non-magnetic. Lø-1 shows several layers that differ in density. Thus, for instance, $\rho = 2.96 \text{ g/cm}^3$ at 5 - 25 m, $\rho = 2.8 \text{ g/cm}^3$ at 40 - 55 m, $\rho = 3.00 \text{ g/cm}^3$ at 60 - 120 m and $\rho = 3.82 \text{ g/cm}^3$ at 125 - 145 m. IP determinations were done in Lø-1 at intervals of 5 m. At a depth of 60 - 145 m there is a layer that becomes clearly polarized.

Table 3. Petrophysical data on the type samples from the Løkken formation.

Sample	density		suscept. resistivity	
	g/cm ³	x10 ⁻⁵ SI	Ωm	
Svartfjell, H-71 155 m	3.58	40	8 x 10 ⁻²	
Urenkis	4.14	80	2 x 10 ⁰	
Vasskis	3.39	1100	1 x 10 ⁻¹	
Massiv malm A	4.66	520	1 x 10 ⁻¹	
Massiv malm B	4.57	570	1 x 10 ⁻²	
Vesicular putelava	2.97	90	2 x 10 ⁵	
Puterbreksje	2.87	110	1 x 10 ⁵	
Massiv grönsten	2.82	2360	3 x 10 ⁵	
Putelava	2.89	610	7 x 10 ⁴	
SU-1 125 m	Gabbro	3.05	120	7 x 10 ⁵
" 159 m	"	3.08	140	1 x 10 ⁶
" 263.5 m	"	3.03	150	5 x 10 ⁵
" 303 m	"	3.10	170	8 x 10 ⁵
" 311.5 m	"	3.01	140	4 x 10 ⁵
" 314.5 m	"	2.98	130	1 x 10 ⁶
" 315 m	"	3.10	170	3 x 10 ⁵
" 560 m	"	3.04	120	8 x 10 ⁵
" 698 m	"	3.02	110	1 x 10 ⁷
" 816 m	"	2.91	190	1 x 10 ⁶

The result from the type samples (Table 3) is clear. The ore and sulphide-bearing rocks differ from the country rocks very distinctly in density and conductivity but not in magnetic properties.

The ore does not differ from the sulphide-predominant rocks (vasskis) in petrophysical properties.

The measurements on the gabbro samples from drill hole Su-1 indicate that the density of the gabbro is anomalously high ($2.91 - 3.10 \text{ g/cm}^3$), that the samples are only slightly magnetized ($110 - 190 \times 10^{-5} \text{ SI}$) and that they are insulators (ρ more than $5 \times 10^5 \text{ } \Omega\text{m}$).

The number of samples was too small to permit the differences in petrophysical parameters between the country rocks to be evaluated.

Svinsås

The laboratory measurements demonstrate that drill hole SV-5 (appendix 14) intersected several thin zones that are intermediate ($10 - 100 \text{ } \Omega\text{m}$) or moderate ($0.1 - 10 \text{ } \Omega\text{m}$) conductors. The three lowest values of resistivity are: $0.1 \text{ } \Omega\text{m}$ at 233 m, $4 \text{ } \Omega\text{m}$ at 235 m and $6 \text{ } \Omega\text{m}$ at 211 m; pyrite seems to be the conductive mineral in all of them. Magnetite makes the first two highly magnetic as well.

This discontinuous layer composed of several thin conductive zones (appendix 17) crops out on profile $y = 0.3$ at $x = 0.9$ as suggested by the Genie measurement (appendices 54 - 56). The conductive zone shows a distinct improvement eastwards.

The lowest resistivity values measured from the cores of drill holes SV-3 and SV-4 (appendices 12 - 13) are 1000 and 3000 Ωm . The lowest resistance values measured from holes are 50 - 100 Ω .

All three holes SV-3, 4 and 5 intersected a discontinuous zone, 7 - 15 m thick, that is intensely magnetized in places (appendix 18). This layer may crop out at $x = 0.8 - 1.0$ (appendices 49 and 58). The magnetized mineral seems to be invariably magnetite.

Holes SV-3, 4 and 5 start with a 20 - 30 m thick layer that has a density exceeding 2.9 g/cm^3 . Below it the density is reduced. In drill holes SV-3 and 4 the density increases again below the magnetized layer (appendix 19). The high densities in the holes (density exceeding 3.5) were measured on the vasskis intersections. Drill hole SV-5 is bottomed (at a depth of 260 - 275 m) in quartz porphyry with a low density of ca. 2.65 g/cm^3 .

Høydal

Most of the open holes in area were measured with Norma (appendices 20 - 23). In drilling profile 121, which was surveyed with AMT and gravimetry, only holes Hø-31 and 51 were open down to the bottom (appendices 24 - 25). Drill hole Hø-31 intersects a thin layer with disseminated chalcopyrite at 193 - 198 m. Holes Hø-43, 44 and 45 intersect a thicker Cu-bearing

zone that could not be measured because of blocking in the holes. The lowest resistance of all the holes at Høydal, 20 Ω , was encountered at 194 m in Hø-50. The conductive mineral is pyrite.

Elsewhere the resistance is 150 Ω or higher. Thus, highly conductive zones were not encountered. Felsite, however, differs from its environment owing to its distinctly lower resistivity (appendices 24 - 25). The contact between the upper surface of the felsite with disseminated chalcopyrite and greenstone is manifest as a marked boundary surface of resistivity. The resistivity contact between the felsite and the underlying agglomerate is even more distinct. The layer with the disseminated chalcopyrite at 193 - 198 m in Hø-31 does not differ in conductivity from the felsite.

The same lithological association, albeit without mineralized portions, was, however, intersected in profile 117 (appendices 25 - 26) west of drilling profile 121. Susceptibility, density and resistivity were measured for the core samples from Hø-55 drilled in this profile.

Felsite also differs from the environment in being more conductive in the Norma measurements. Laboratory measurements do not indicate a difference in resistivity. The higher in situ conductivity is due to the ionic conductivity. The felsite at a depth of 100 - 110 m as well as the overlying greenstone at 40 - 100 m are fairly intensely magnetized (ca. $10\,000 \times 10^{-5}$ SI) (appendices 25 and 27). The magnetized zone is also manifest as slightly elevated density values. The same magnetized zone is probably encountered on drilling profile 121.

AMT MEASUREMENTS

General

Audiomagnetotellurics, or AMT for short, is a little brother of magnetotellurics, differing from the latter only in its limited frequency range. Both are passive electromagnetic sounding methods, i.e. Nature herself acts as transmitter. The frequency range used in AMT exceeds 1 Hz, i.e. it comprises ELF (3 - 3000 Hz) and the lower part of VLF (max. 20 kHz), with thunder storms, which can be at a distance of thousands of kilometres, as a source of energy. The electric field is measured with oriented electrodes and the magnetic field with coils tuned for the appropriate frequency band. The square of the ratio of the voltages measured with electrodes and coil multiplied by a natural constant gives the

apparent resistivity, R_a , which is an absolute value when the ground is homogeneous. The scalar equipment, French ECA-541 used by Outokumpu Oy Exploration, measures directly the R_a of the frequency desired, thus speeding up the measurements. On account of the random nature of the source, the result is the mean of several pulses, and attempts are made to eliminate fast variations and man-made disturbances. Over 10 soundings can be done with the scalar AMT in one working day; the corresponding figure for magnetotellurics is one at most.

As an electromagnetic method the AMT hunts for conductors. The more the conductor differs from its environment the more unambiguously the technique localizes it. It is even sensitive to conductors that are poor in absolute values provided the channelling of the electric currents results in significant enhancement. The depth penetration of the method is good, even up to 2000 m, owing to the intensity of the natural fields and the great distance from the source. The location of the surficial conductors must be known if the aim is to reach great depths, and they must not be so conductive as to mask the information coming from deeper levels. Little has been written about the positive and negative features of the method, and this cannot be done briefly. The measuring philosophy developed by Outokumpu Oy has been described by Lakanen (1985, submitted for publication in Geophysics).

Measurements and data processing

The profile over the Lökken ore deposit comprised 11 soundings over a distance of 600 m. At Svinsås 20 soundings were made over a distance of 1150 m and at Høydal 10 soundings over a distance of 500 m. For the intensity of the natural fields the time was not the best possible. Nevertheless the fields were strong enough to exceed the sensitivity of the equipment at each site for all the frequencies except at 8 and 3700 Hz a couple of times. To eliminate the short-lasting variations each frequency was measured at least three times at suitable intervals. One site along each profile was chosen as a reference station, which was measured when starting the day's survey of the profile. The minimum azimuth was determined at each station, as described by Lakanen (1985). The reference station showed that the variation in the distance of the source fields was so small that no corrections were needed.

The data were processed with a HP9845 into profiles as sets of three frequencies. The layered earth model interpretation, 1D, was accomplished with an interactive program first as a routine for all the profiles, then with integration of all the relevant factors. The Bostick inversion, a rough multi-layer interpretation, which considers even the slightest variations in the data, was performed on the manually smoothed results. The depth contours are shown with static correction and automatic gain, which means that the results were normalized in relation to each other, thus improving their readability. The mean of each sounding, R_a , is given in ohm-metres. The results of the 1D interpretation are given as cross-sections, in which a short line indicates the upper surface of the conductive layer, and the number next to it the interpreted resistivity. The bar extending downwards means that the lower surface of the conductor was not reached. The azimuth of the measurement in relation to the profile is indicated by an arrow clockwise from the north and numbers are in gones ($90^\circ = 100$ g).

Løkken

The orebody is located on the survey profile at a depth of about 800 m. Unfortunately a new power line had been erected about 200 m south of the orebody and running parallel to it. This still interferes with the readings at a distance of 300 m, and a station (100 m) close to it could not be surveyed at all. An unknown, intense peak occurred in the electric field at regular intervals of about one second making integration impossible and hampering reading of the instrument. Only one sounding, 300 m north of the orebody, could be done in the normal way. The ventilation machine of the mine a few hundred meters below the profile was suspected of causing the disturbance. The interference was weaker at a supplementary site measured 100 m higher up the hill. Tests done early on Saturday and Sunday morning did not help; the disturbance existed all the time.

The reliability of the sounding data suffered severely because of the interferences, see appendices 28 - 32. Nevertheless the more detailed examination indicated the anomalous behaviour over the orebody at low frequencies. The interpretation also gave the correct depth, 800 m, fairly accurately (appendix 60). The anomaly is weaker at the next station 100 m northwards, and still weaker at the station 150 m

northwards. A spacing of 100 m between the first three sounding stations was chosen in order to get rid of the interference caused by the power line. The remaining soundings indicate a weak conductivity contrast at great depth, but it has no significance and may just be due to lateral changes. The anisotropy is small, i.e. the readings in minimum and maximum azimuths do not differ much. The results corroborate those from previous AMT measurements performed by Sulitjelma AS before the construction of the power line.

Svinsås

A profile with four drill holes and a known vasskis horizon with a gentle dip was selected here. Measuring was easy in the area, and there were none of the interferences encountered at Løkken. A distinct minimum azimuth, 100 - 140 g, was established at intermediate frequencies. At lower frequencies, however, a different azimuth, 60 g, with weak anisotropy was obtained. The results indicate weak conductivity contrasts, see appendices 33 - 37. Only a few indications of higher conductivity were noted in the southern portion of the profile, but they are at depths on which there are no drilling data (appendix 36). The known vasskis horizon is not conductive, continuous or thick enough, because even the high frequencies penetrate it. Rather, the data suggest that another more uniform zone exists beneath the vasskis, in which case it should crop out farther south. The phenomenon could also be attributed to a change in the strike of the vasskis horizon, to its edge, a break in it or to a strong bend close to the profile. At any rate the observed conductive layer is as gently dipping as the vasskis horizon. The strongest indication of the conductor was measured at 250 S (-0.25). At about the same site drill hole No. 5 intersected a narrow but conductive zone, 0.1 ohm-metres. It may be cut by a fault to the north, where five soundings indicate a shallower conductor with lower conductivity correlating with the zone of disseminated sulphides intersected by the drill holes. The point close to the road gives abnormally high resistivities. North of the road there are only low conductivity contrasts. Notice that rather low resistivity of 1 ohm-meter was used to determine depth. This is needed, because Bostick-inversion indicates only narrow zones.

Høydal

The known orebody gave a straightforward result, appendices 38 - 42. At the outcrop there is a strong minimum but the orebody seems to lack depth extension. Two smaller minima, which may be due to outcropping greenstone zones rich in magnetite, were detected at 50 and 200 S (0.05, 0.2). The other indications may be due to pseudoeffects, though they do correlate with the bottom of the formation. No big massive conductors were encountered here.

GRAVITY MEASUREMENTS

General

Sulphide ores are often associated with skarn rocks, mafic formations or other rocks that are heavier than the country rocks and show up on the gravity map as positive anomalies. The anomaly caused by the ore cannot usually be distinguished from the anomaly of the host rock.

According to petrophysical measurements, host rocks heavier than the country rocks occur in neither the ore deposits at Løkken and Høydal nor in the showing at Svinsås. Thus a gravity anomaly, if present, is due to the ore alone and small orebodies cannot be located at great depths. This was demonstrated by calculating a few examples for each target.

The rough topography in the environment of Løkken is another factor hampering application of gravity survey. Its influence dominates the anomaly pattern as is demonstrated by the two rough terrain corrections calculated for the Løkken profile.

Apart from localizing ore, gravity measurements can also be used to develop and test a regional geological model; for that purpose a regional gravimetric survey on a sparse grid is sufficient. This, however, requires that comprehensive and representative density measurements be made on the rocks in the area.

All the profiles measured exhibit a distinct and rather linear gradient to the north, 1.0 - 4.5 mGal/km.

Execution of the measurements

The measurements were made with a Worden Master gravimeter No. 1207 owned by Outokumpu Oy Exploration. The reading accuracy of the equipment is 1×10^{-2} mGal.

After a training period of one day Mr. Tor Walseth was ready to be our surveyor. The three helpers required were from the mine. Mr. T Katajarinne did the book-keeping and supervised the survey on the Løkken 1 and Svinsås profiles. The Høydal and Løkken 2 profiles were surveyed under the supervision of Mr. Tor Walseth. The elevation was measured with a RRKM-20 elevation difference meter manufactured by Rautaruukki Oy. It has an accuracy of ± 20 cm/km.

The survey data were calculated to Bouguer values, i.e. drift, latitude, relative elevation and Bouguer corrections were applied to the data.

Terrain correction

The influence on the survey data caused by the rough topography in the Løkken area was evaluated by calculating a rough terrain correction for the Løkken-1 profile with both a prism model and a sector method (appendix 43).

For the prism method the elevation data were collected for each survey point parallel to the slope from an economy map (ekonomisk kartverk) at a scale of 1:5000. In this example the shape of the terrain was outlined with four prisms.

In the sector method the environment of a point was divided into four sectors. The terrain correction was calculated with the following equation (P Kearey & M Brooks: An Introduction to Geophysical Exploration, p. 153).

$$T = 0.491 \times 10^{-3} \frac{\rho}{n} (r_2 - r_1 + \sqrt{r_1^2 + z^2} - \sqrt{r_2^2 + z^2})$$

T = terrain correction of a sector

ρ = density (kg/m³)

n = number of sectors

r_1 = inner radius (m) of the sector

r_2 = outer radius of the sector

z = elevation of the calculation sector (= difference in elevation between the survey point and the centre of the sector).

In both models of calculation only the influence of the nearby topography, which causes sharp variation in the anomaly curve, was taken into consideration, i.e. over a distance of 0 - 200 m from the survey point. The variation in topography in the terrain farther away may induce large changes in the anomaly curve, but these changes are gently sloping.

Topography has a marked effect on the anomaly pattern. The sharp changes in the anomaly curves of the four profiles measured may be attributed almost wholly to the variation in topography (appendix 44).

Løkken

Profile 1 was measured across the orebody at a site where the orebody is at a depth of 800 m. An anomaly caused by an orebody 50 m high, 100 m wide and 1000 m long at a depth of 800 m and with a vasskis horizon 30 m high, 200 m wide and 1000 m long 20 m beneath it was calculated on the ground surface. The densities measured, 4.5 g/cm^3 for ore, 3.5 g/cm^3 for vasskis and 2.8 g/cm^3 for country rock, were used. The interpretation profiles were calculated to pass through the middle of the prisms (appendix 45).

The ore and vasskis at this depth produce an anomaly of about 0.1 mGal, which cannot be distinguished from the Bouguer curve. According to the example calculated the upper surface of the orebody should be at a depth of about 200 m before the anomaly attributed to its manifest in profile surveying. In systematic measurements the orebody in the example manifests itself at somewhat greater depth in the anomaly pattern.

The gradient rising northwards is 1.5 mGal/km on the Løkken 1 profile. A shorter profile (appendix 46) was measured east of the above profile. No clear gravity anomaly could be observed here either. The northward gradient is 1 mGal/km.

Svinsås

No anomaly caused by ore or any other rock heavier than the country rocks was encountered in the measurements.

On account of the smoother terrain the anomaly curve is more tranquil than at Løkken.

The gradient rising northwards is linear and 4 mGal/km in magnitude. A thin vasskis horizon has been intersected at Svinsås by drill holes at a depth of 200 - 300 m (appendix 16). In the interpretation example the ore is positioned at depths of 150 m and 400 m. The ore is represented by a prism 200 m wide, 300 m long and 20 m thick. A prism measuring 20 x 400 x 300 m has been positioned 30 m below the ore to correspond to a vasskis horizon.

The ore can be observed at a depth of 150 m, 200 m but not at 400 m (appendix 47). The size of the orebody in the example is 5.4 million tonnes, that of the vasskis horizon 8.4 million tonnes.

Høydal

No gravity anomaly due to the ore or any other rock heavier than the country rocks is known here either. The linear gradient, 4.5 mGal/km, increases northwards. In the interpretation model the low-grade

Cu mineralization intersected by drill holes was replaced by prisms 100 m long with cross-sections the same size as the cross-section of the Cu mineralization.

The model does not produce on the ground surface an anomaly detectable in measurements (appendix 48). An orebody like the one described (ca. 2.4 mill. t) might respond to the gravity measurements if its upper surface is at a depth of 0 - 50 m.

ADP DRAWING OF THE GEOPHYSICAL MAPS OF SVINSÅS

As agreed upon in the status by K Mäkelä (5.7.1984), the results of the magnetic, VLF, Genie and IP (n = 4) measurements undertaken at the Svinsås target were stored and drawn as maps by computer (appendices 49 - 57). Two prism interpretations were done on the data of the magnetic survey.

The trend of the magnetized conductive zones could have been established more reliably had the line spacing been shorter. If the lines are diagonal to the anomaly zones and the line spacing is long the interpolation technique used in drawing the maps does not always connect the zones correctly. According to the interpretation, the magnetized zone in the southern margin of the survey area dips northwards (appendices 58 - 59), which is consistent with the results of the drilling. As indicated by the interpretation, the width of the outcrop in the zone is greater than that of the outcrop intersected by drill holes. The magnetized zone may consist of several narrow layers. To establish whether this is the case, the spacing between the survey points should be 5 or 10 m. A survey done on a denser grid would also permit more detailed interpretation.

CONCLUSIONS AND RECOMMENDATIONS

In spite of the interfering power line close to the survey site the AMT measurement gave a weak but distinct response for the Løkken ore at a depth of 800 m. Highly conductive continuous zones were not encountered along the survey profiles at Svinsås and Høydal (poorly conductive zones were though). According to the resistivity measurements, the drill holes have not intersected such zones either. As shown by the measurements on the type samples the Løkken ore is highly conductive as was expected. AMT is a suitable method when searching for blind ores in the extensions of the known feeder zones. It is useful particularly because of its cheapness and because the data can be interpreted fairly reliably when extending the survey below 500 m.

The results of the gravity survey, the prism interpretations, the examples of the terrain corrections and the density determinations have revealed two factors that hamper application of the gravity survey in the area: 1. The Løkken ore deposit does not seem to have a host rock heavier than the country rocks, 2. the rough topography in the area dominates the anomaly pattern.

It is difficult to discover small blind orebodies by gravity methods. Interpretation succeeds only after a detailed terrain correction has been done.

For future geophysical measurements and interpretations it is recommended that, if possible, a reliable and representative petrophysical model cross section be constructed for the Løkken formation to establish the electric (conductivity, FE), magnetic and density properties of the rocks. This is important for the planning of survey methods and the interpretation of data.

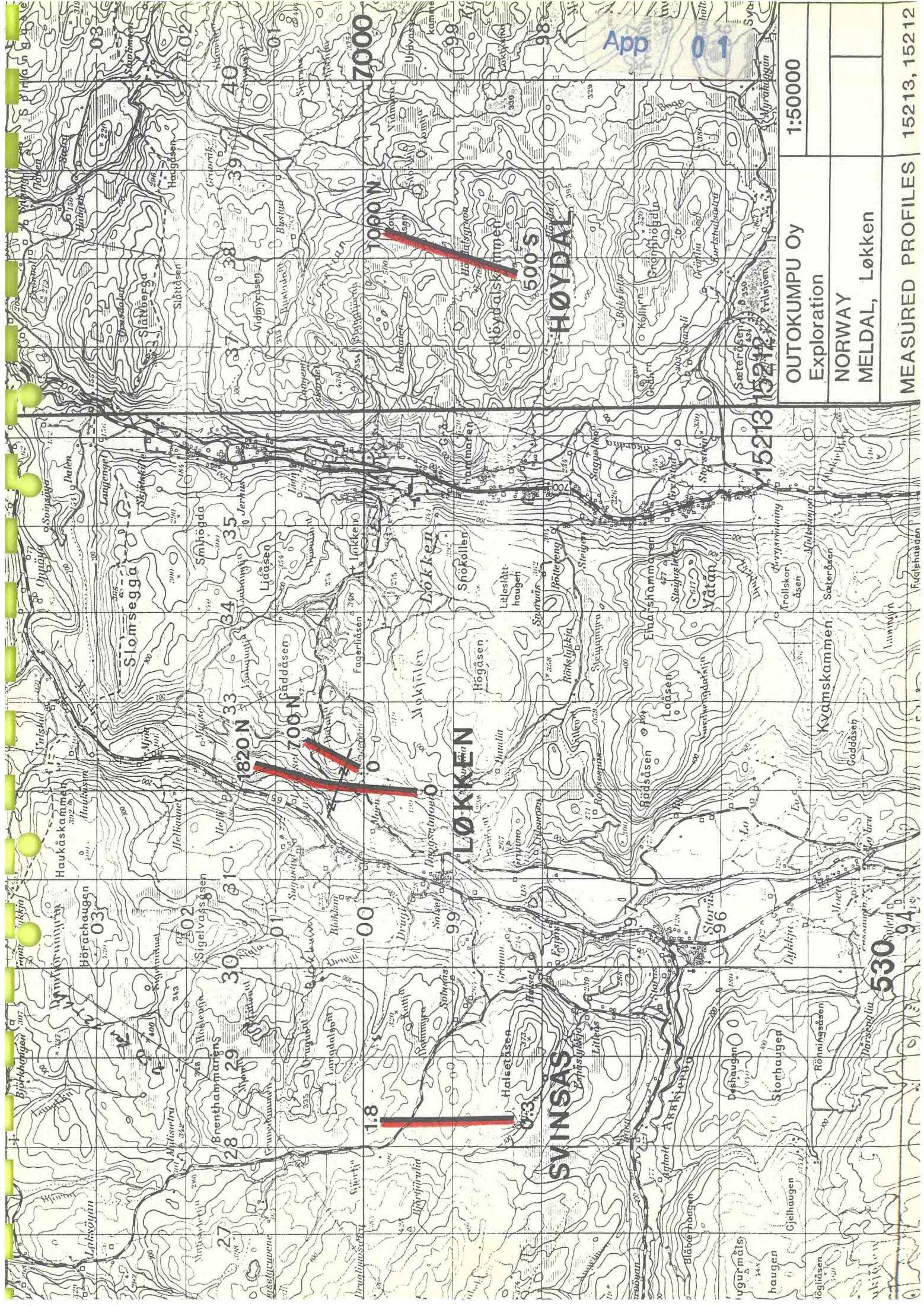
It is proposed that the following instruments of reasonable price be acquired to measure the petrophysical parameters:

- A resistance meter (Norma or similar) and a cable winch ca. 10,000 - 15,000 Nok.
- A field susceptibility meter (e.g. JH-8/Geoinstruments) ca. 8,000 - 10,000 Nok.
- A device to measure chargeability (IP).
- An ordinary balance for determining density.

It is proposed that a desk top calculator be acquired with the necessary interpretative programs to process and interpret the survey data. The price of a package that could accomplish these tasks is likely to be from 100,000 Nok upwards.

APPENDICES

1	Profiles measured, topographic map	1:50000
2	" geological map	1:50000
3	" aeromagn. map (Dighem)	1:50000
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7	Løkken, economic map	1:5000
8	Svinsås "	1:5000
9	Høydal " "	1:5000
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16	Drilling profile, Svinsås y = 0.3 (600 W)	1:5000
17 - 19	Petroph. cross-section, Svinsås y = 0.3	1:5000
20	Drill holes measured, Høydal	1:5000
21 - 23	Petroph. results, Høydal (Norma)	1:2000
24	Petroph. cross-section, Høydal prof. 121	1:5000
25	Geol. cross-sect., Høydal prof. 117 and 121	1:5000
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27	Petroph. results, Høydal Hø-55	1:2000
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46	" Løkken 2	1:5000
47	" Svinsås	1:5000
48	" Høydal	1:5000
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50-51	VLF maps "	1:5000
52-53	IP maps "	1:5000
54-56	Genie maps "	1:5000
57	Geophysical profile, Svinsås y = 0.3	1:5000
58	Magnetic interpretation, Svinsås y = 0.3	1:5000
59	" y = 0.6	1:5000
60	AMT " , Løkken station 0	



App 01

OUTOKUMPU Oy	1:50000
Exploration	
NORWAY	
MELDAL, Løkken	
MEASURED PROFILES	15213, 15212

15213

15212

15211

15210

15209

15208

15207

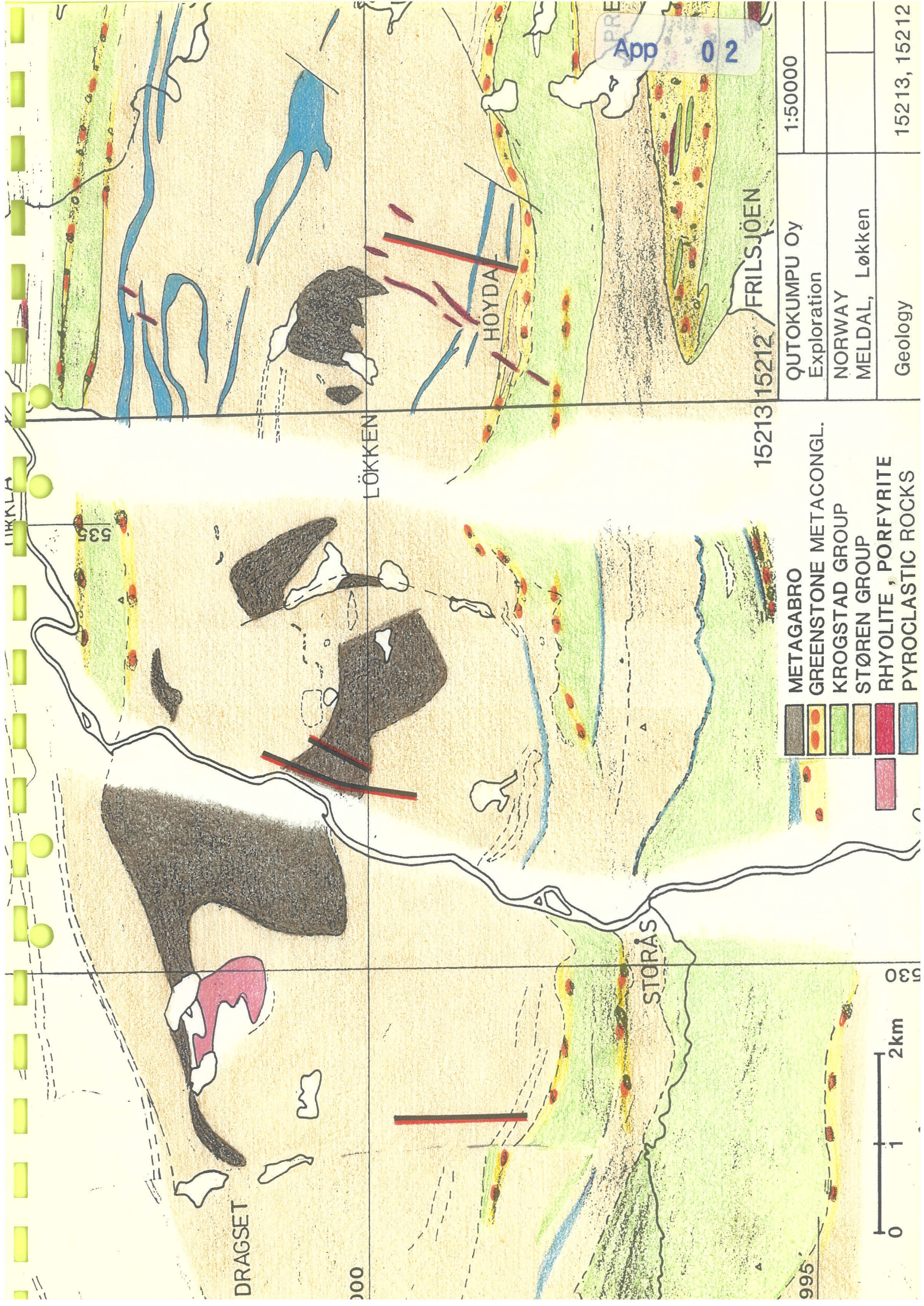
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15205

15204

15203

15202



App 02

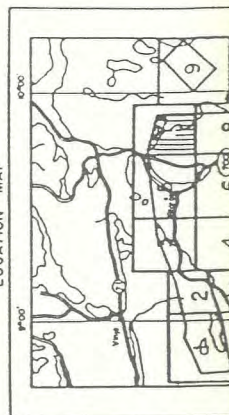
QUTOKUMPU Oy Exploration	1:50000
NORWAY MELDAL, Løkken	
Geology	15213, 15212

- METAGABRO
- GREENSTONE METACONGL.
- KROGSTAD GROUP
- STØREN GROUP
- RHYOLITE, PORPHYRITE
- PYROCLASTIC ROCKS

0 1 2 km



LOCATION MAP



ISOMAGNETIC LINES

(total field)

1000 gammas
200 gammas
50 gammas
25 gammas

magnetic depression

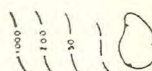


Figure line

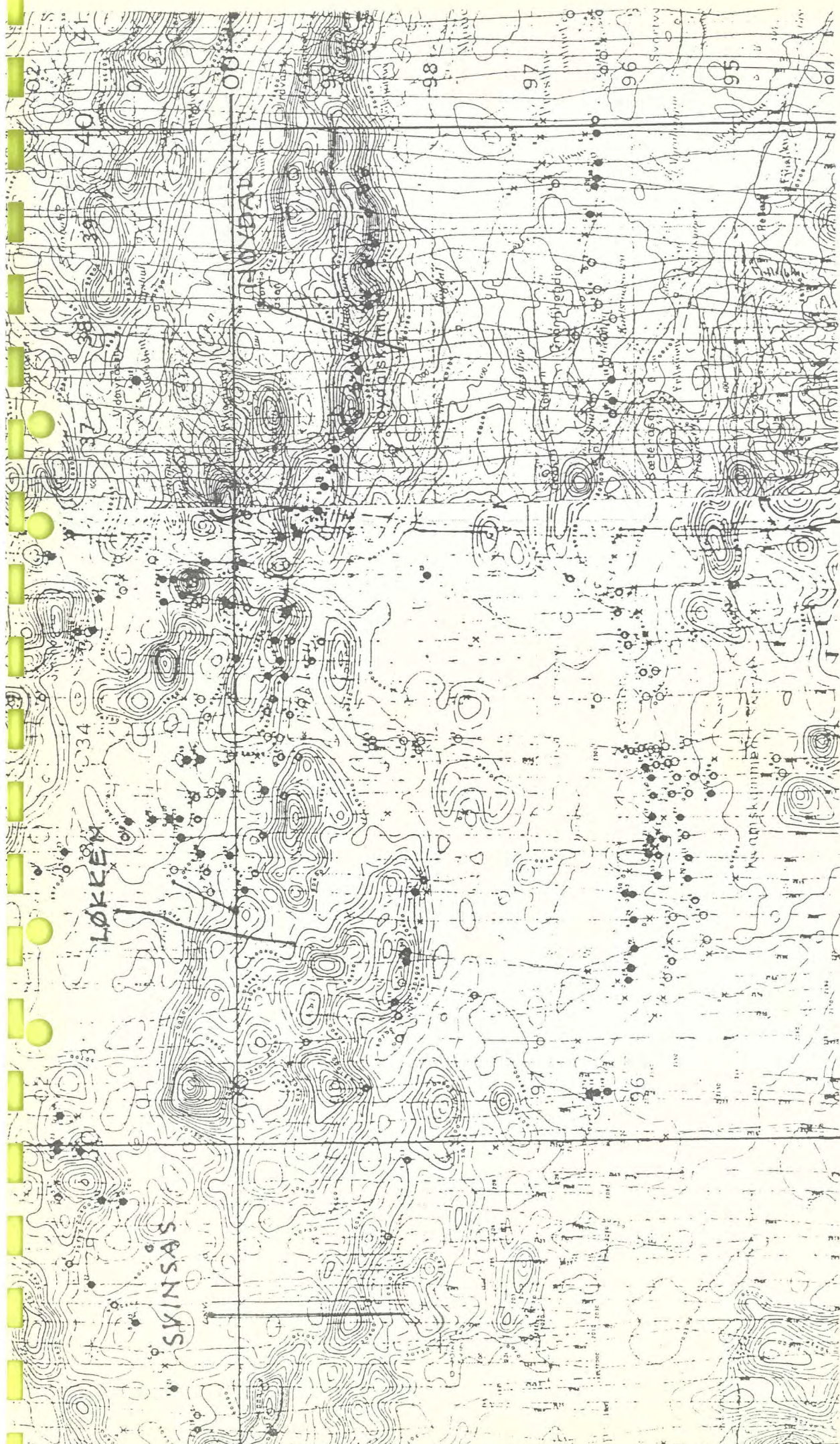
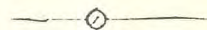
Figures
and
numbers

DIGHEM^{II} SURVEY

LOKKEN AREA, NORWAY

MAGNETICS

FOR



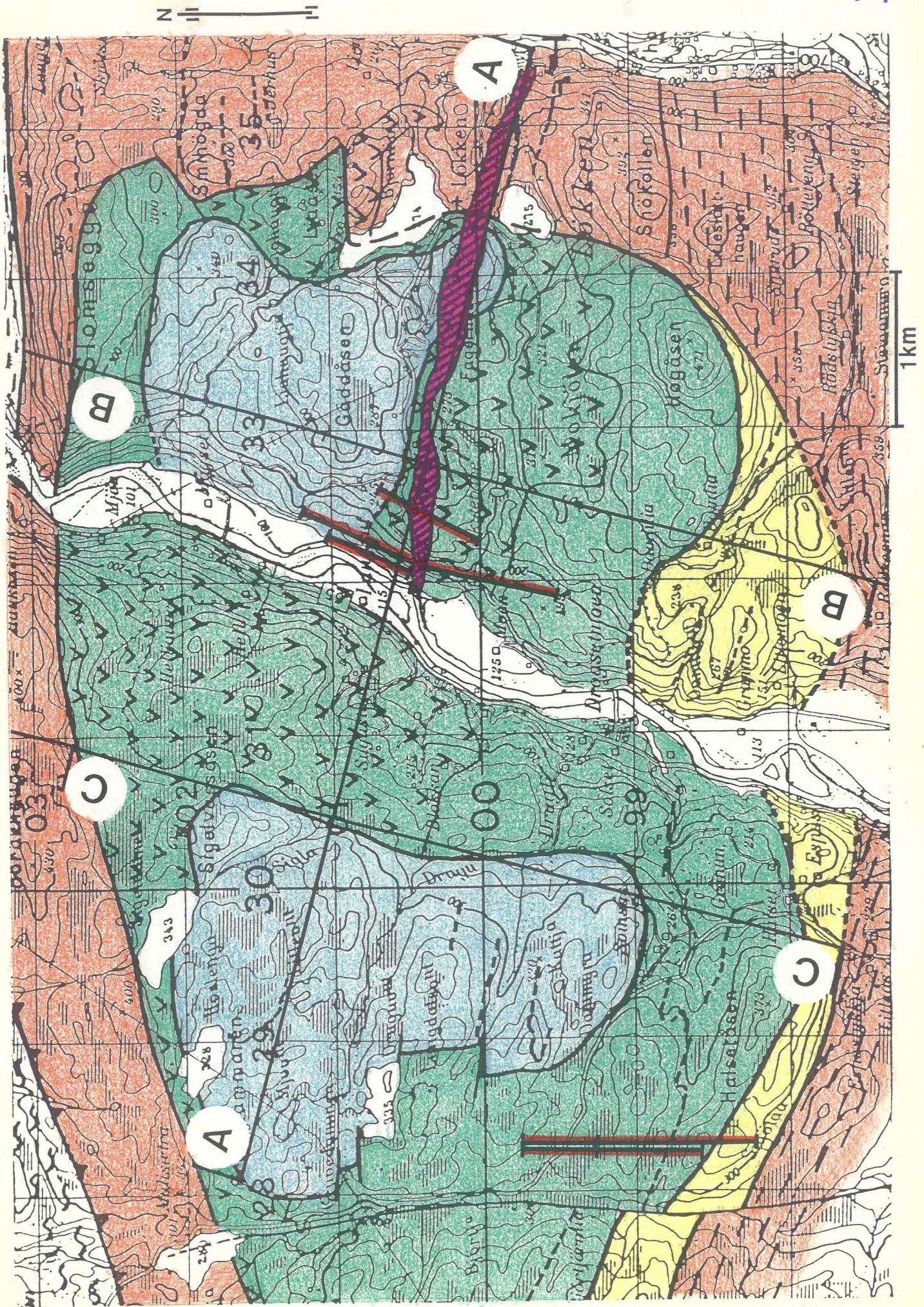


Fig 1

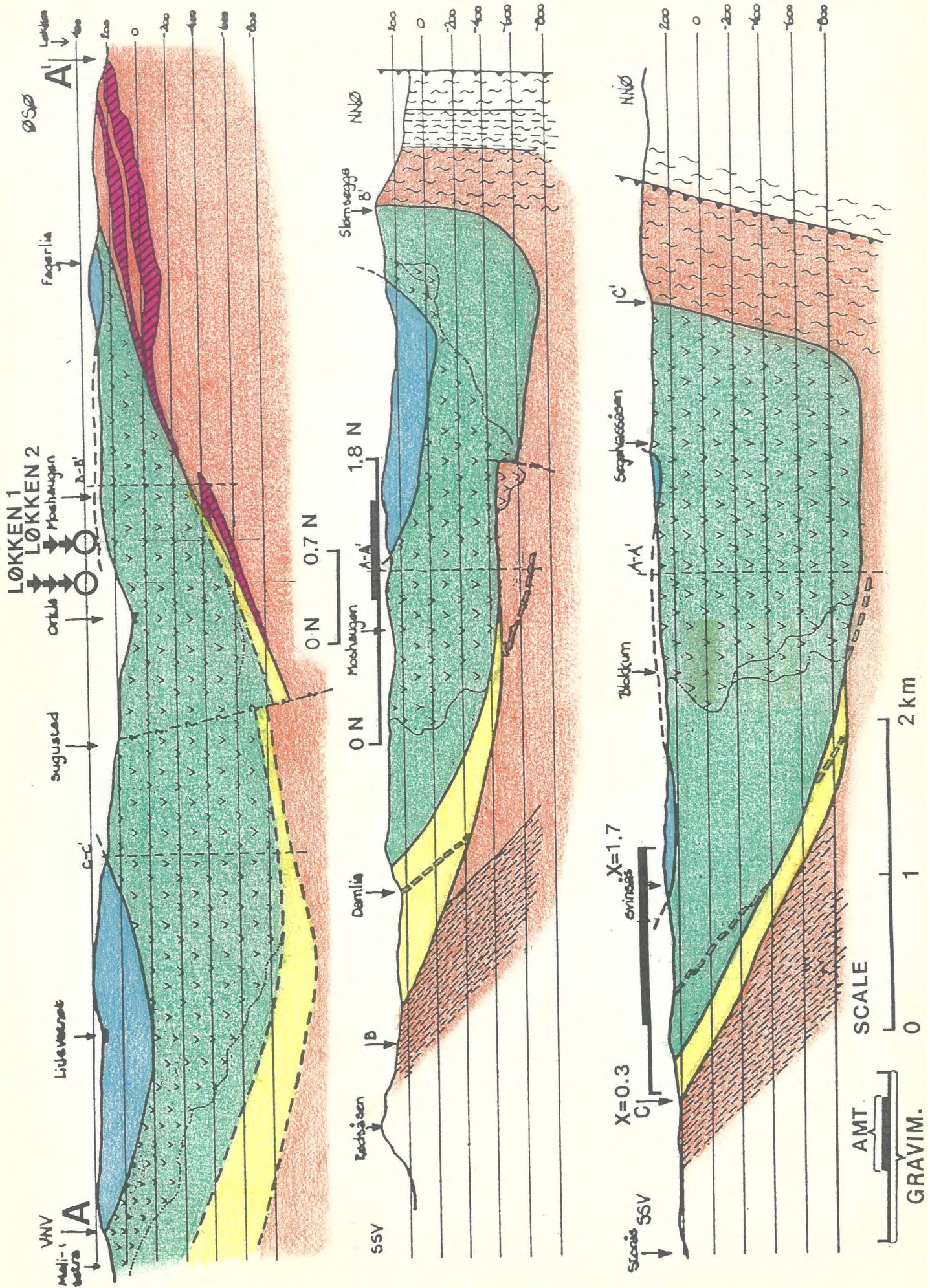
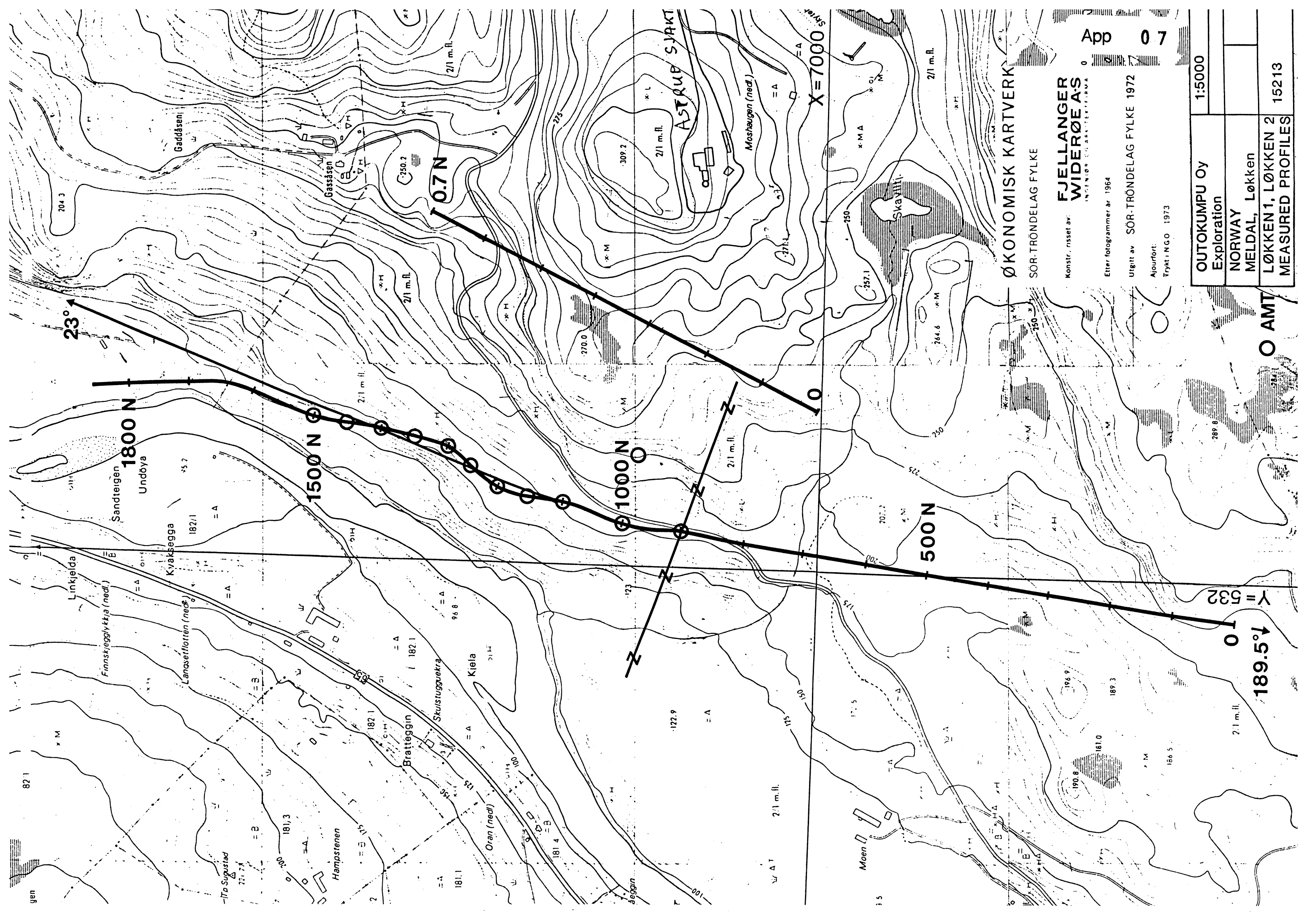


Fig 2

TEGNFORKLARING TIL FIGUR 1 og 2

	Dekke IV	(Bjørnli/Segelvann)
	Dekke III	(Moen)
	Dekke II	Damli
	Dekke I	Løkken
	Sandsten, skifer, konglomerat (yngre sedimenter)	
	Fyllitt	
	Gabbro	
	Vasski, jaspis	
	Løkkenmalmen	
	Forkastning	
	Skyvegrenser, innen Størendekket	
	Skyvegrense mellom Størendekket og fyllittene	



**FJELLANGER
WIDERØE AS**
INGENIØR- OG ARBEIDSFIRMA

Konstr. risset av:

Etter fotografier år 1964

Utgitt av SØR-TRØNDELAG FYLKE 1972

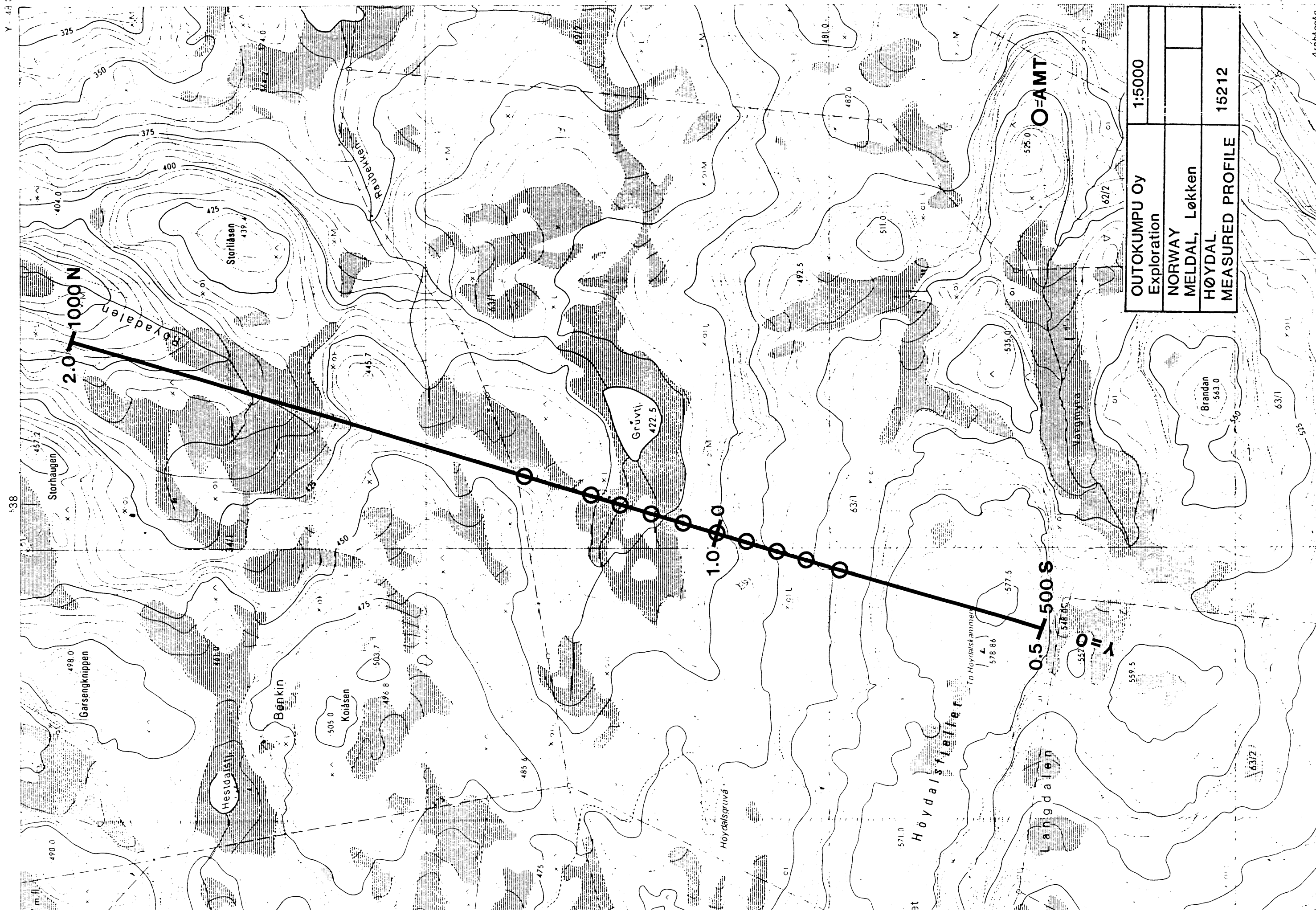
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Trykt i N.G.O. 1973

App 0 7

OUTOKUMPU Oy Exploration	1:5000
NORWAY MELDAL, Løkken	
LØKKEN 1, LØKKEN 2 MEASURED PROFILES	15213

Y- 43 000 X 571 7

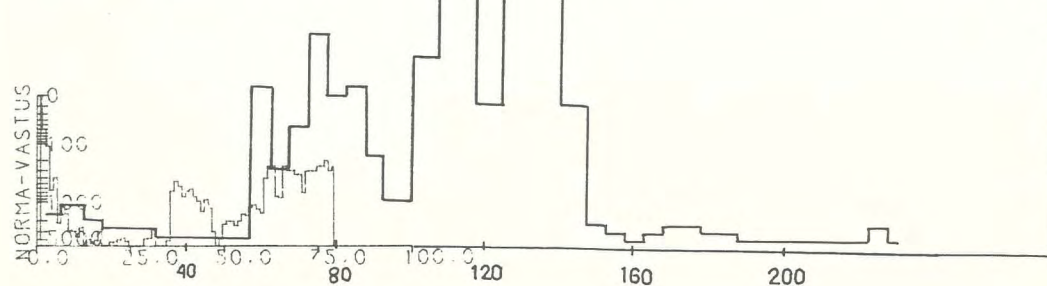
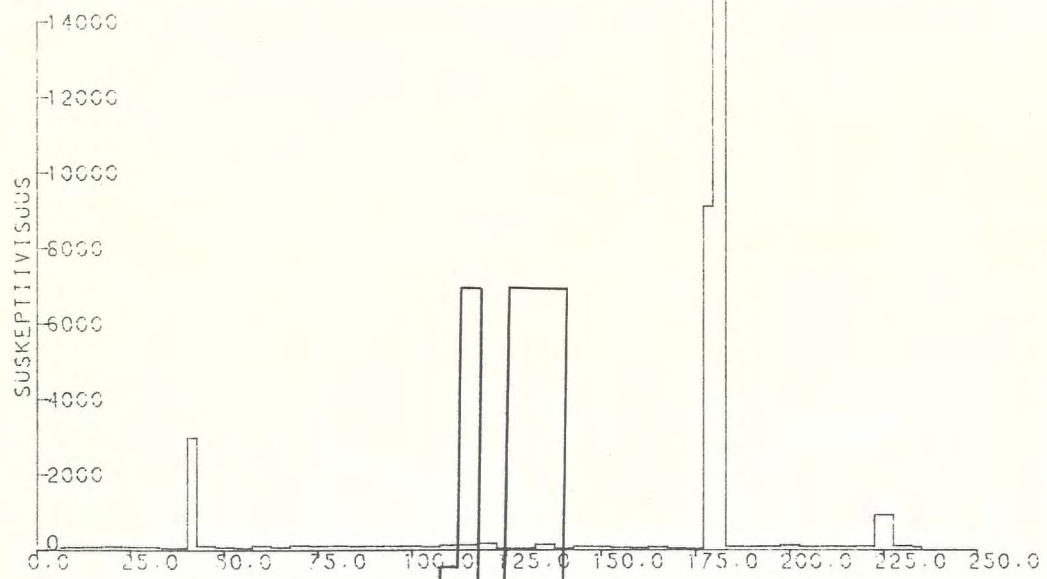
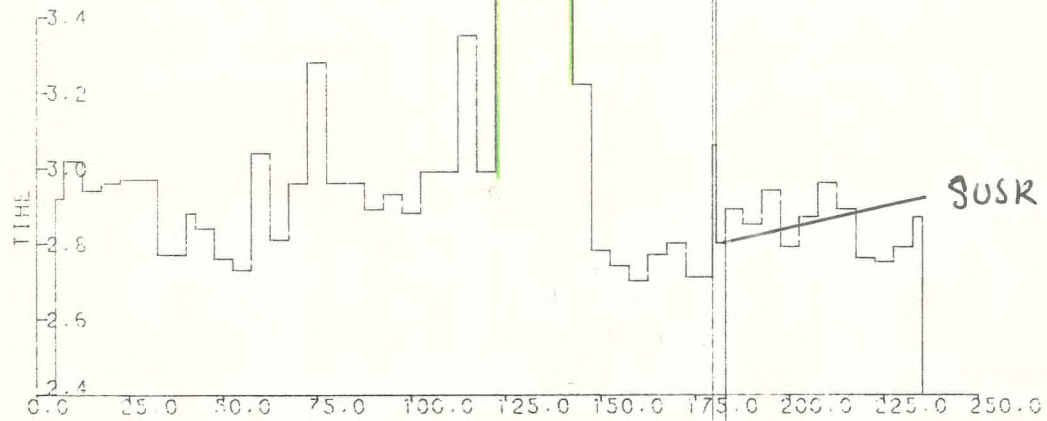
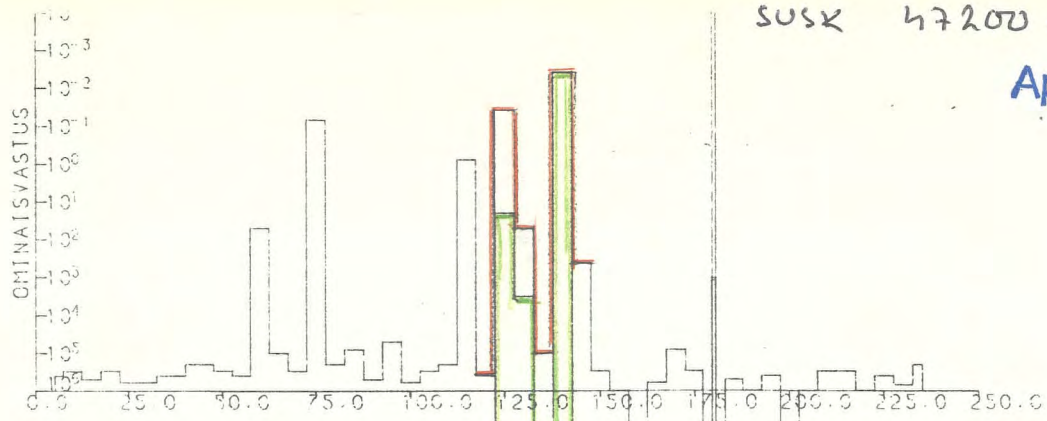
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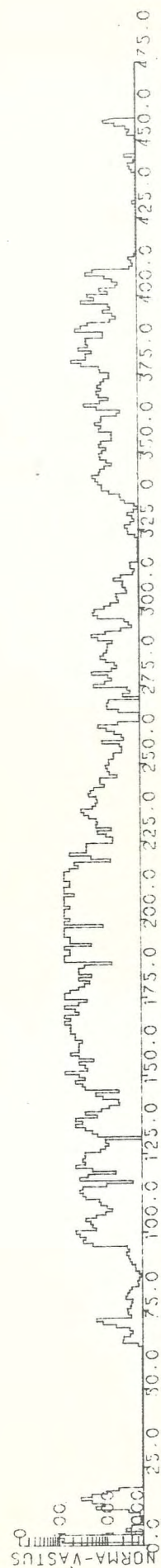
OUTOKUMPU Oy	1:5000
Exploration	
NORWAY	
MELDAL, Løkken	
HØYDAL	15212
MEASURED PROFILE	

SUSK 47200.10⁻⁵ S1

App 10



%
80
70
60
50
40
30
20
10
0
FREQUENCY EFFECT



2

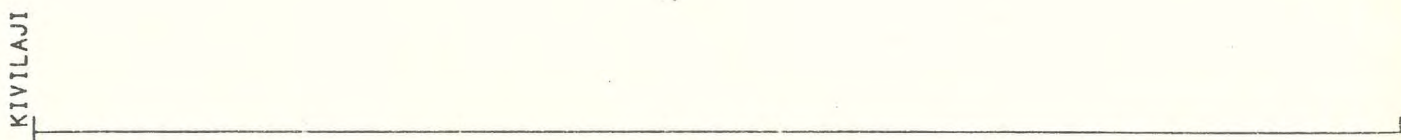
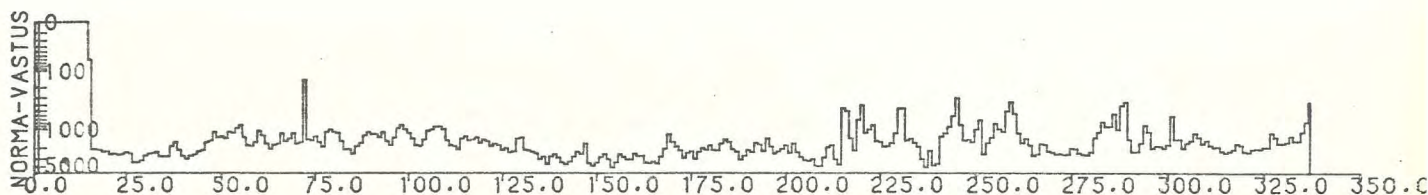
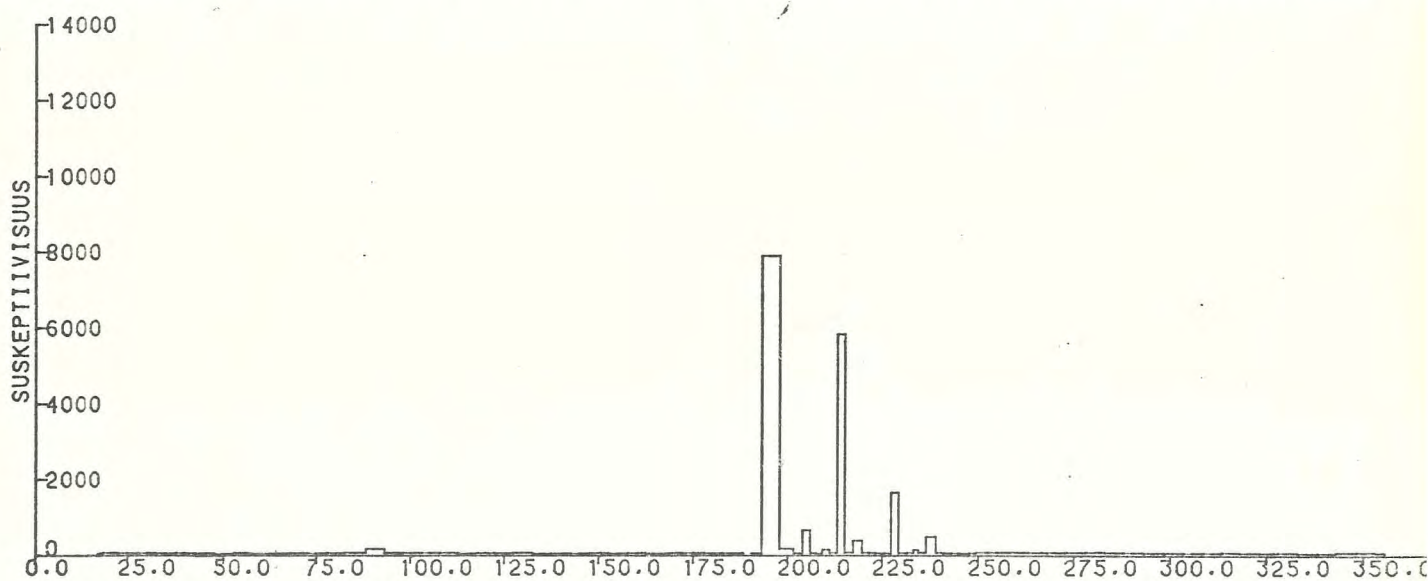
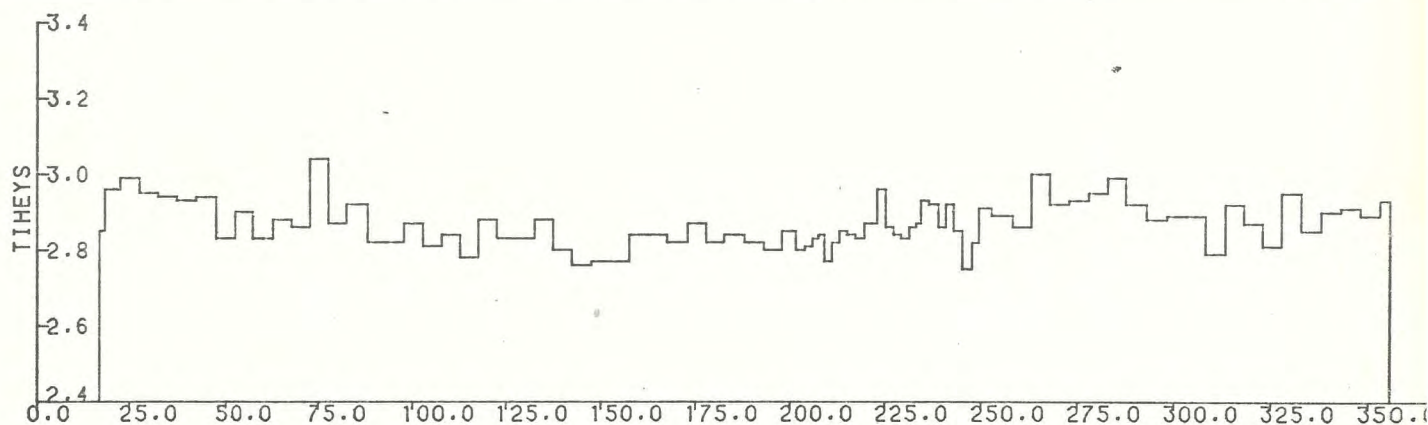
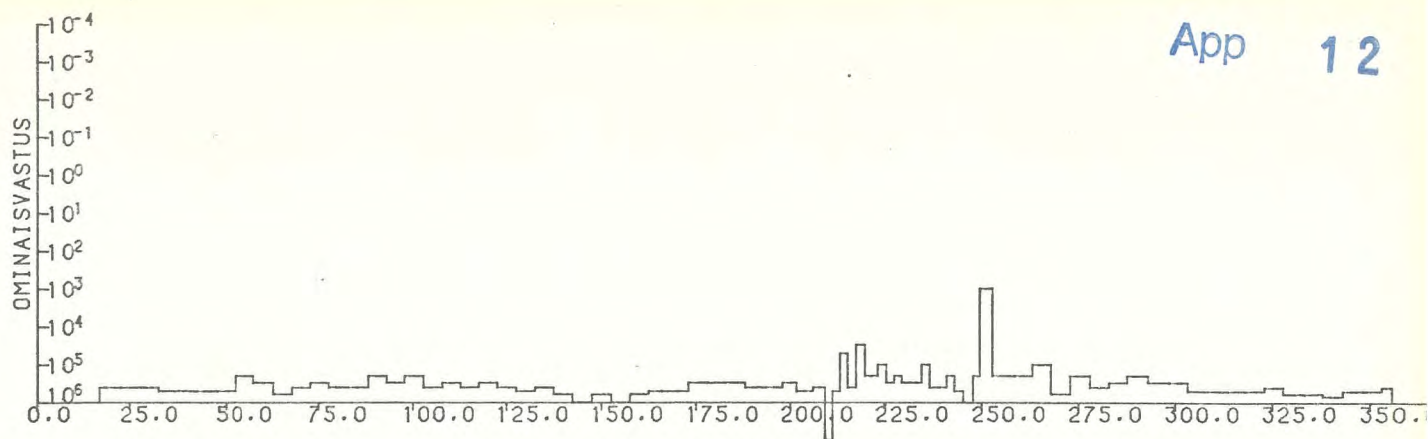
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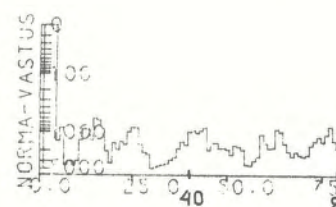
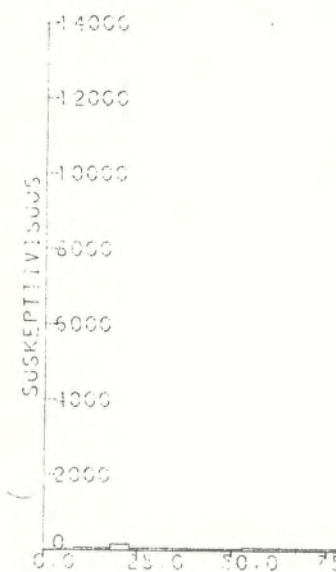
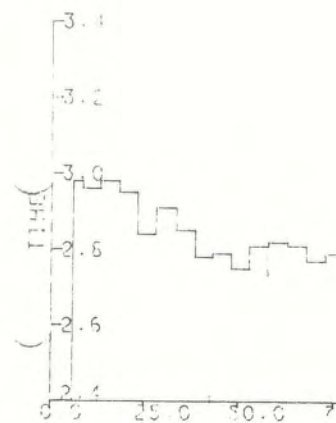
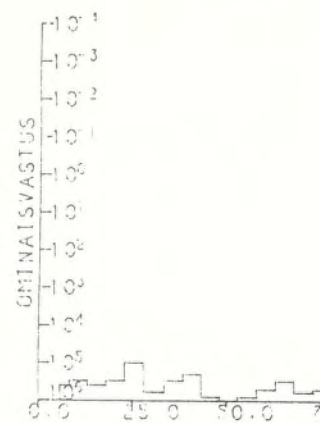
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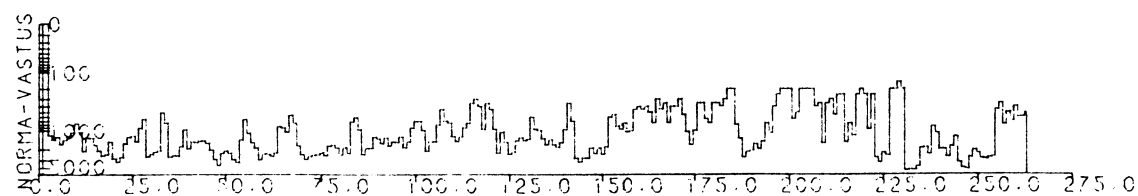
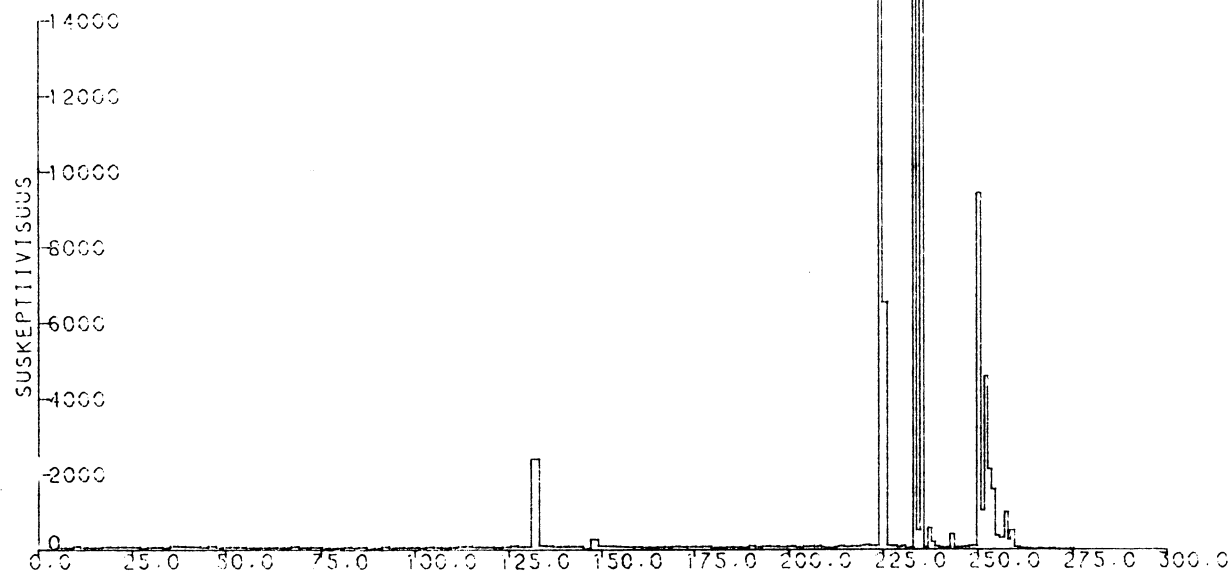
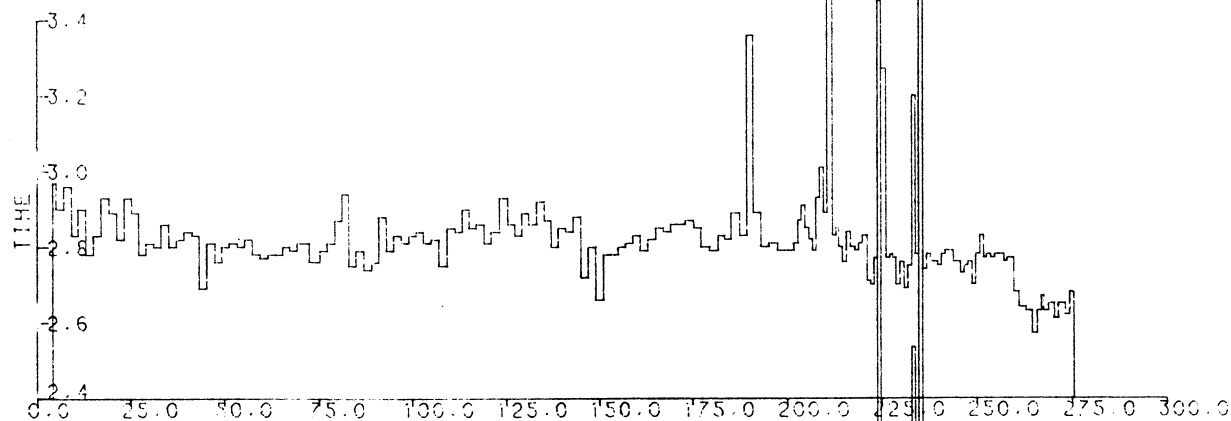
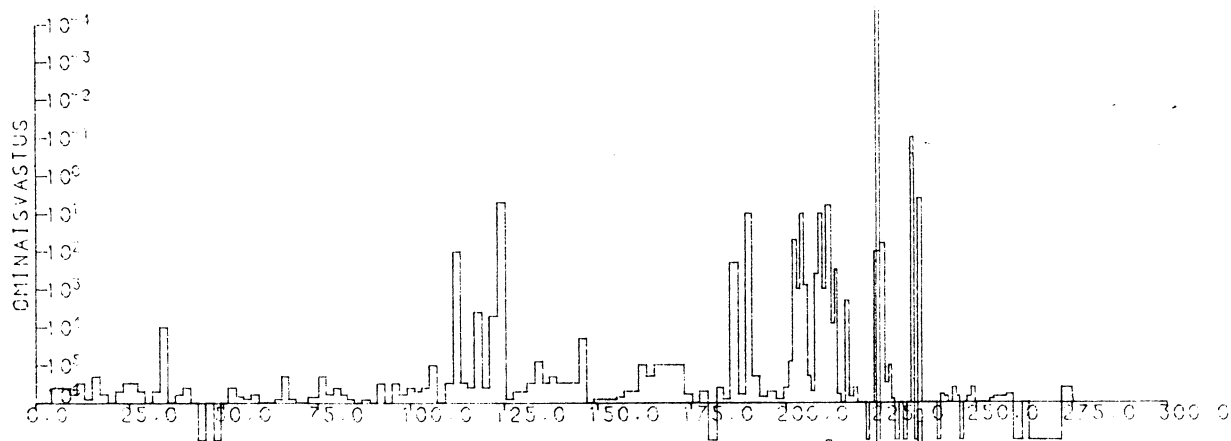
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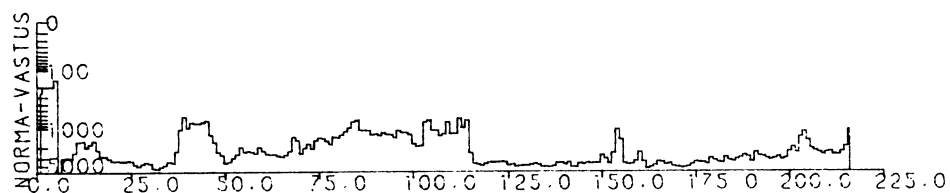


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1: 2000 85.0



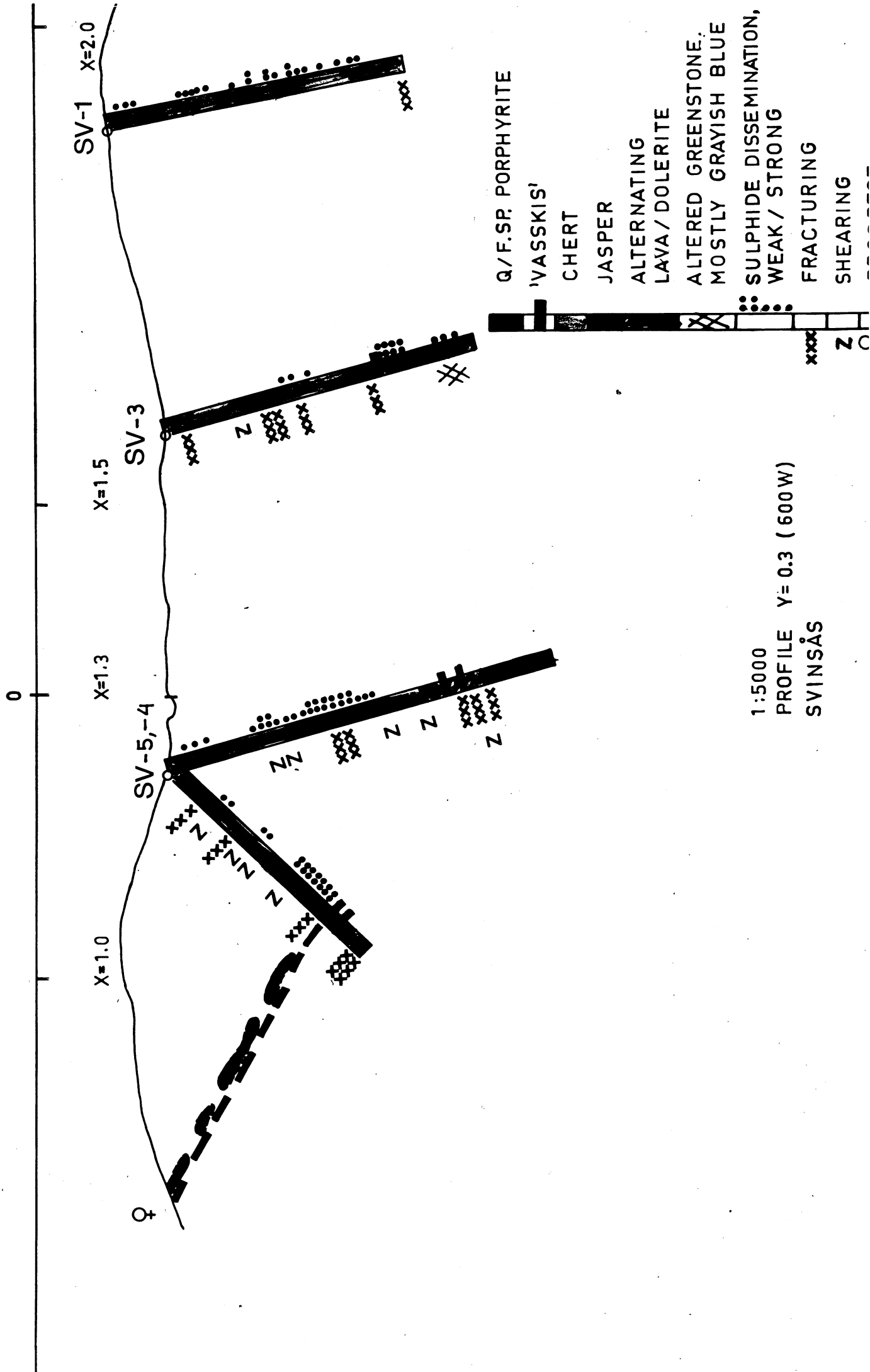
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015213A X= 1.775 Y= 0.300 SV

6

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1:5000
 PROFILE Y= 0.3 (600W)
 SVINSÅS

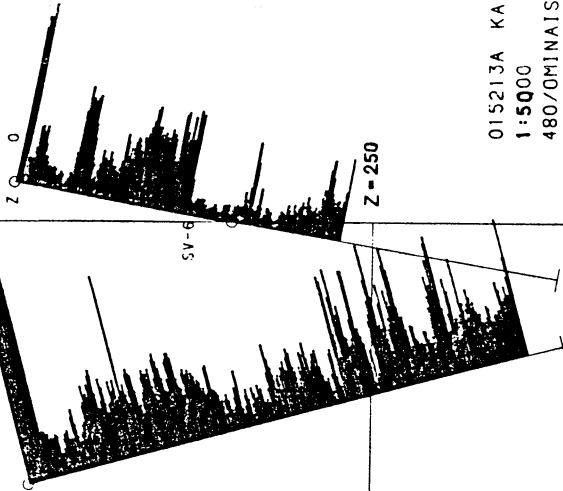
Ass 17

X=1.000

X/K= 1.750
Y/L= 0.300
Z= 0

SV-3

SV-1



Z= 250

275.00 M

015213A KAIRAUSPROFILILI Y= 0.300
1:5000
480/OMINATSVAKTODIAGRAMMI
04.05.85
NOLLATASO= 350.00
NORMA-VASTUS (IN SITU)

360.00 360.00 M

432.00 M

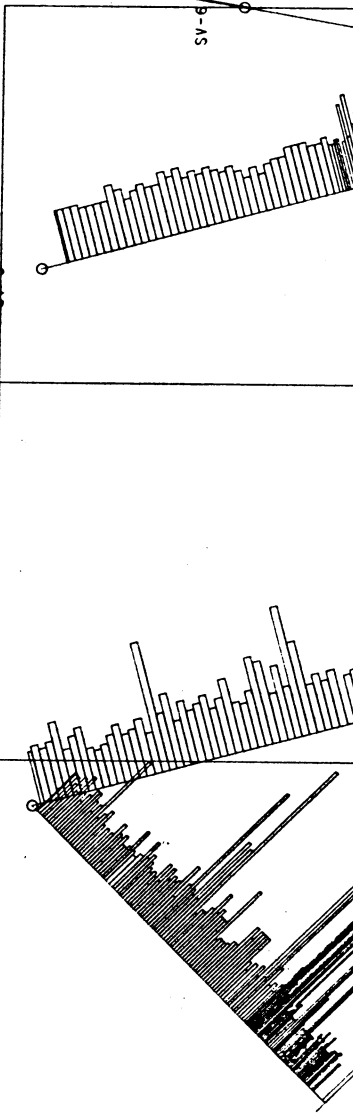
X/K	Y/L	Z	SUU	KAL
1.575	0.300	323.00	0	75
1.220	0.300	324.00	0	75
1.220	0.300	324.00	180	45
1.775	0.300	334.00	180	80

REIKA
Z=500
SV-3
SV-4
SV-5
SV-6

X/K= 1.750
Y/L= 0.300
Z= 0

SV-3

SV-1



SV-6

SV-4

SV-3

SV-6

275.00 M

432.00 M

360 360.00 M

125000

015213A KAIRAUSPROFIILI Y= 0.300

1:5000

480/OMINAISVAKIODIAGRAMMI

24.10.84

NOLLATASO= 350.00

SUSKEPTIIVISUUS

5000 YKS/CM

REIKÄ	X/K	Y/L	Z	SUU KAL
SV-3	1.575	0.300	323.00	0 75
SV-4	1.220	0.300	324.00	0 75
SV-5	1.220	0.300	324.00	180 45
SV-6	1.775	0.300	334.00	180 80

X = 1.000
Y = 0.300
Z = 0

SV-8

SV-3

SV-6

275.00 M

432.00 M

360.00 M

DENSITY

015213A KAIRAUSPROFIILI Y= 0.300
1:5000

480/OMINAISVAKIODIAGRAMMI

21.05.85

NOLLATASO= 350.00

TIHEYS 0.3 YKS/CM TASO=2.7

$\frac{g}{cm^3}/CM$ O-LEVEL = $2.7 \frac{g}{cm^3}$

REIKÄ

X/K

Y/L

Z

SUU KAL

SV-3

1.575

0.300

323.00

0 75

SV-4

1.220

0.300

324.00

0 75

SV-5

1.220

0.300

324.00

180 45

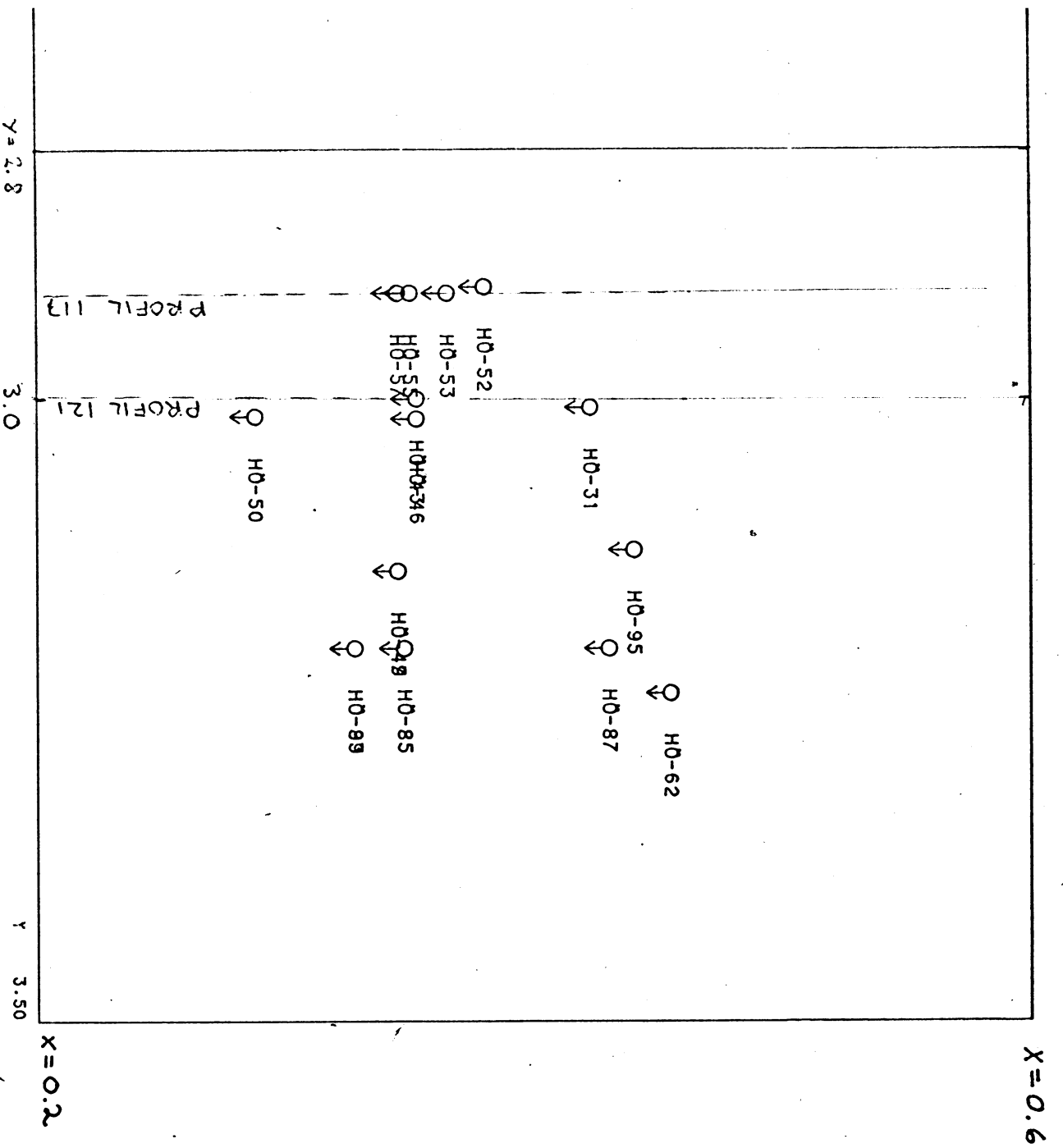
SV-6

1.775

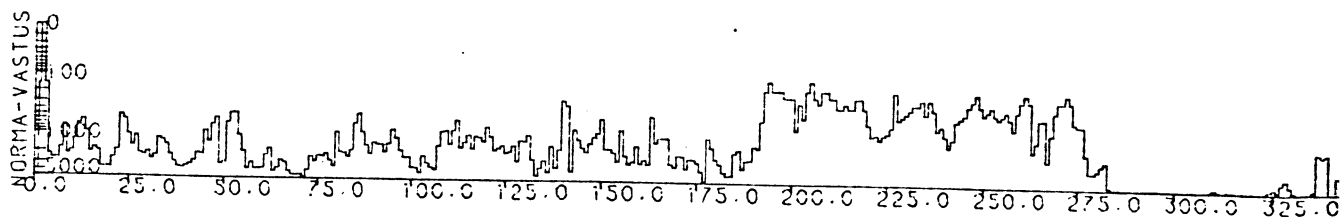
0.300

334.00

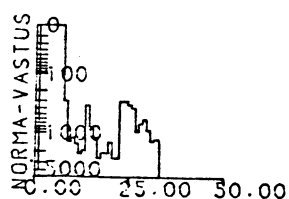
180 80



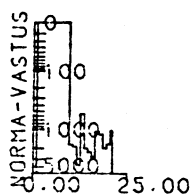
015212 A/X -0.20/Y 2.50
 KAIRAUSTIEDOT
 300/SIJAINTIKARTTA/07.11.84
 1:5000
 0 M 250



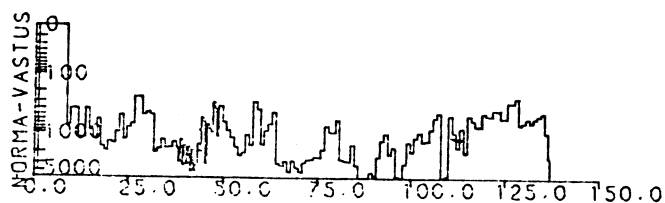
015212A X= 0.245 Y= 3.007 HÖ 3i



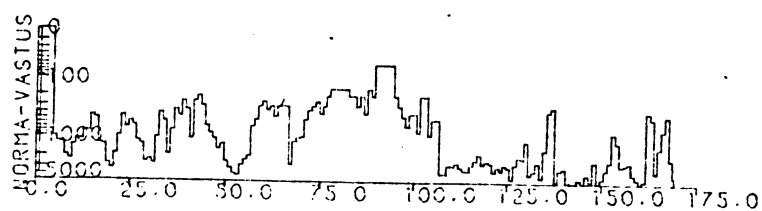
015212A X= 0.105 Y= 3.000 HÖ 43



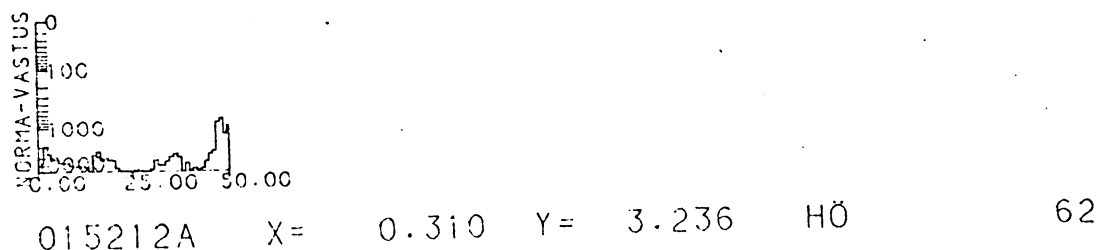
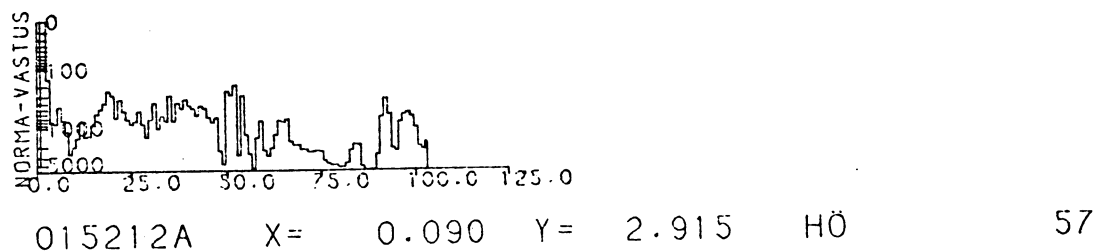
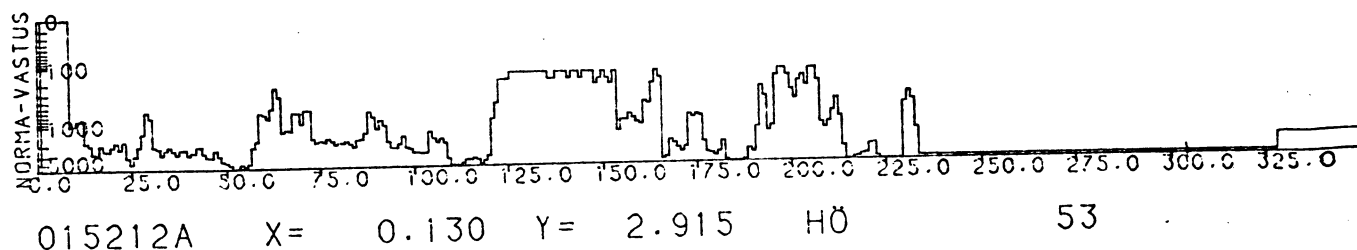
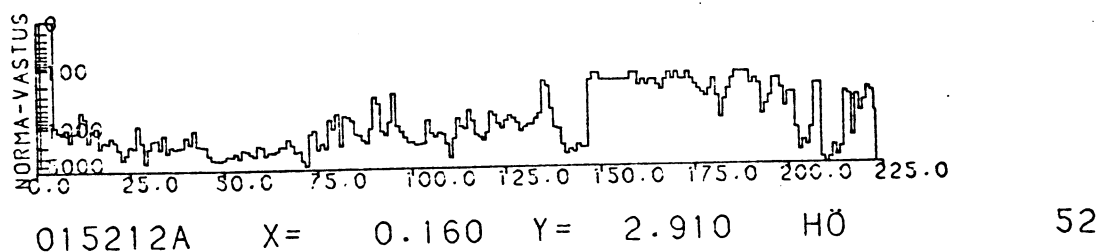
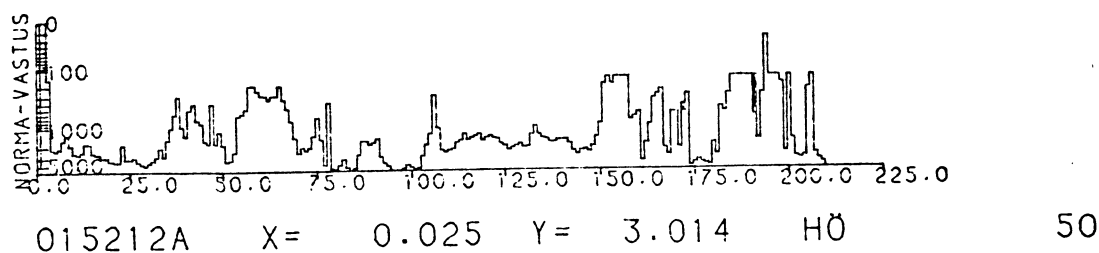
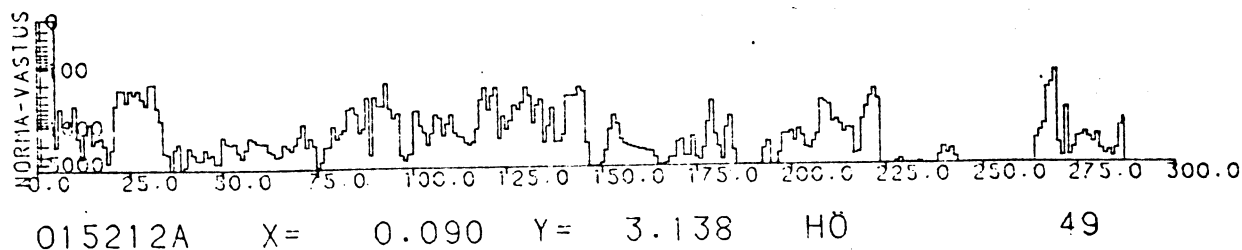
015212A = 0.000 = 0.000 HÖ 45

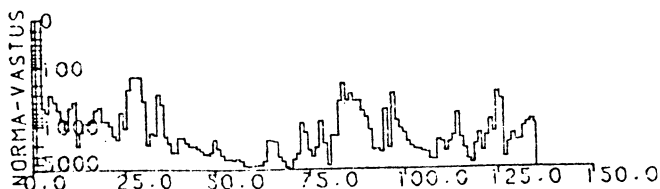


015212A X= 0.105 Y= 3.016 HÖ 46

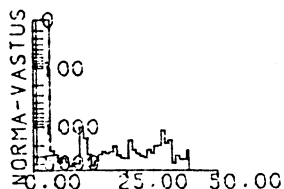


015212A X= 0.090 Y= 3.138 HÖ 47

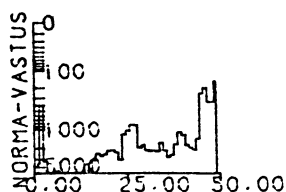




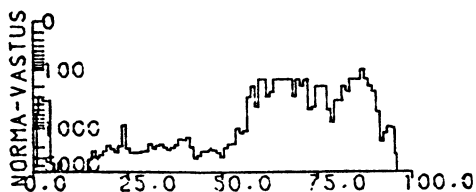
015212A X= 0.095 Y= 3.200 HÖ 85



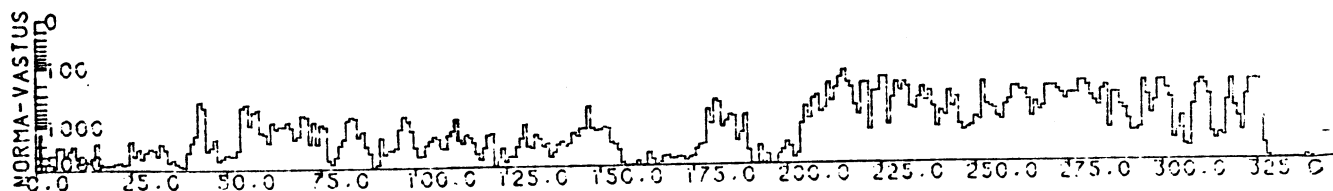
015212A X= 0.260 Y= 3.200 HÖ 87



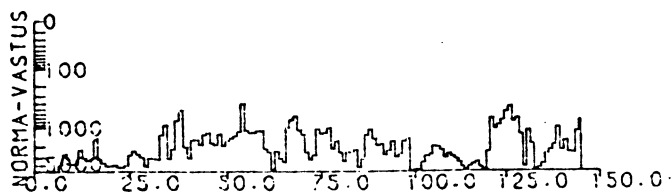
015212A X= 0.055 Y= 3.200 HÖ 89



015212A X= 0.055 Y= 3.200 HÖ 93



015212A X= 0.280 Y= 3.121 HÖ 95



015212A = 0.000 = 0.000 HÖ 45A

X/K=-0.150
Y/L= 3.000
Z = 0

HÖ-50

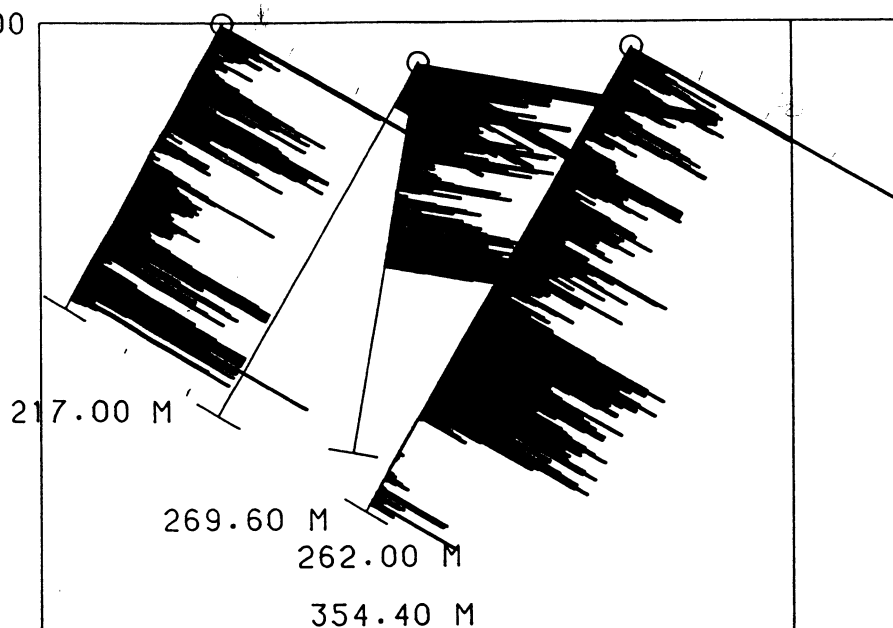
HÖ-46

HÖ-31

K=0.350

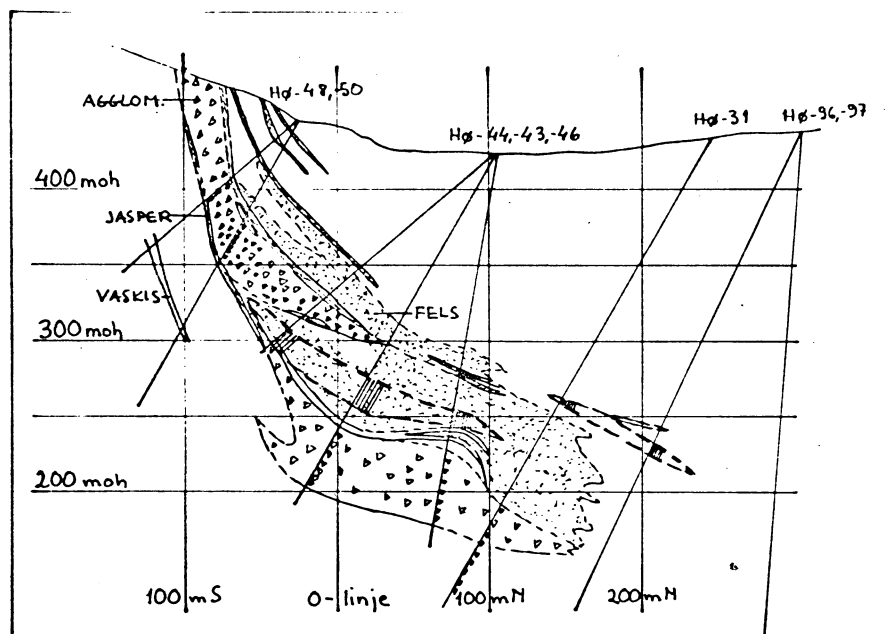
App

24

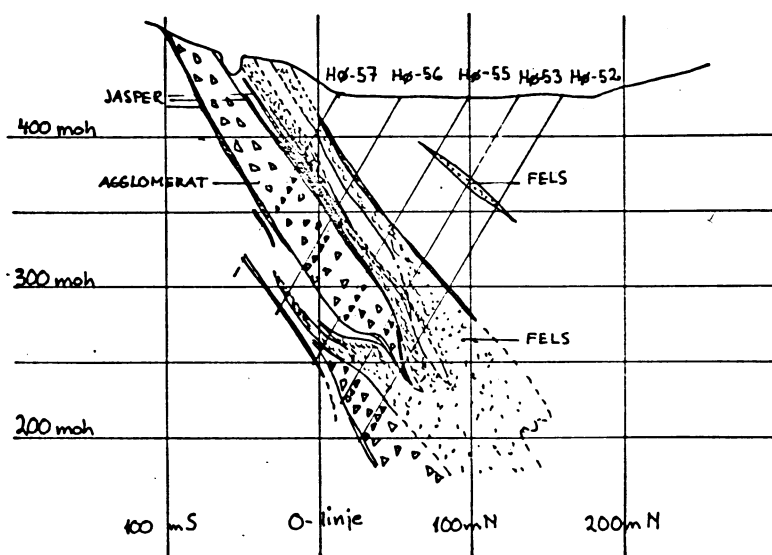


015212A KAIRAUSPROFIILI Y= 3.000
1:5000 VÄLI=±20.0 M PROFILE 121
480/OMINAISVAKIODIAGRAMMI
07.11.84
NOLLATASO= 450.00
NORMA-VASTUS

REIKÄ	X/K	Y/L	Z	SUU	KAL
HÖ-31	0.245	3.007	433.00	180	60
HÖ-43	0.105	3.000	423.00	180	60
HÖ-46	0.105	3.016	423.00	180	80
HÖ-50	0.025	3.014	449.00	180	60

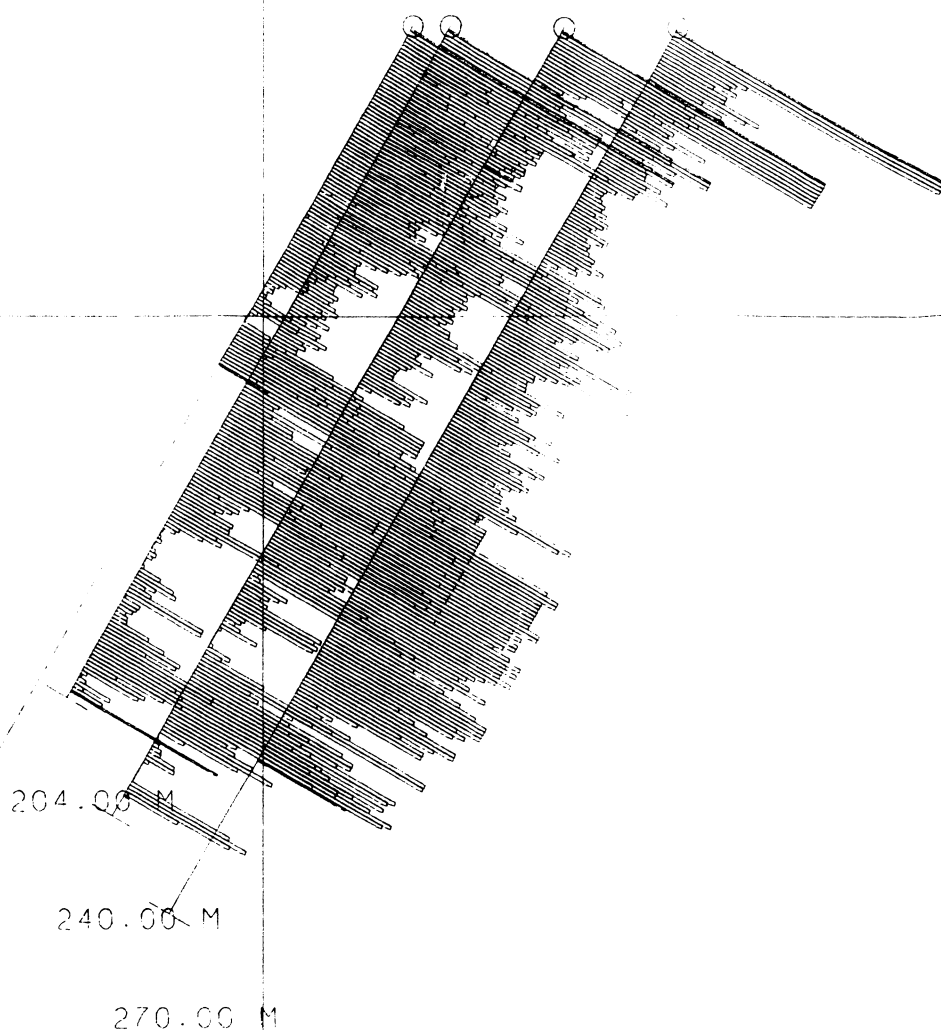


1:5000
 PROFILE 121
 HØYDAL



1:5000
 PROFILE 117
 HØYDAL

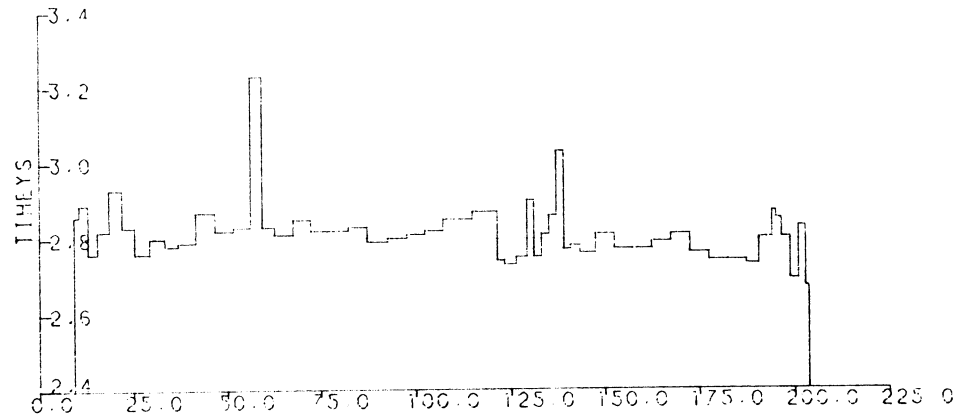
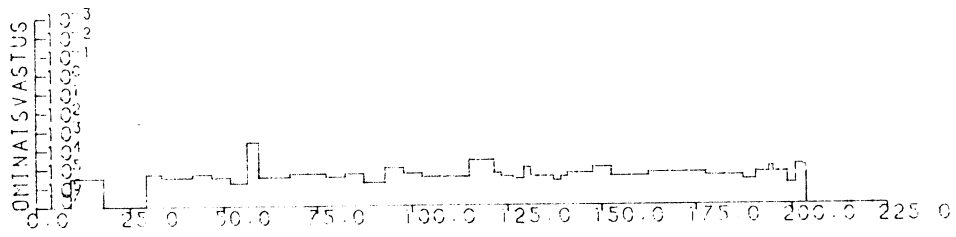
H045755 H0-53 H0-57



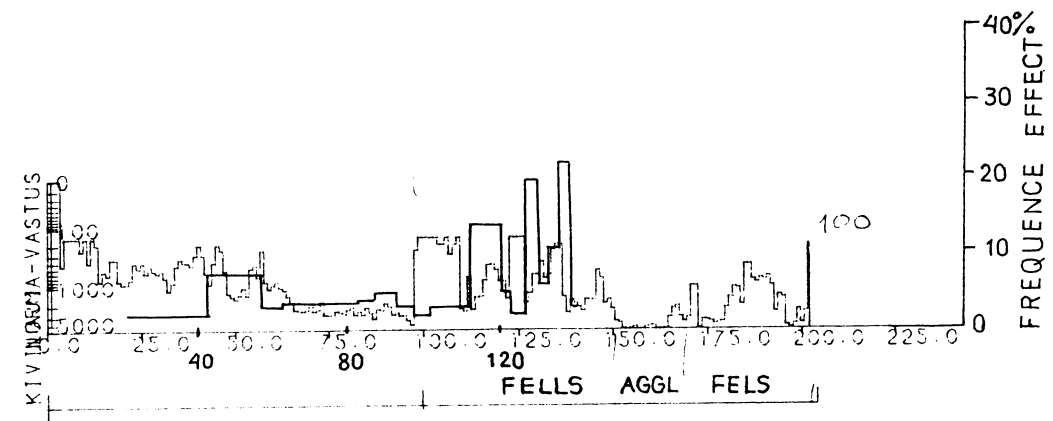
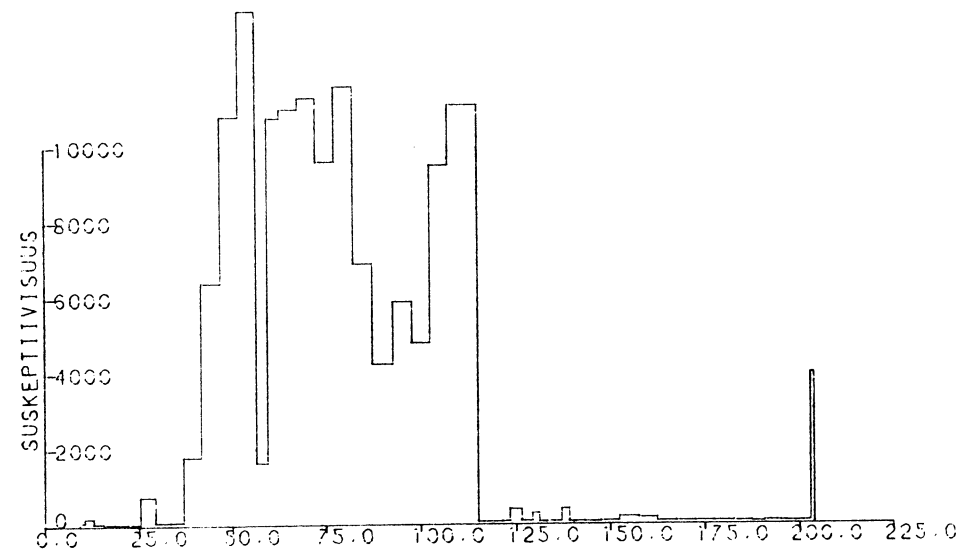
015212A KAIRAUSPROFIILI Y= 2.900
 1:2000 VÄLI=±20.0 M
 480/OMINAISVAKIODIAGRAMMI
 21.05.85
 NOLLATASO= 450.00
 NORMA-VASTUS (RESISTANCE)
 PROFIL 117

426.00 M

REIKA	Y/K	Y/L	Z	SUU	KAL
H0-52	0.160	2.910	426.00	180	60
H0-53	0.130	2.915	426.00	180	60
H0-55	0.100	2.915	426.00	180	60
H0-57	0.090	2.915	426.00	180	60



2.8

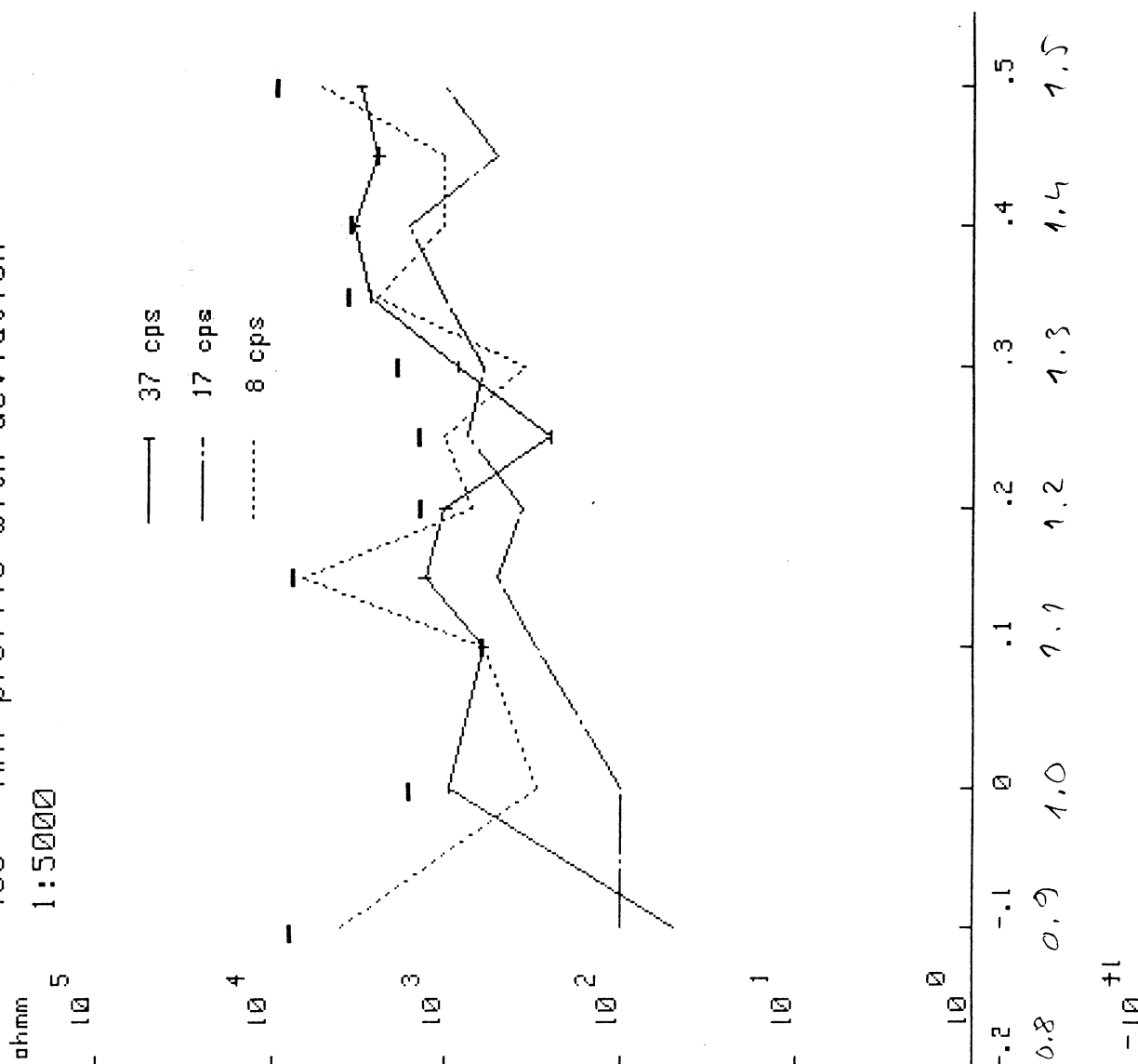


015212A X= 0.100 Y= 2.915 H0

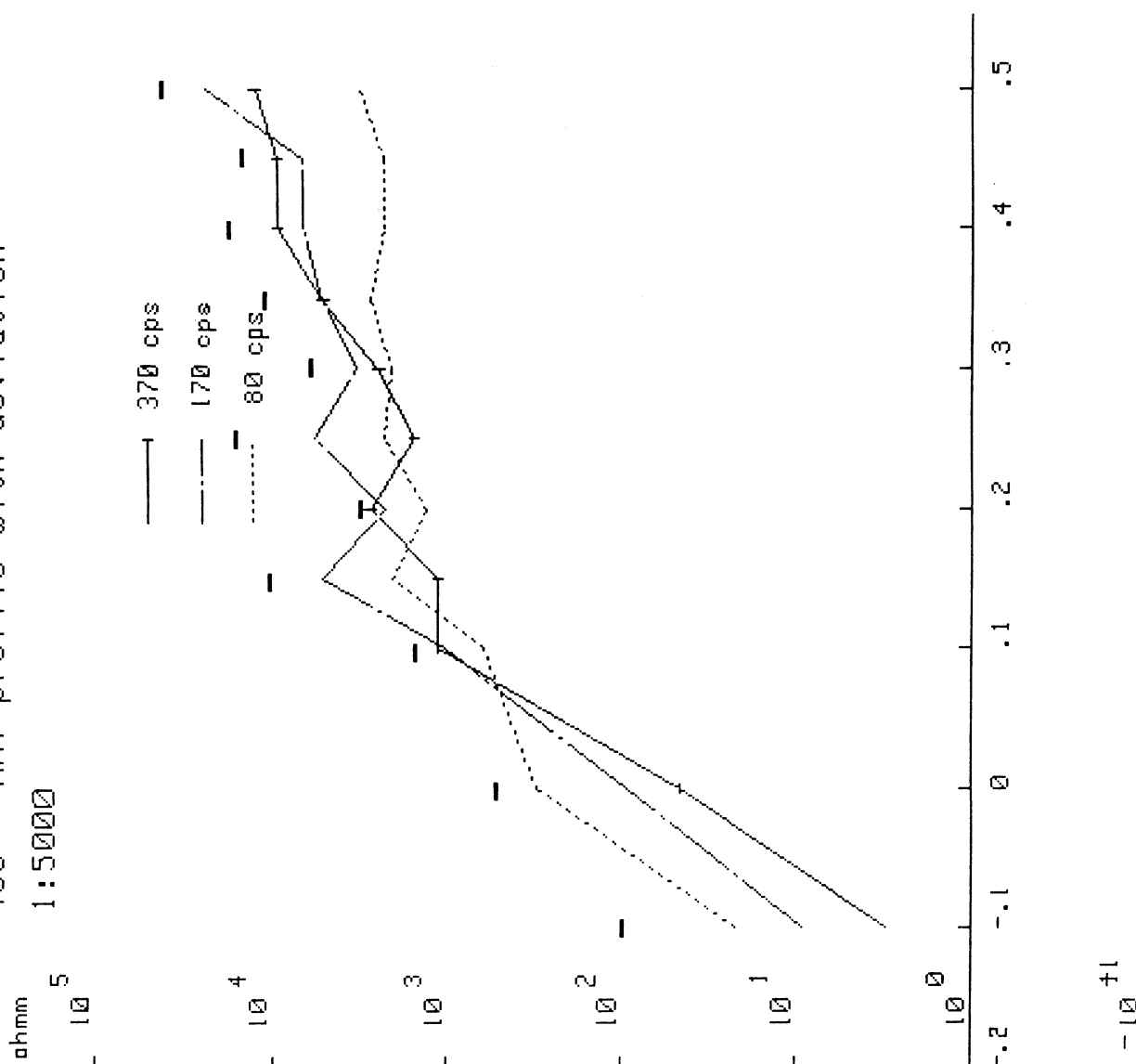
55

1: 2000 84.10.25

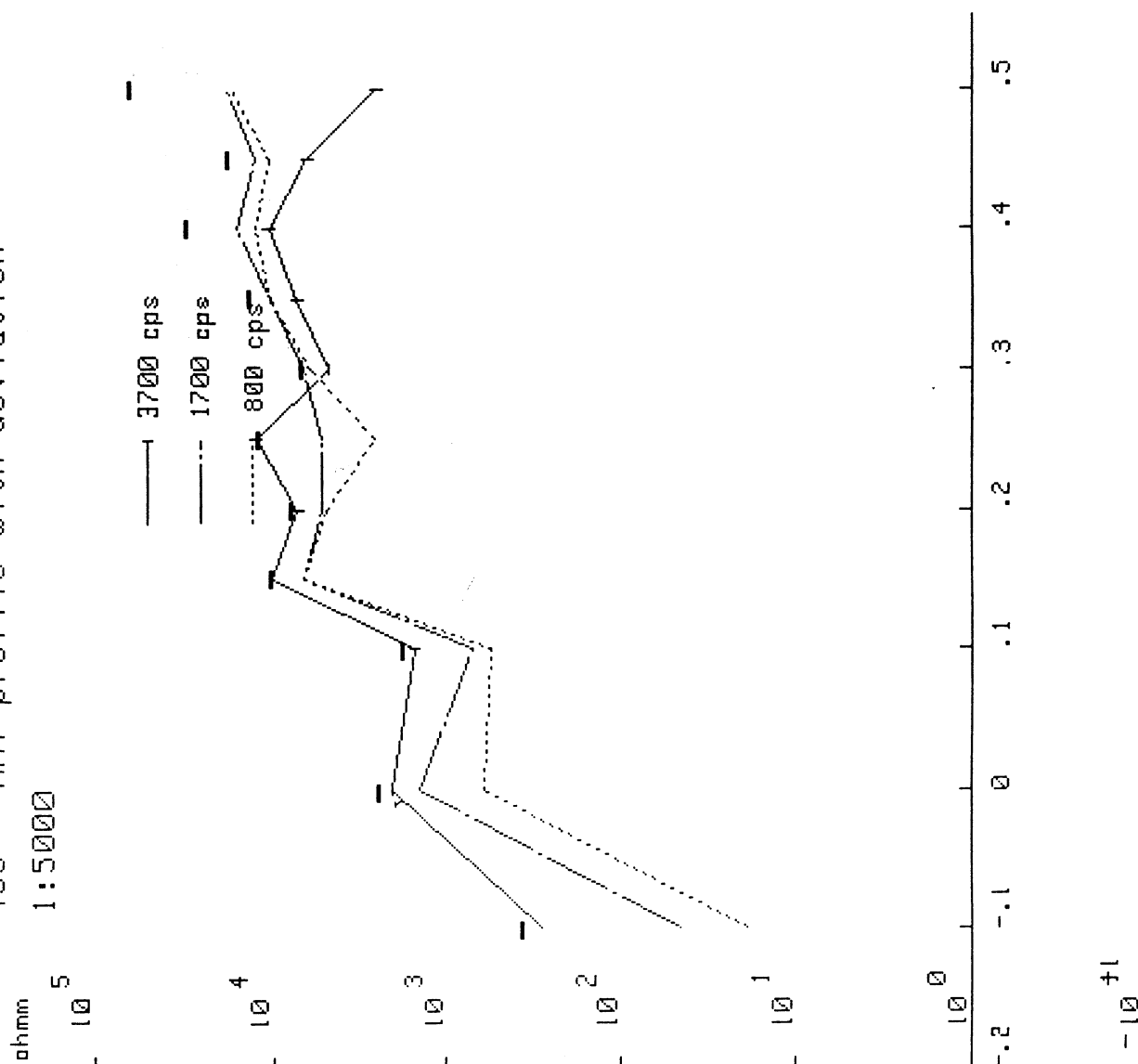
15212 LØKKEN =0
 433 RMT-profile with deviation
 1:5000



15212 LØKKEN =0
 433 RMT-profile with deviation
 1:50000



15212 LØKKEN =0
 433 RMT-profile with deviation
 1:5000



+dec.

mean

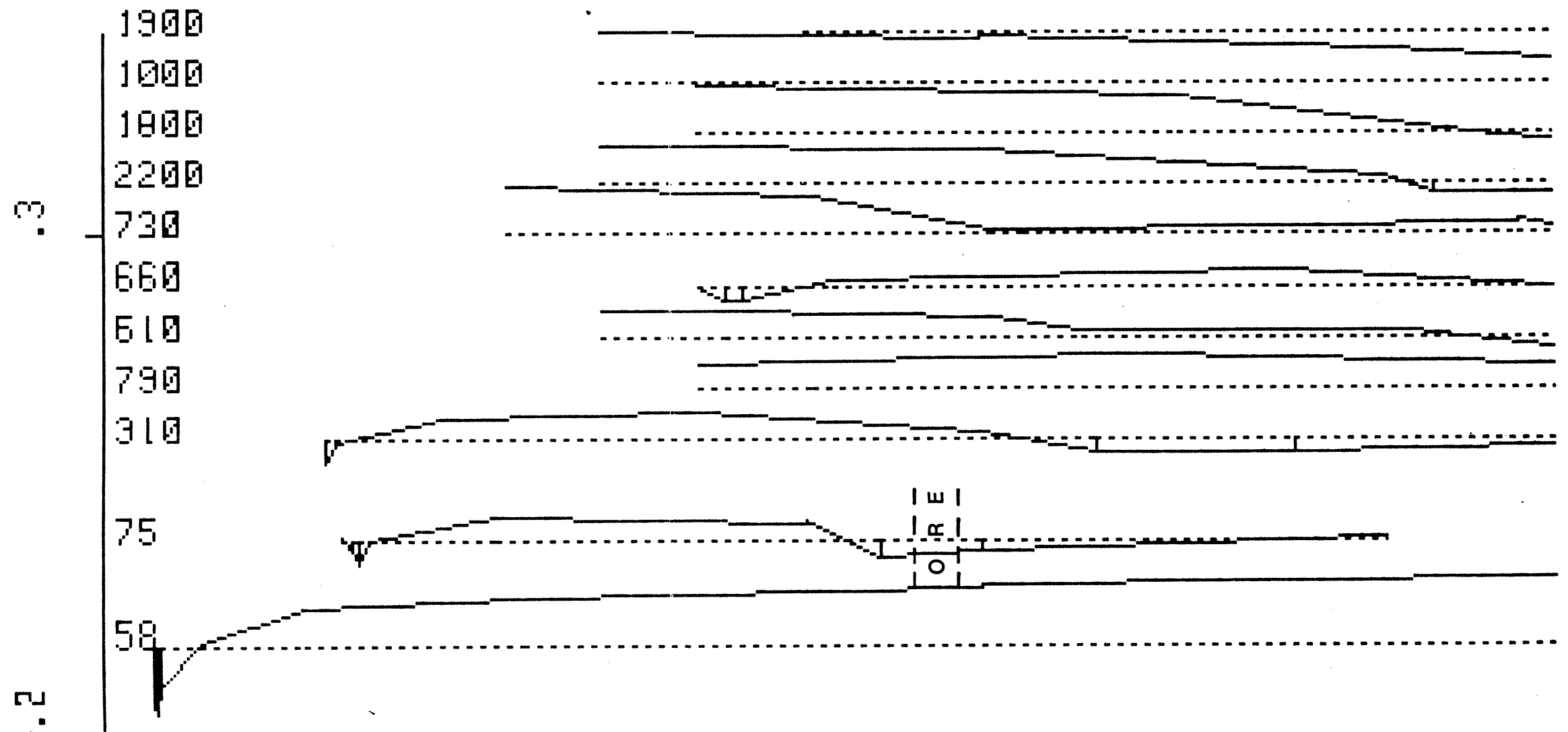
-dec.

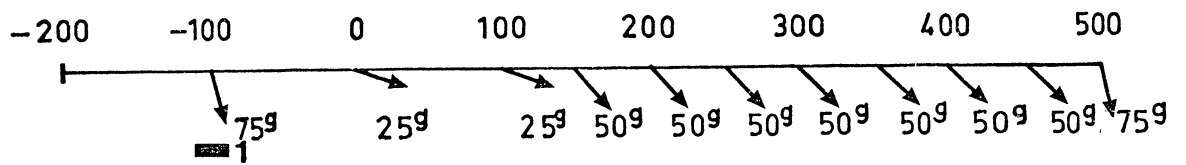
Ra

LØKKEN Suod-0

433 RMT-soundings, Bostic Inversion

1:5000





—5

—1

— — — —
O R E
— — — —
T₁

INTERPRETATION

—¹ CONDUCTORS WITH
T⁵ RESISTIVITY

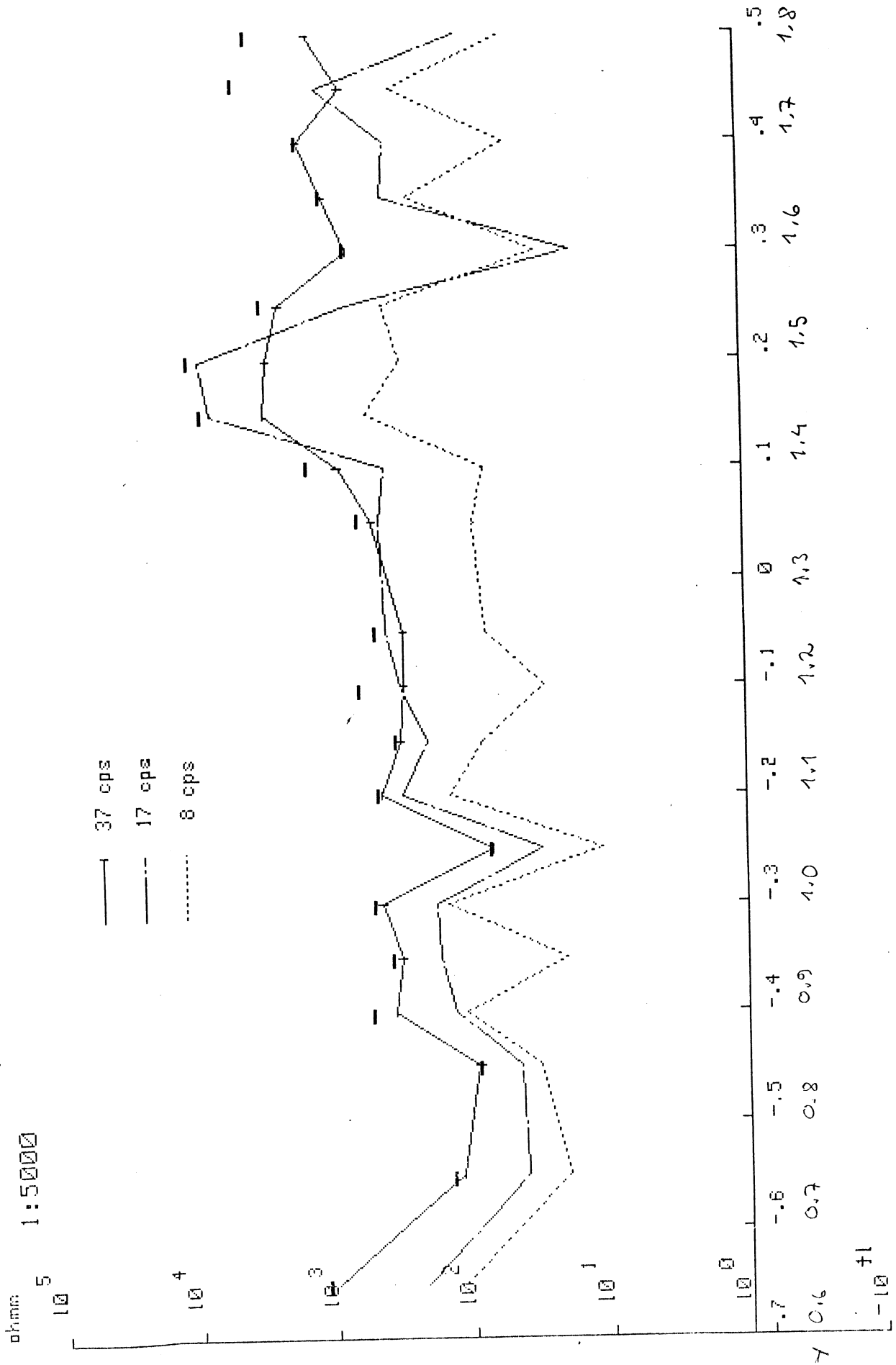
T₅₀

AMT-INTERPRETATION

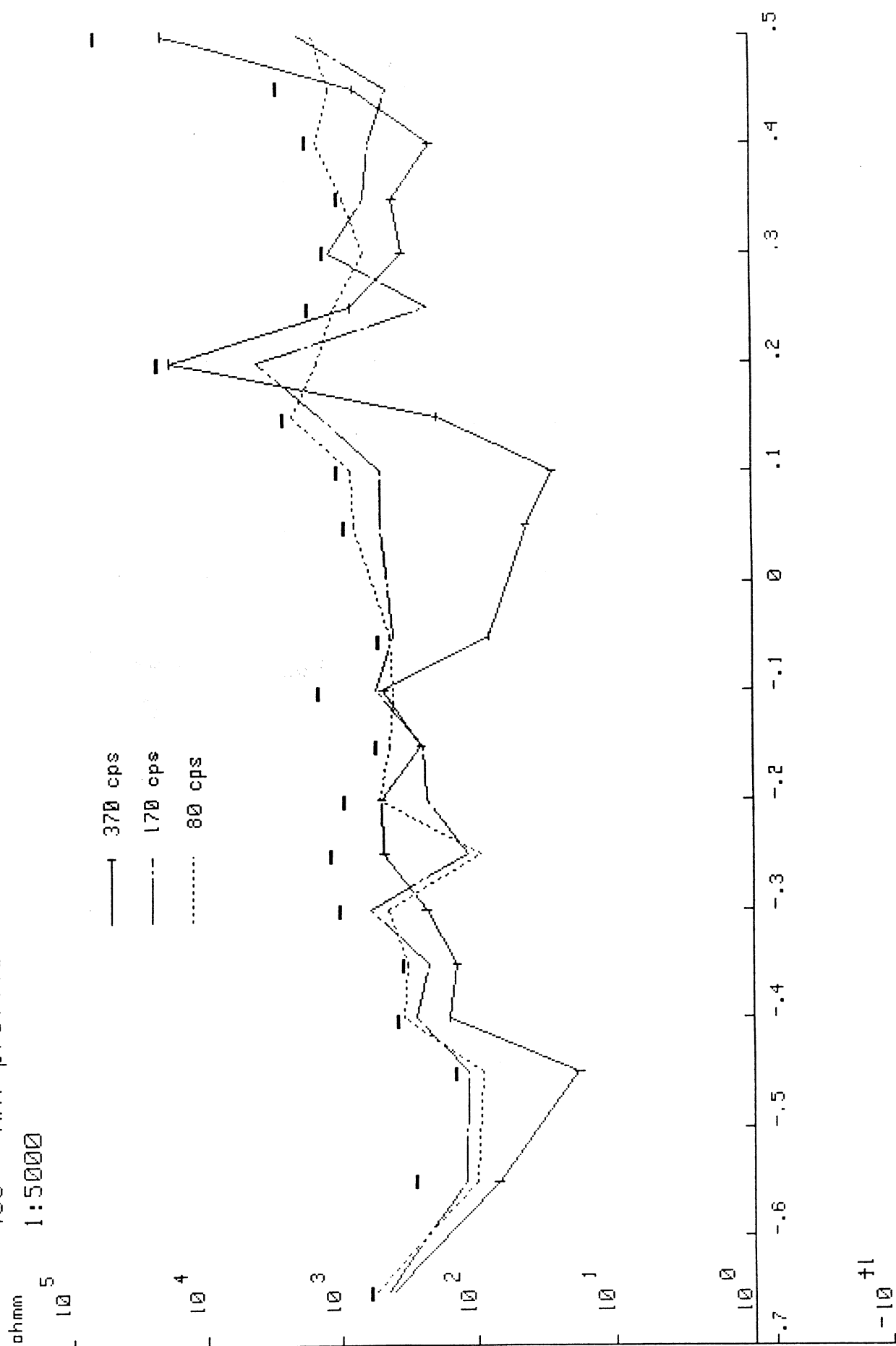
1:5000

LØKKEN

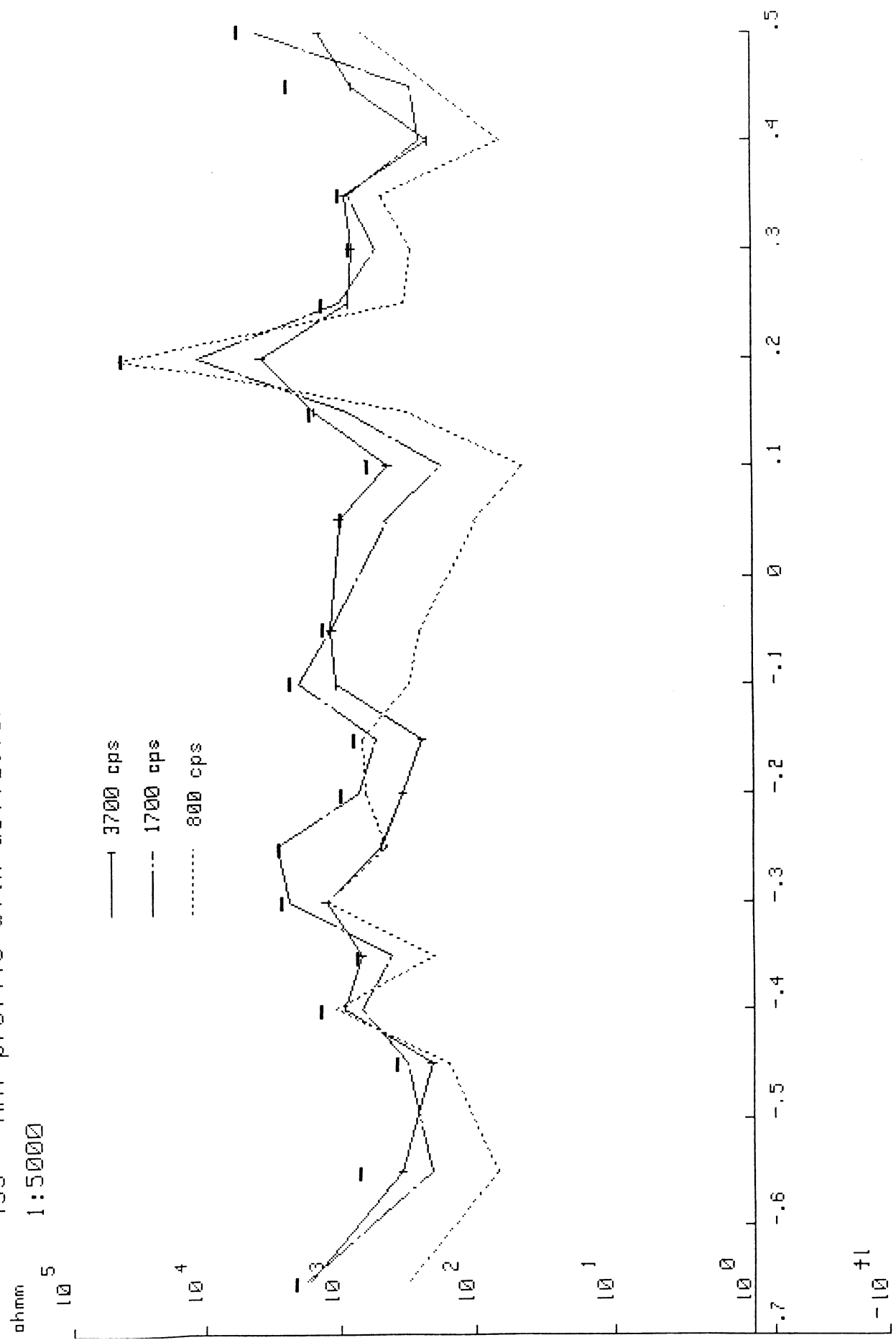
LØKKEN SVINSÅS W 30
 433 AMT-profile with deviation
 1:50000



LØKKEN SVINSÅS W=0
 433 RMT-profile with deviation
 1:50000



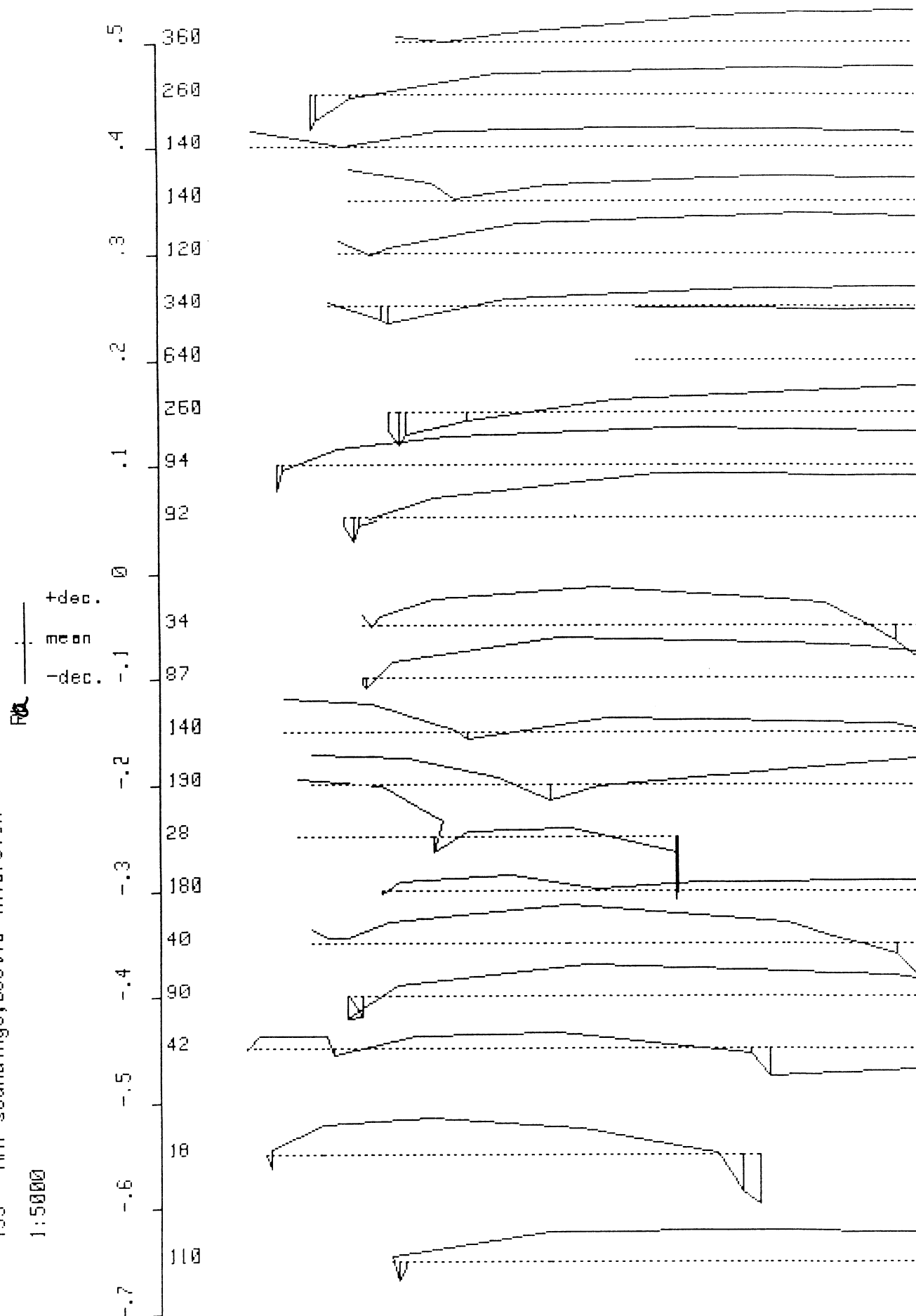
LØKKEN SVINSÅS $W=3$
 433 AMT-profile with deviation
 1:50000

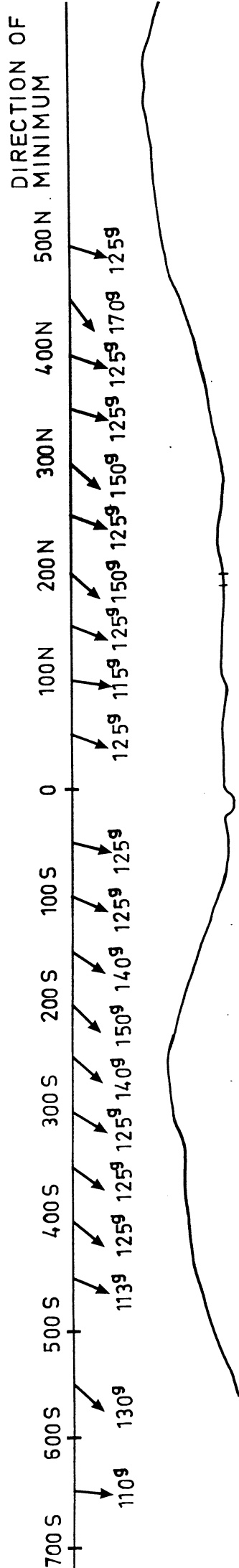


SVINSAS Sud/W-600

433 AMT-soundings, Bost1c Inversion

1:5000





INTERPRETATION

15 CONDUCTORS WITH RESISTIVITY

AMT-INTERPRETATION

1 : 5000

54

PROFILE W-600

LØKKEN, SVINSÅS

5

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54

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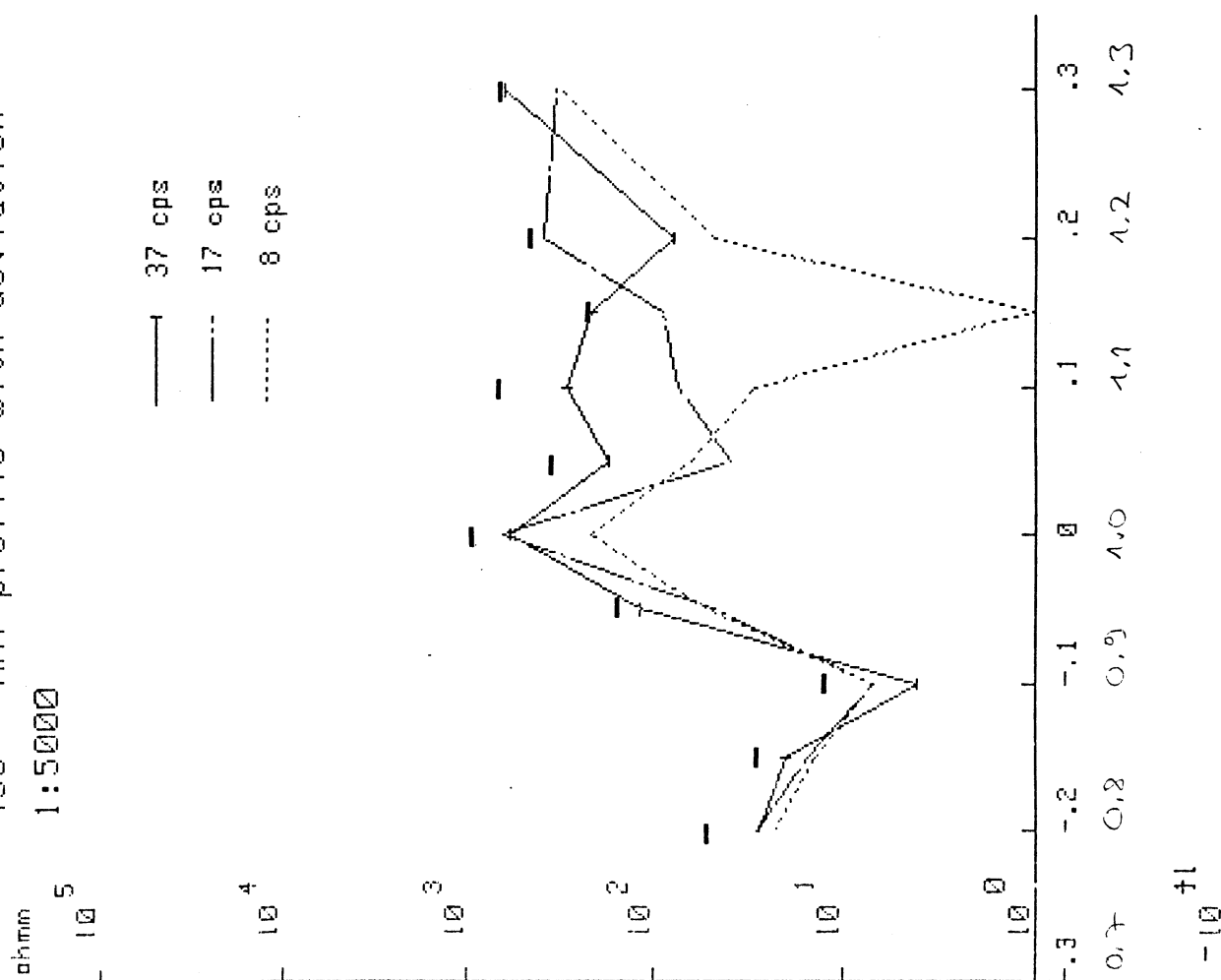
T

T

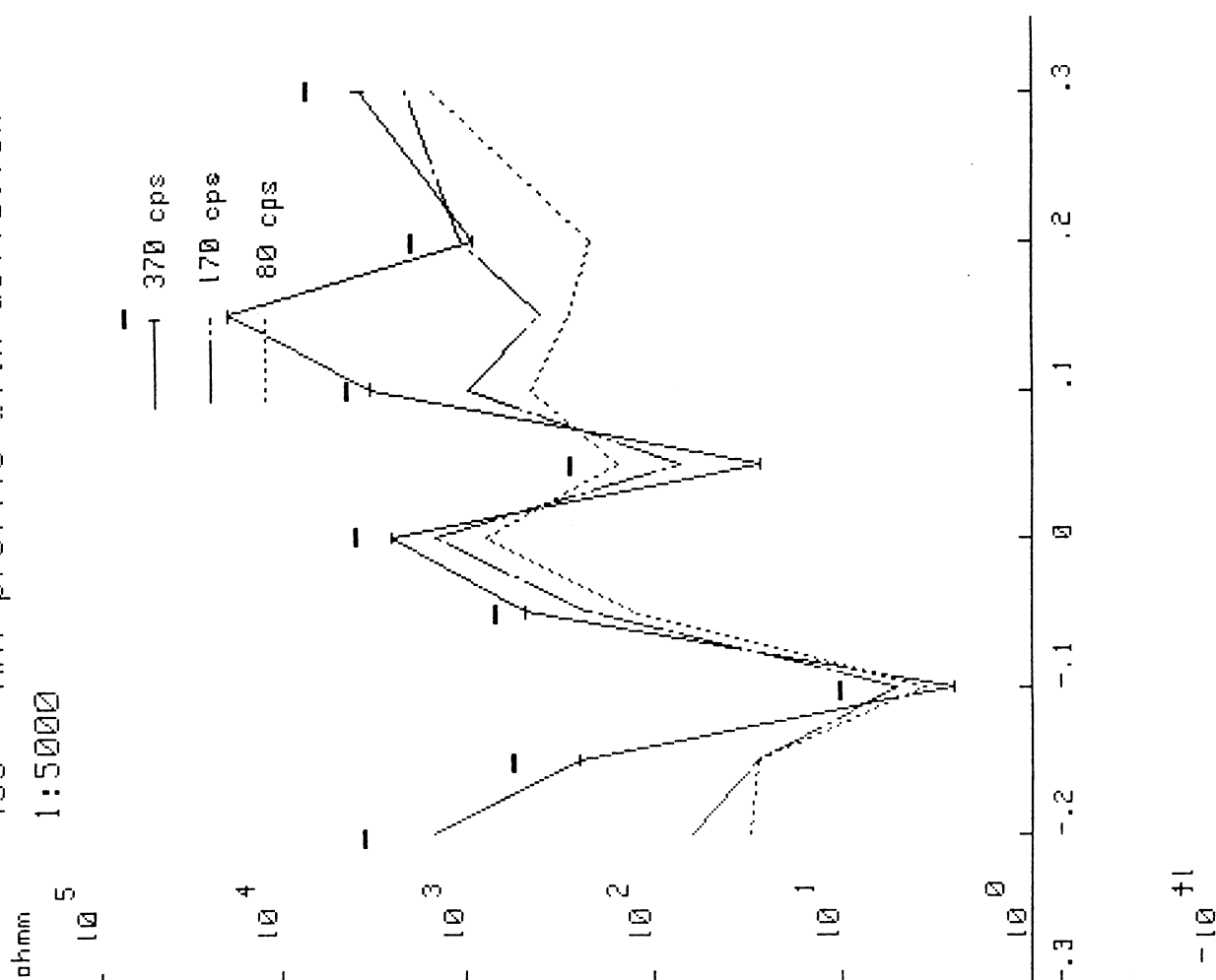
1

— 0.1

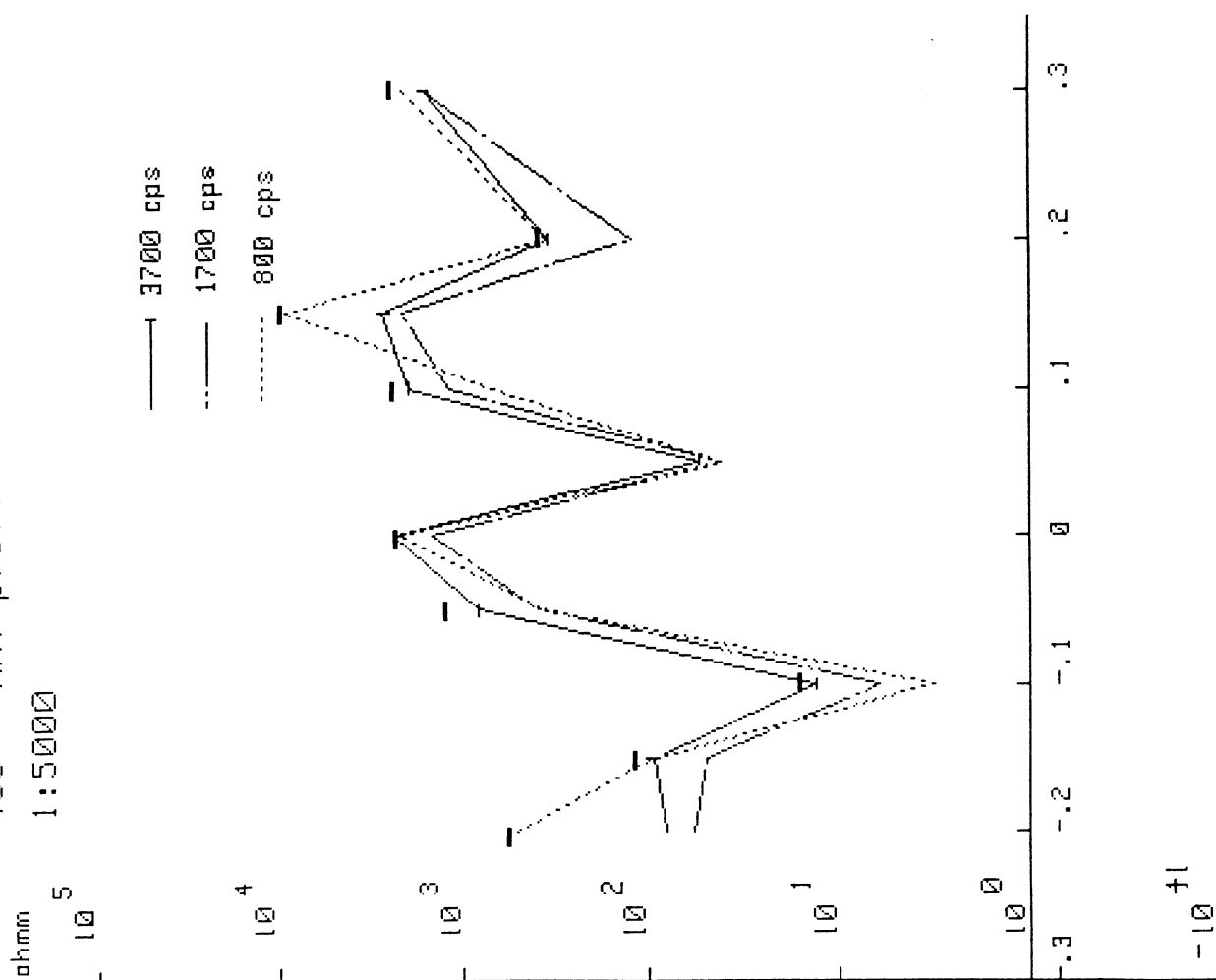
15212 LØKKEN HØYD PRC .121
 433 AMT-profile with deviation
 1:50000



15212 LØKKEN HØYDE PROF 121
 433 RMT-profile with deviation
 1:50000



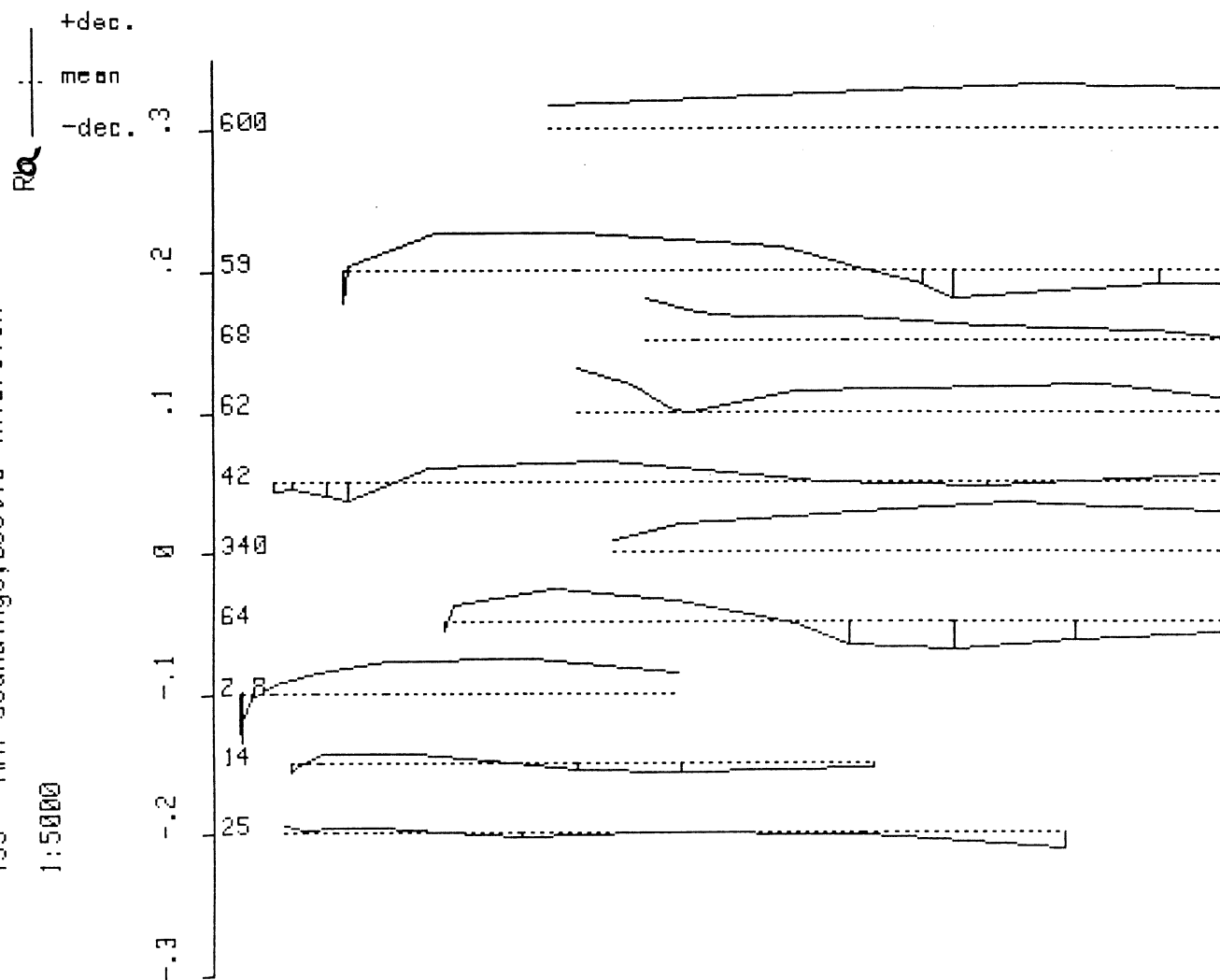
15212 LØKKEN HØYDAL PROF 21
 433 AMT-profile with deviation
 1:50000

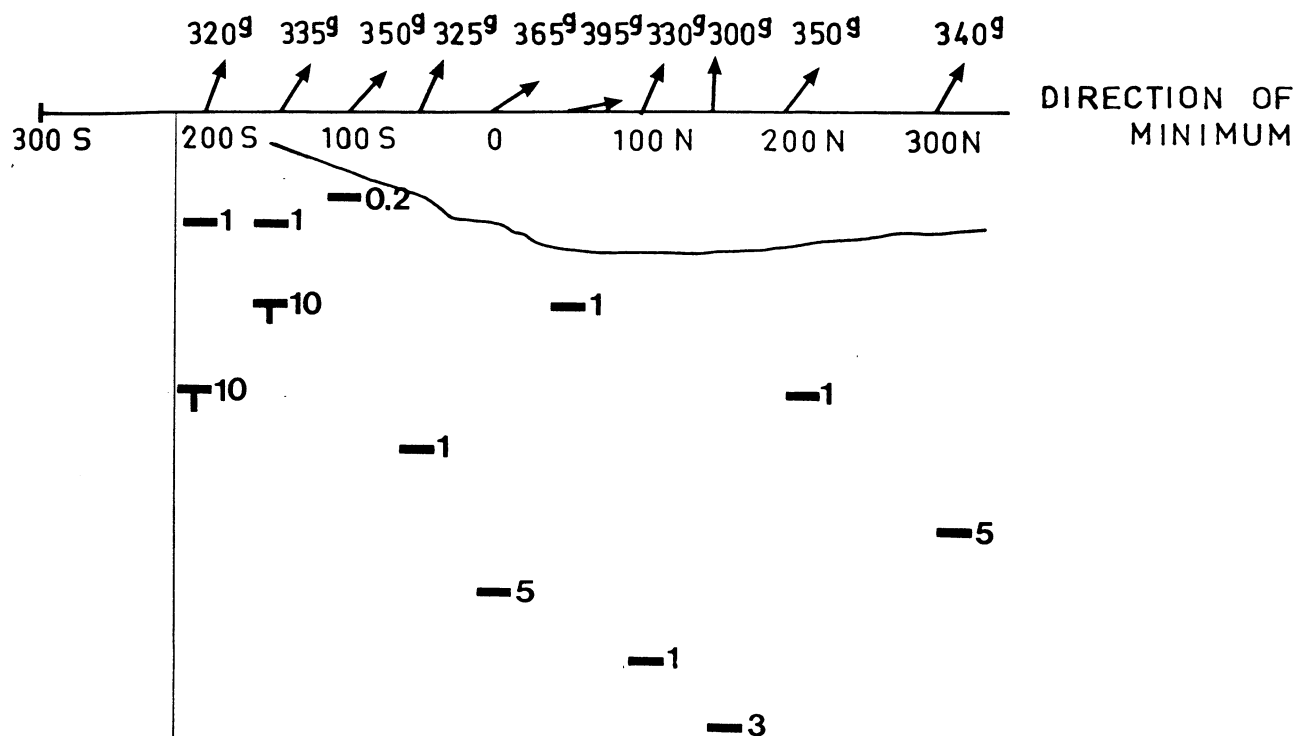


H0YDRL Suod/S-200

433 AMT-soundings, Bostic inversion

1:5000





INTERPRETATION

—1 CONDUCTORS WITH
T⁵ RESISTIVITY

AMT - INTERPRETATION

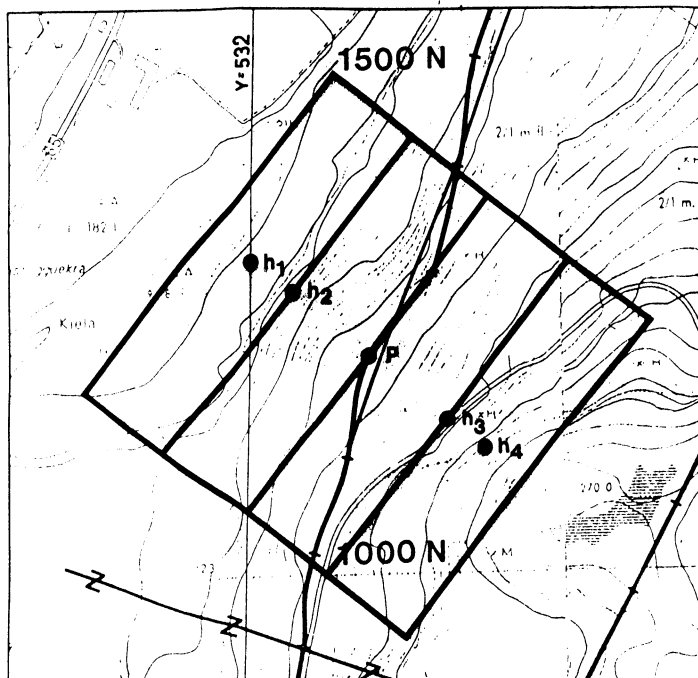
1 : 5000

PROFILE 121

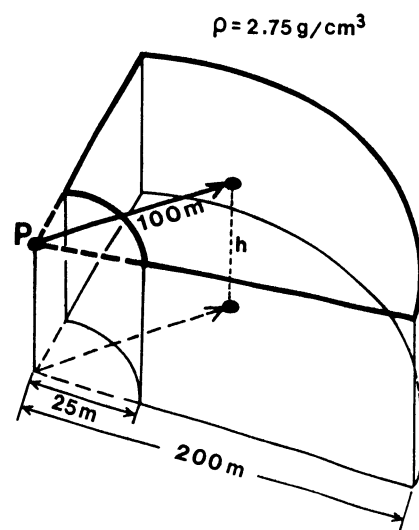
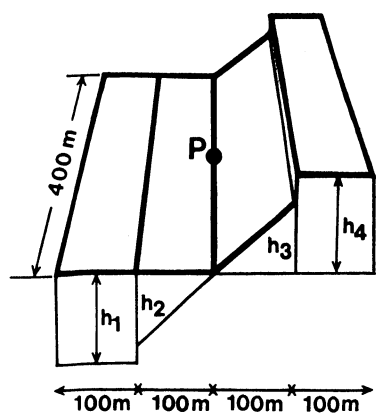
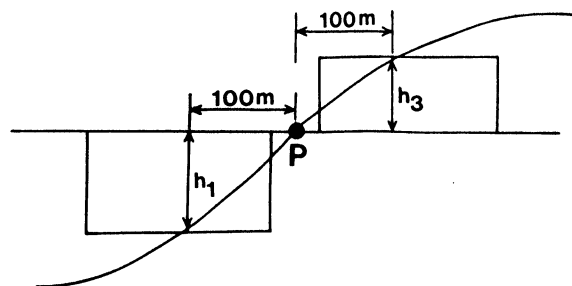
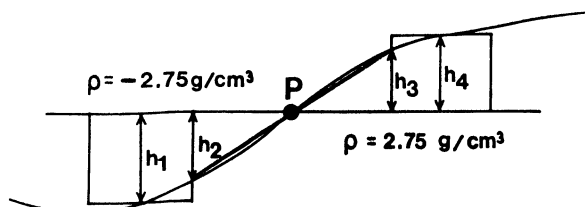
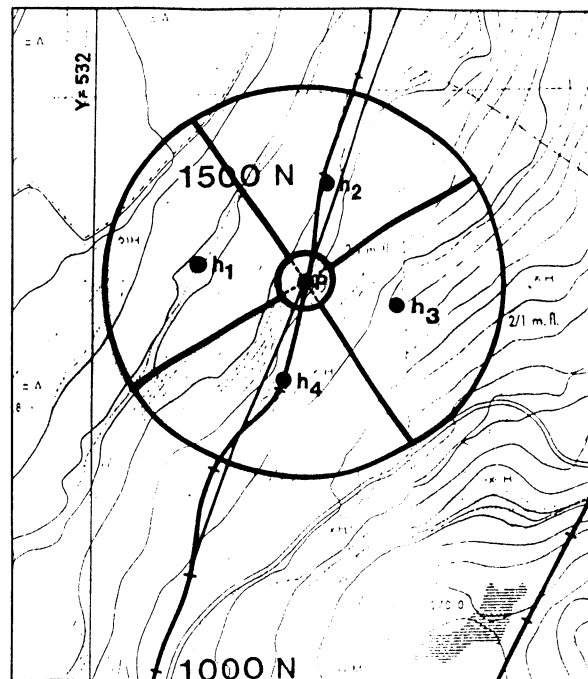
HØYDAL

TERRAIN CORRECTION

PRISM METHOD



SECTOR METHOD



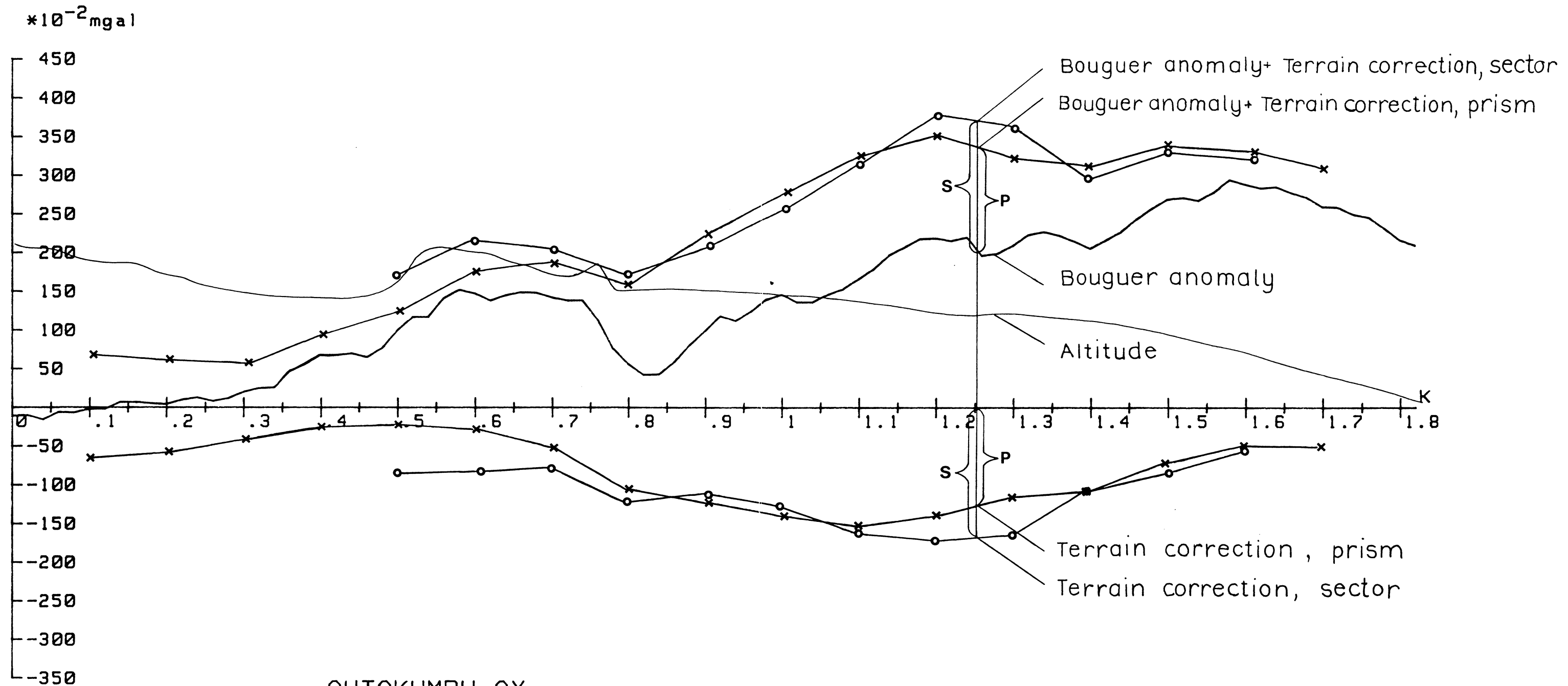
L=1

15213/LÖKKEN 1 GRA

450/19300

415/1:5000

GRAVITY INTERPRETATION TERRAIN CORRECTION



OUTOKUMPU OY
EXPLORATION
28.1 1985 / TVK

L=1

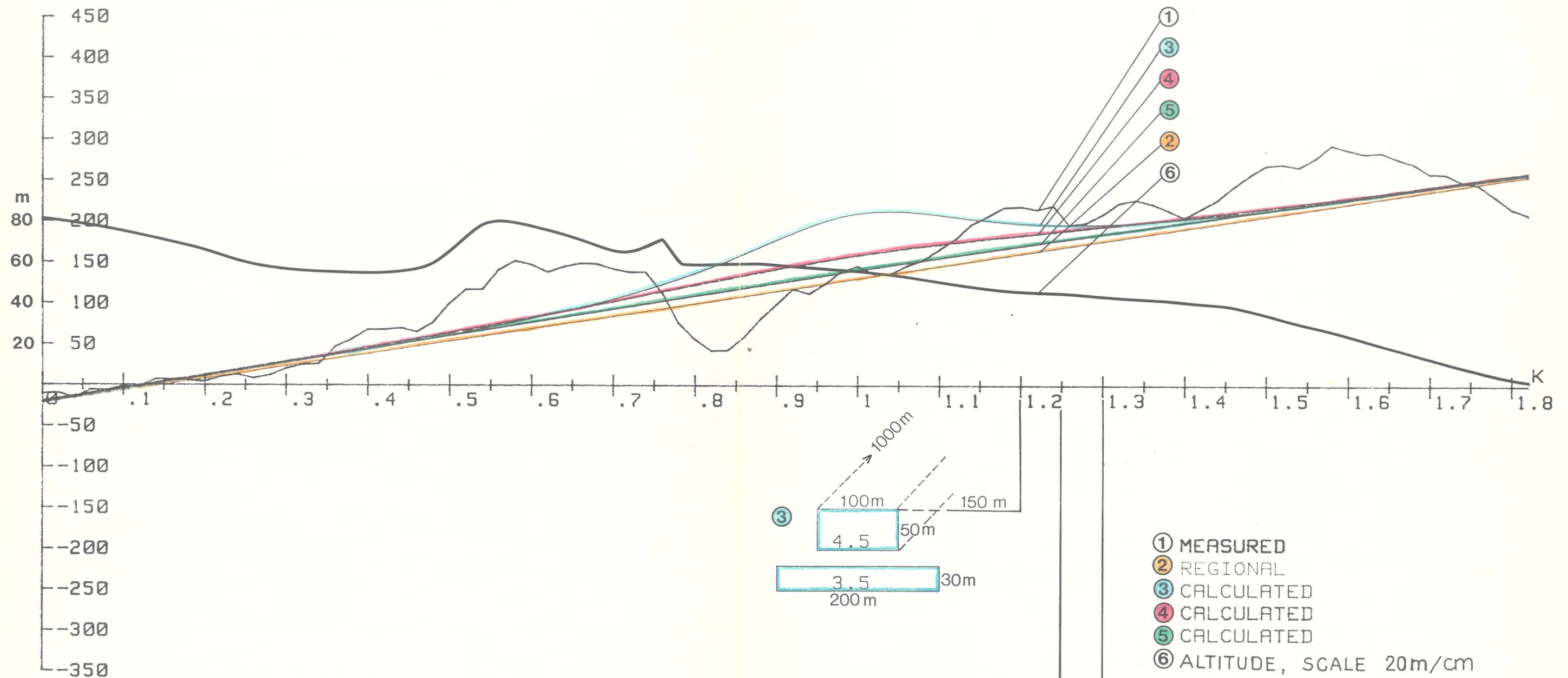
15213/LÖKKEN 1 GRA

450/19300

415/1:5000

$\times 10^{-2} \text{ mgal}$

GRAVITY INTERPRETATION



OUTOKUMPU OY
EXPLORATION
24.1 1985 / TVK

- ① MEASURED
- ② REGIONAL
- ③ CALCULATED
- ④ CALCULATED
- ⑤ CALCULATED
- ⑥ ALTITUDE, SCALE 20m/cm

DENSITY

ORE	4.5	g/cm ³
VASSKIS	3.5	g/cm ³
WALL ROCK	2.8	g/cm ³

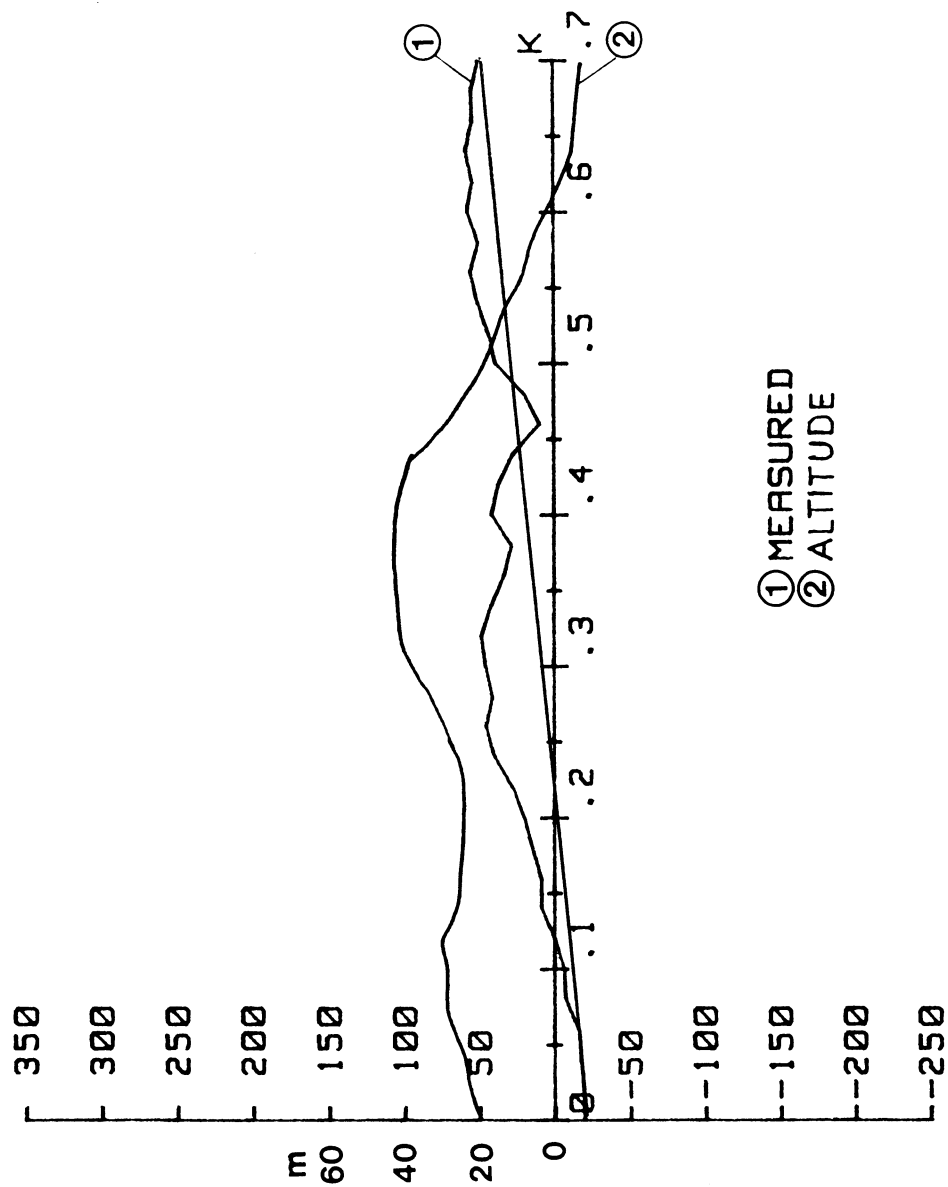
L=2

15213/LÖKKEN 2

450/15200

415/1:5000

$\times 10^{-2} \text{ mGal}$



OUTOKUMPU OY
EXPLORATION
28.1 1985 / TVK

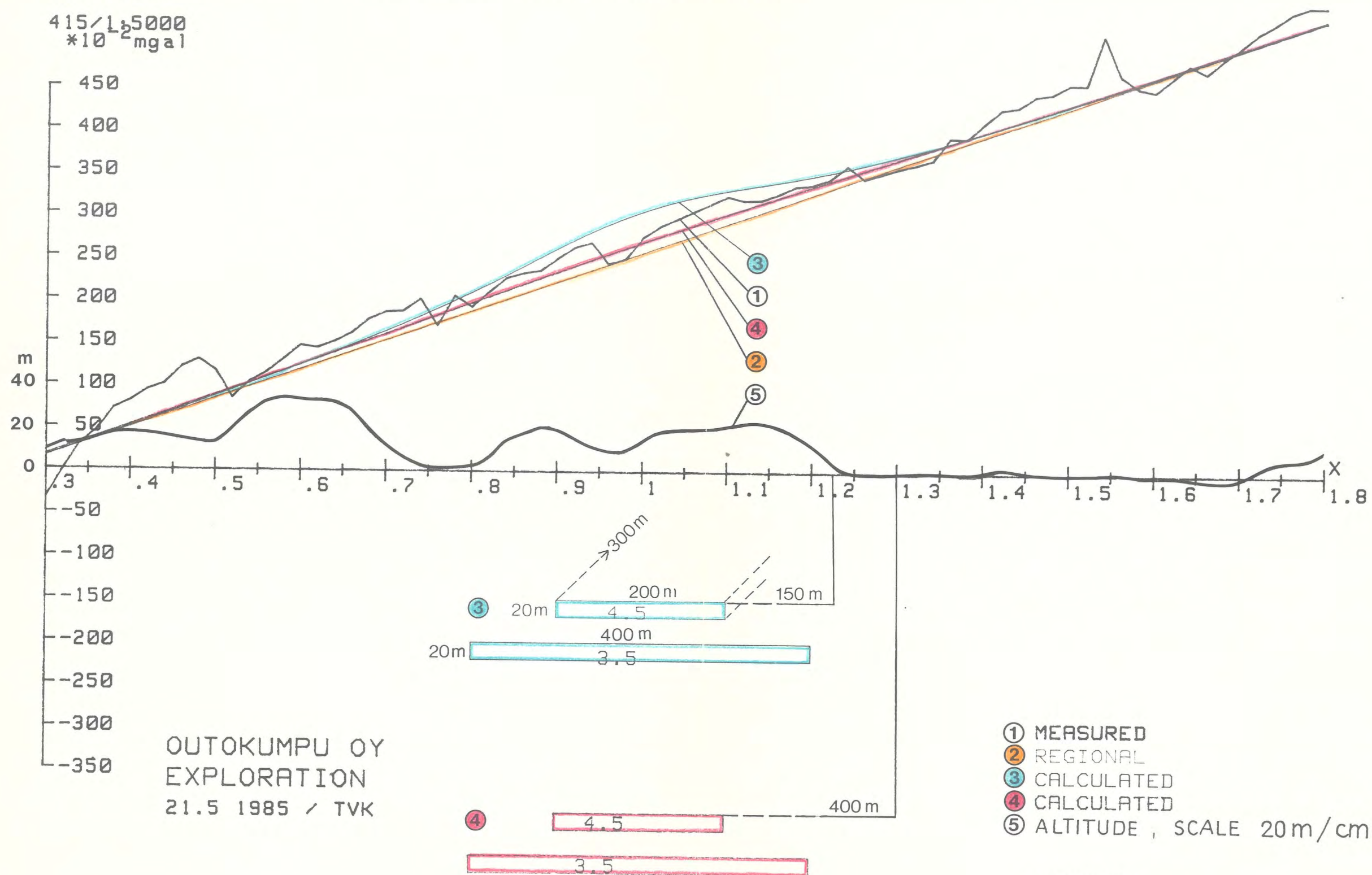
App

4 6

Y=.3

15213/SVINAS GRA
450/19300415/1.5000
*10⁻² mgal

GRAVITY INTERPRETATION



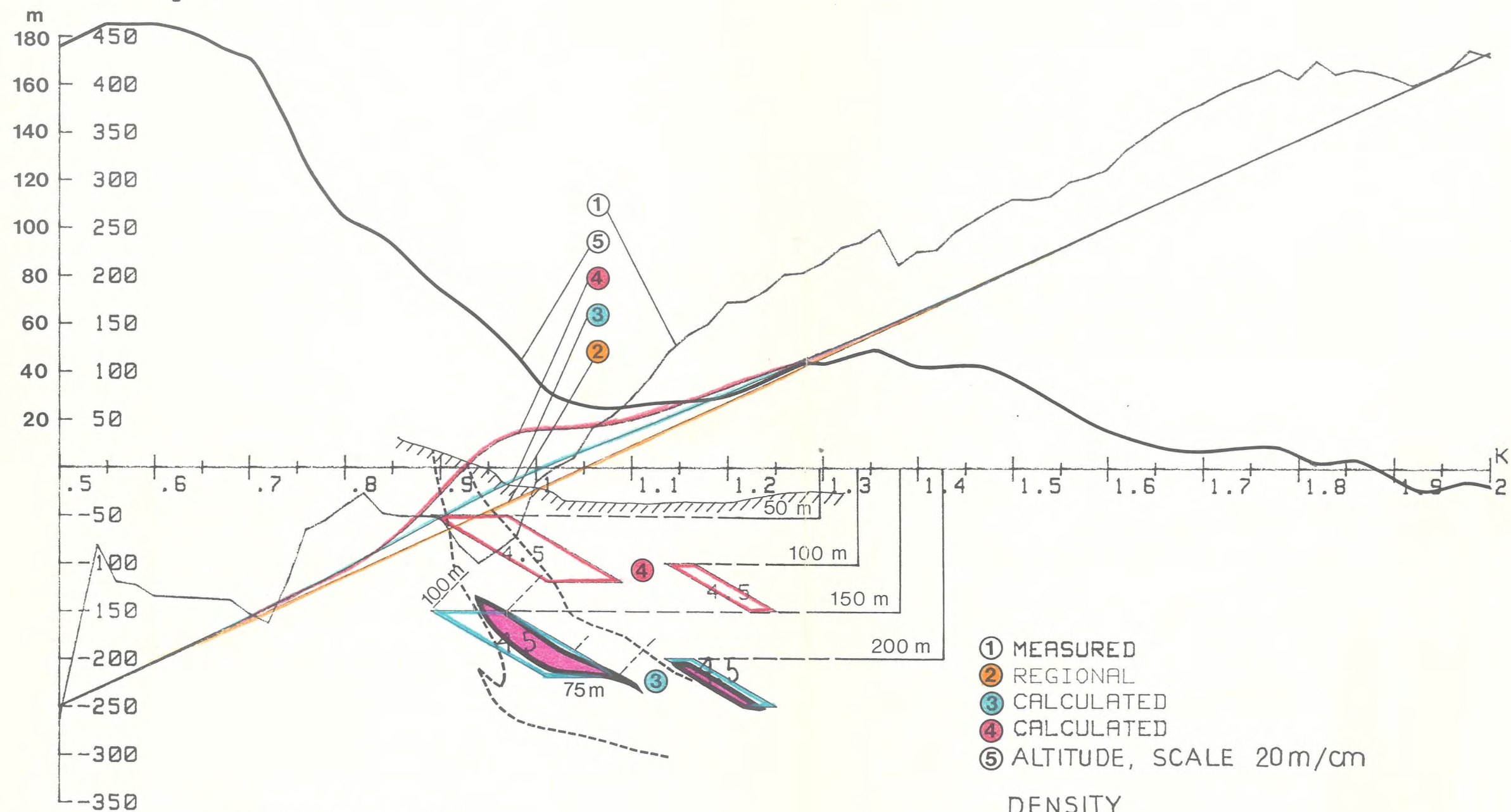
L=121

15212/HÖYDAL

450/24000

415/1.5000
*10⁻² mgal

GRAVITY INTERPRETATION



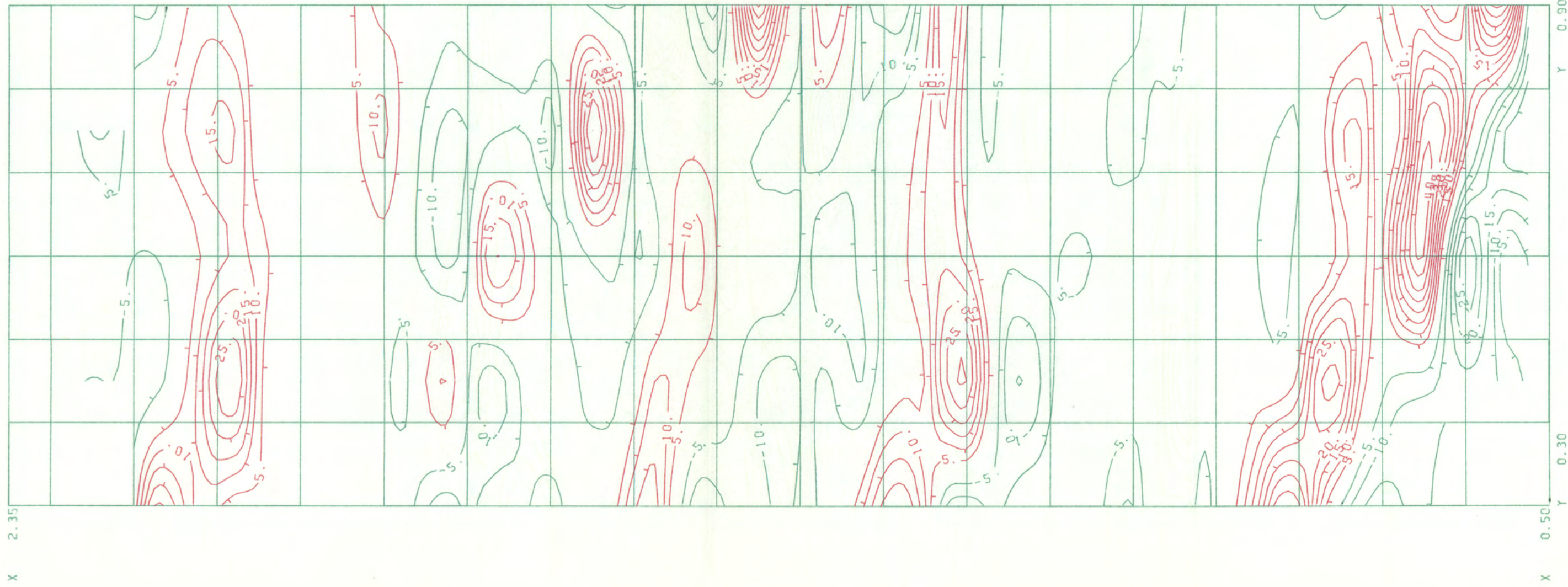
OUTOKUMPU OY
EXPLORATION
24.1 1985 / TVK



15213/X 0.50/Y 0.30
 L0/SVINSOS GEN 8/122/84
 499/P/150/25/100/337
 0/0/-0+/16.05.85
 1:5000

0 M 250

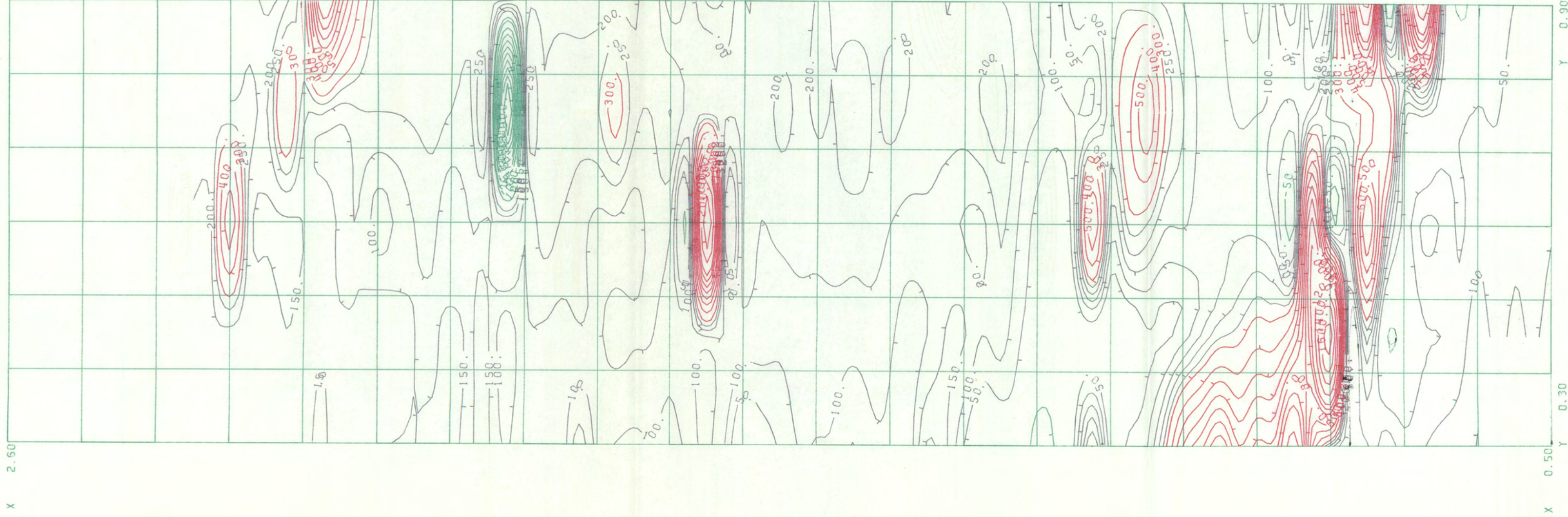
0.50 , 1.00, 2.00, 3.00, 4.00
 6.00 , 8.00, 10, 12, 14
 16 , 18, 20, 22, 24
 26 , 28, -0.50, -1.00, -2.00
 -3.00 , -4.00, -6.00, -8.00, -10
 -12 , -14, -16, -18, -20
 -22 , -24, -26, -28, -30



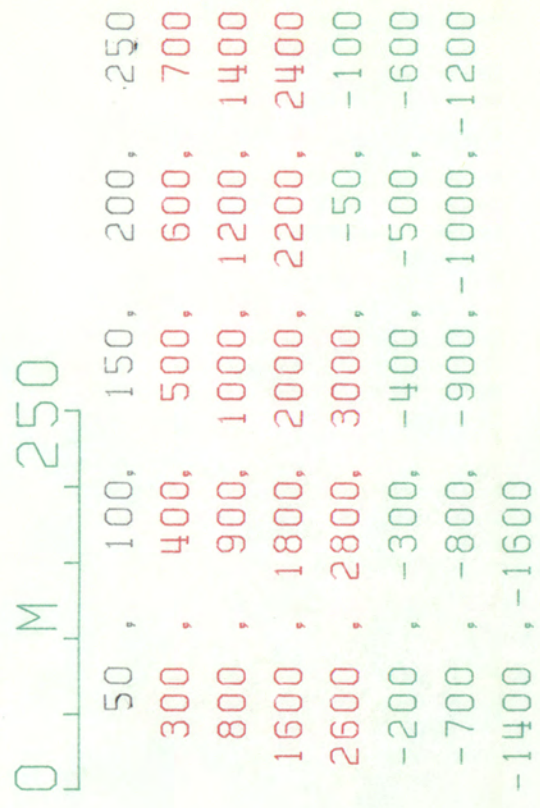
15213/X 0.50/Y 0.30
 LØKKEN SVINSAS/84
 442/P/150/25/2/17.8 kHz
 VLF-DIP ANGLE
 0/0/-0+/17.04.85
 1:5000

0 M 250

5.00 , 10, 15, 20, 25
 30 , 35, 40, 45, -5.00
 -10 , -15, -20, -25, -30
 -35 , -40, -45



15213/X 0.50/Y 0.30
LØKKEN SVINSAS/84
422/P/150/25/50600
MAGNETIC TOTAL FIELD
0/0/-0+/17.04.85
1:5000



MARI KRISTINA
HOLTNE
g.m.

INGRID CELLE
HOLTNE

MIRA ELISE
GLAVER HOLTNE
1984 -

HUDETTE
GLAVER HOLTNE
1987 -

KRISTINA
GLAVER HOLTNE
1989 -

JEUS KRISTINA HOLTNE
1951 -
g.m. MOLLICA
GUSTAVSON

OLAV HOLTNE
1954 -
g.m. VIGENE GLAVER
1961 -

ANNE IERNE HOLTNE
1957 -

LARS HOLTNE
1966 -
g.m. EVA HULSTAD

NINA f. 1903
RUNE f. 1908

JAMUNG f. 1970
LARS ERIK f. 1973

WIGER LISE HANSEN
1943 -
g.m. OLAF DINGESEN

KJELL ERIK HANSEN
1949 -

TOR ERIK
JAN STEINAR
BERIT
WALSHAG
1947 -
1952 -
1950 -

MARTIN MATHSEN
1903 -
1920 -
1922 -
g.m. LILV
g.m. JOHN JONLUND

NUSS MATHSEN
1971 -

PER ERIK
JAN STEINAR
BERIT
WALSHAG
1947 -
1952 -
1950 -

SIGRID
WALSHAG
1939 -
1904 -
1955 -
TOR HOLTNE

ASBJORN
HOLTNE
1964 -

GREID HOLTNE
1915 -
g.m. ODD HANSEN

HARVEY HOLTNE
1917-1943
g.m. MARY JOHANNE
TILDE
1925-2001

AF HOLTNE
1921 -
g.m. LUCEBORG
GELLES

KARI HOLTNE
g.m. BJARKE
MATHSEN

PET LINDER
WALSHAG
1920 -
g.m. LILV

SOLVEIG MARENHE
HOLTNE WALSHAG
1922 -
g.m. JOHN JONLUND

TORBJORN ODDAR
HOLTNE
1920 -
g.m. ALVING TORVIK

KARE HOLTNE
1922 -
g.m. ARTEID
THASGVR

SOLVEIG BJARNOR
JACOBSEN
1923
g.m. HELMUS JACOBSEN
g.m. VILLY SVANELEID

ELIAR MARUS HOLTNE
1922 -
HUTELLEICE f. TR II.
g.m. SOPHIE

BERIT HOLTNE
1890 -
g.m. HILMAR
MOLLER

OLAF HOLTNE
1894-1941
H. DEIVANNE f. TR. II.
g.m. HANSE ARHJEL

PETRA GRUNHILDE
HOLTNE
1894 -
g.m. EINAR LARSEN
WALSHAG

KONRAD THEODOR
HOLTNE
1899 -
g.m. MAREIE ALTHE
LENGEN

MARGIT BERTINE
HOLTNE
1902-1915

ELEONORE KASTARA
HOLTNE
1905
g.m. JOHANNUEL
BERGTON JACOBSEN

PETER KUNGERIUS
OLSEN HOLTNE
1902-1943
g.m. GYNNILD
THORSTEN DYDAL

JOHAN PEDERX OLSEN
1877-1919
TOLLBORG f. TR. II.
g.m. SIBERUD JONSTE
g.m. PETERINE GEHADE

LUNDIG OLSEN
1854-1935
MAJLUBERT f. TR. II.
g.m. OLAVIE EMMIE
KISTHANS THORSENSTR.

MARTIN KRISTIAN OLSEN
1879-1940
HARJACOB f. TR. II.
g.m. OLAVIE EMMIE
KISTHANS THORSENSTR.

METTE OLSEN OLSTR.
ca. 1850 -
BOUDE PA FEVIG
g.m. TRULS ERIKSEN

PETER KUNGERIUS
OLSEN HOLTNE
1902-1943
g.m. GYNNILD
THORSTEN DYDAL

ELEONORE KASTARA
HOLTNE
1905
g.m. JOHANNUEL
BERGTON JACOBSEN

MARGIT BERTINE
HOLTNE
1902-1915

PETER KUNGERIUS
OLSEN HOLTNE
1902-1943
g.m. GYNNILD
THORSTEN DYDAL

ELIE LARSEN.
1807-1899
g.m. ANDERS HANSEN
OVERKOT
g.m. JACOB JOHANSEN
GEHIDE

ELIE LARSEN.
1808-1923
g.m. ANDERS PAVSEN
HARSAKER

LARS LARSEN
BEKRESKIFTE
1810-1905
BOUDE f. STADSVAR
g.m. ALVIE MATHIA
KUNSTOR HANSEN

PETER LARSEN
BEKRESKIFTE
1813-1902
BOUDE f. STADSVAR
g.m. MALENA
WALSTEDT LIDT

FREDRIK LARSEN
BEKRESKIFTE
1815-1903
BOUDE f. STADSVAR
g.m. MALENA
WALSTEDT LIDT

OLE LARSEN FEVIG
1919-1904
HUSMAN f. STADSVAR
g.m. BEET MATHIA
JOHANNUEL FEVIG

ERIKKA LARSEN.
1820-1903
g.m. JOHANNUEL
OLSEN KOLEN

INGEBRIGT LARSEN
BEKRESKIFTE
1823-1873
LIDT

KAREN JOHANNA
LARSEN
1826-1832
g.m. ENE HANSEN
GEBBETH

MARGIT LARSEN.
1844-1836
g.m. REISA ANDERSEN
BOUDE f. STADSVAR

EDRIKA LARSEN.
1847-1899
g.m. SAMUEL HANSEN
BOUDE f. STADSVAR

LARS LARSEN
BEKRESKIFTE
1876-1834
BOUDE f. STADSVAR
g.m. KIRSTI PEDERSEN
FOLLOE

GURU LARSEN.
1889 -
g.m. LARS PEDERSEN
FOLLOE

ERIKKA LARSEN.
1820-1903
g.m. JOHANNUEL
OLSEN KOLEN

INGEBRIGT LARSEN
BEKRESKIFTE
1823-1873
LIDT

KAREN JOHANNA
LARSEN
1826-1832
g.m. ENE HANSEN
GEBBETH

LUCEBORG LARSEN
1736-1905
BOUDE f. STADSVAR

ARI LARSEN RYE
1739-1803
BOUDE f. STADSVAR
g.m. RYAN BEATSTRE
ERIKKA HANSEN

LARS LARSEN KJARNEN
1741-1804
BOUDE f. STADSVAR
g.m. GURU OLSEN
KJARNEN f. STADSVAR

OLE LARSEN FEVIG
1919-1904
HUSMAN f. STADSVAR
g.m. BEET MATHIA
JOHANNUEL FEVIG

ERIKKA LARSEN.
1820-1903
g.m. JOHANNUEL
OLSEN KOLEN

INGEBRIGT LARSEN
BEKRESKIFTE
1823-1873
LIDT

KAREN JOHANNA
LARSEN
1826-1832
g.m. ENE HANSEN
GEBBETH

LARS LARSEN BERGE
1709-1902
BOUDE f. STADSVAR
g.m. MARI ARHJEL
VORHAGE

JOH LARSEN REHAGEN
1711-1902
BOUDE f. STADSVAR
g.m. ALE PEDERSEN
REHAGEN

KIRKEN LARSEN.
1711-1902
g.m. JOH LARSEN
YTERLIDEN
g.m. OLE PEDERSEN
VORHAGE

ANDERS LARSEN
LINDBERG
1716-1902
BOUDE f. STADSVAR

LUCEBORG LARSEN.
1736-1905
BOUDE f. STADSVAR

ERIKKA LARSEN.
1820-1903
g.m. JOHANNUEL
OLSEN KOLEN

INGEBRIGT LARSEN
BEKRESKIFTE
1823-1873
LIDT

KAREN JOHANNA
LARSEN
1826-1832
g.m. ENE HANSEN
GEBBETH

KAREN JOHANNA
LARSEN
1826-1832
g.m. ENE HANSEN
GEBBETH

KRISTEN JOHANSTOR.
1681-1950
g.m. LARS LARSEN
BOUDE f. STADSVAR

ANDERS JOHANSEN
TIEBEN
1681-1950
g.m. MARI OLSEN
BOUDE f. STADSVAR

LOVE JOHANSTOR.
1691-1908
g.m. LARS AMUNDSEN
HOLSTEN
g.m. ALE PEDERSEN
HOLSTEN

MORTEN JOHANSEN
1695-1912
g.m. KARE OLSEN
PFUM

HERMANN JOHANSEN
1697 -
g.m. RYANUS
PEDERSEN KJALE

MARI JALLSTOR
1700-1905
g.m. RYANUS
PEDERSEN KJALE

JOH JOHANSEN
1702-1902
g.m. JOHANNUEL
KJALE

JOHANNUEL JOHANSTOR.
1705-1905
g.m. JOHANNUEL
KJALE

FREDRICH JOHANSEN
1707-1907
g.m. JOHANNUEL
KJALE

LARS ?

KJAND MORTENSEN
1900-1903

JOHN MORTENSEN
1879-1926
g.m. MORTEN KJALE
KJALESTOR. EGGHILL

JOHN MORTENSEN
1879-1926
g.m. MORTEN KJALE
KJALESTOR. EGGHILL

KRISTEN MORTENSEN
1879-1926
g.m. MORTEN KJALE
KJALESTOR. EGGHILL

JOHANNUEL JOHANSTOR.
1705-1905
g.m. JOHANNUEL
KJALE

FREDRICH JOHANSEN
1707-1907
g.m. JOHANNUEL
KJALE

LARS ?

JOHTE JOHANSTOR.
ca. 1615
g.m. STEEN HANSEN
PREST f. OKDAL

JOHN MORTENSEN
1879-1926
g.m. MORTEN KJALE
KJALESTOR. EGGHILL

JOHN MORTENSEN
1879-1926
g.m. MORTEN KJALE
KJALESTOR. EGGHILL

JOHANNUEL JOHANSTOR.
1705-1905
g.m. JOHANNUEL
KJALE

FREDRICH JOHANSEN
1707-1907
g.m. JOHANNUEL
KJALE

LARS ?

JOHN JOHANSEN
1580-1660
HOSJALFJORDSTAD
TRONDHEIM

JOHN MORTENSEN
1879-1926
g.m. MORTEN KJALE
KJALESTOR. EGGHILL

JOHANNUEL JOHANSTOR.
1705-1905
g.m. JOHANNUEL
KJALE

FREDRICH JOHANSEN
1707-1907
g.m. JOHANNUEL
KJALE

LARS ?

JOHN JOHANSEN
1580-1660
HOSJALFJORDSTAD
TRONDHEIM

JOHN MORTENSEN
1879-1926
g.m. MORTEN KJALE
KJALESTOR. EGGHILL

JOHANNUEL JOHANSTOR.
1705-1905
g.m. JOHANNUEL
KJALE

FREDRICH JOHANSEN
1707-1907
g.m. JOHANNUEL
KJALE

LARS ?

JOHN HANSEN
f. ca. 1650

MARGIT OLUFSEN
f. ca. 1620

OLLUF HANSEN
f. ca. 1490

OLLUF HANSEN
f. ca. 1490

OLLUF HANSEN
f. ca. 1490

LARS ?

JOHN HANSEN
f. ca. 1650

MARGIT OLUFSEN
f. ca. 1620

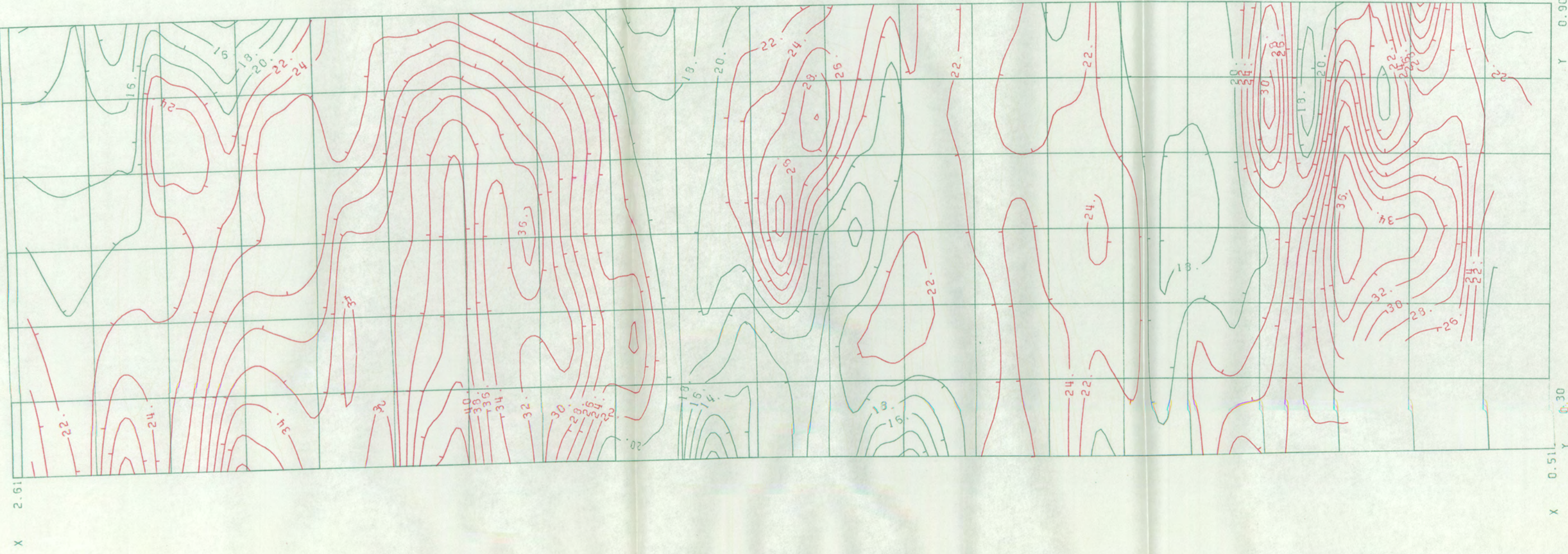
OLLUF HANSEN
f. ca. 1490

OLLUF HANSEN
f. ca. 1490

OLLUF HANSEN
f. ca. 1490

LARS ?

TRONDHEIM JULIEN 1973 /
HOFESS JULIEN 2010



15213/X 0.51/Y 0.30

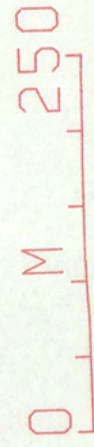
LØKKEN SVINSAS/84

460/P/150/25/2/2/50/4

IP-MAP FE %/CHARGEABILITY

0/0/-0+/17.04.85

1:5000

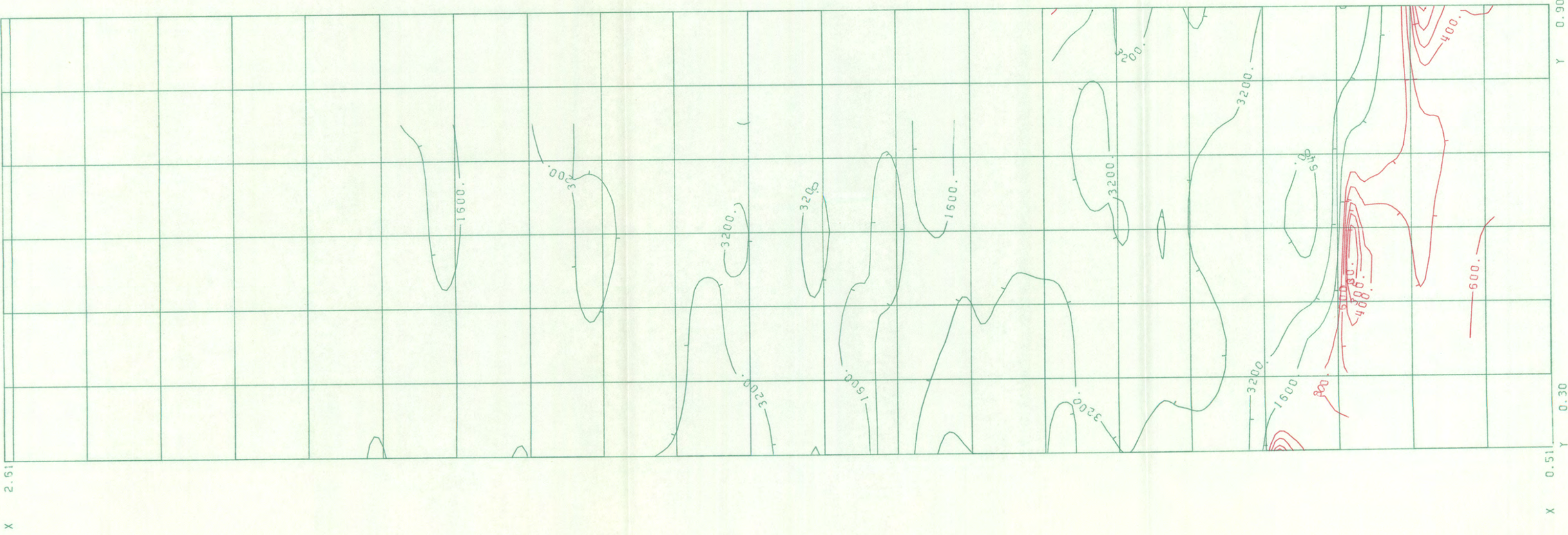


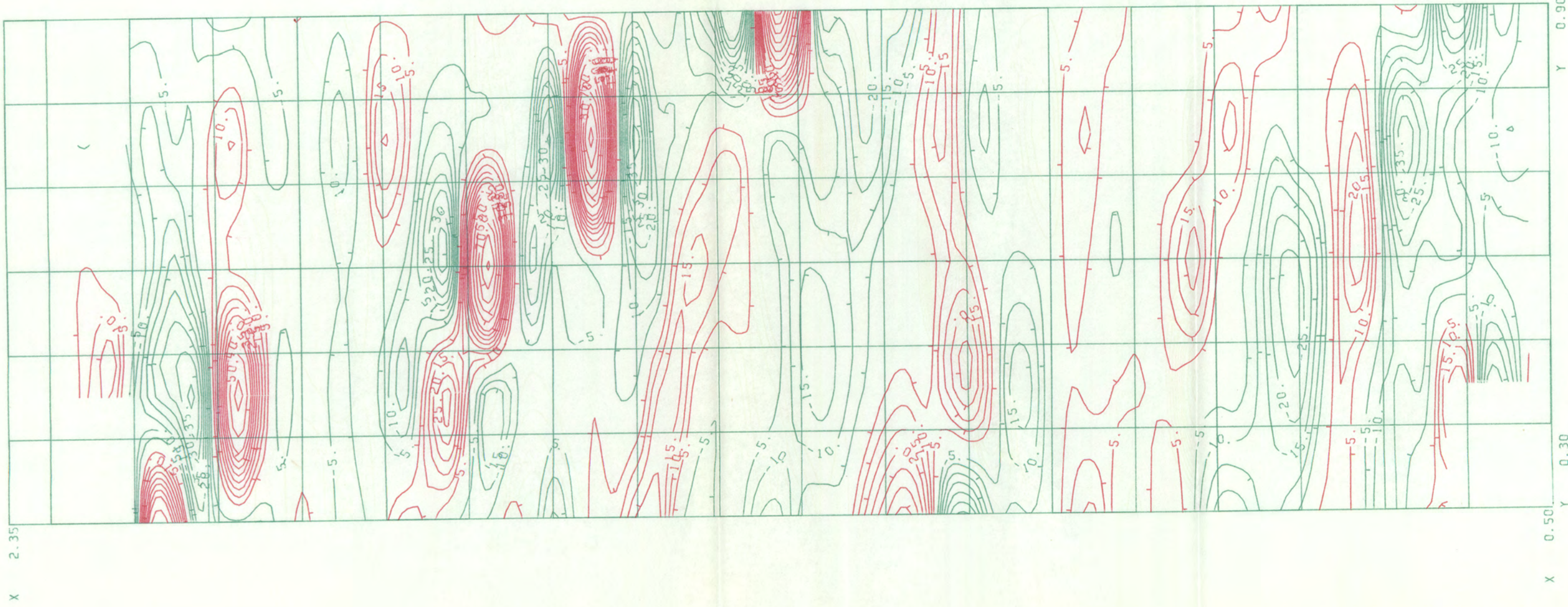
2.00	4.00	6.00	8.00	10
12	14	16	18	20
22	24	26	28	30
32	34	36	38	40
42				

$\alpha = 50m$

$n = 4$

$TL=TT = 20$





15213/X 0.50/Y 0.30

LØKKEN SVINSAS/84

443/P/150/25/2/17.8 kHz

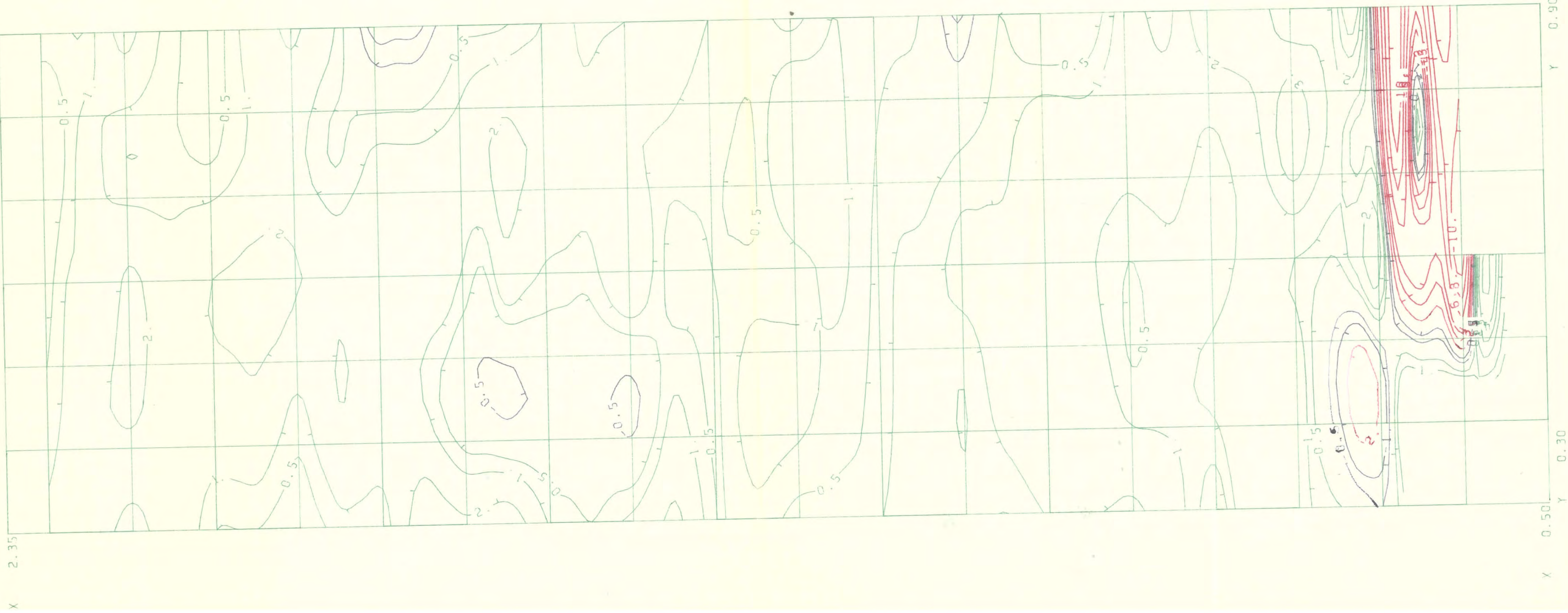
VLF-OUT-ØF-PHASE

0/0/-0+/17.04.85

1:5000

0 M 250

5.00	10	15	20	25
30	35	40	50	60
70	80	90	100	110
-5.00	-10	-15	-20	-25
-30	-35	-40	-45	



15213/X 0.50/Y 0.30

L0/SVINS0S GEN 8/122/84

499/P/150/25/100/1012

0/0/-0+/16.05.85

1:5000

0 M 250

0.50	1.00	2.00	3.00	4.00
6.00	8.00	10	12	14
16	18	20	22	24
26	28	-0.50	-1.00	-2.00
-3.00	-4.00	-6.00	-8.00	-10
-12	-14	-16	-18	-20
-22	-24	-26	-28	-30



15213/X 0.50/Y 0.30

L0/SVINS0S GEN 8/122/84

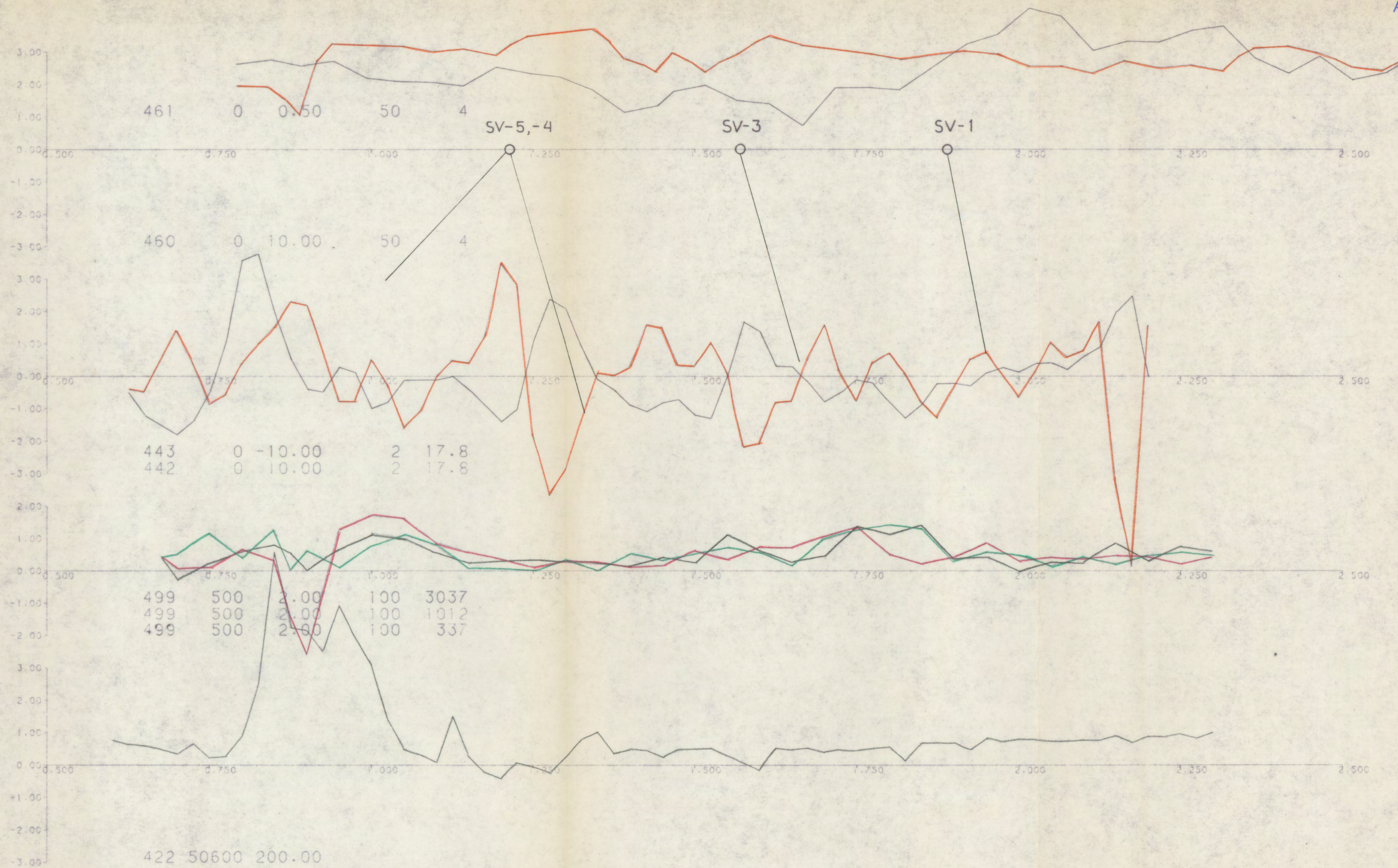
499/P/150/25/100/3037

0/0/-0+/16.05.85

1:5000

0 M 250

0.50 , 1.00, 2.00, 3.00, 4.00
 6.00 , 8.00, 10, 12, 14
 16 , 18, 20, 22, 24
 26 , 28,-0.50,-1.00,-2.00
 -3.00 , -4.00,-6.00,-8.00, -10
 -12 , -14, -16, -18, -20
 -22 , -24, -26, -28, -30



Y=3

15213/LÖKKEN SVINSPS

422/50700

415/1:5000

MAGNETIC INTERPRETATION
TOTAL FIELD
OUTOKUMPU OY
EXPLORATION

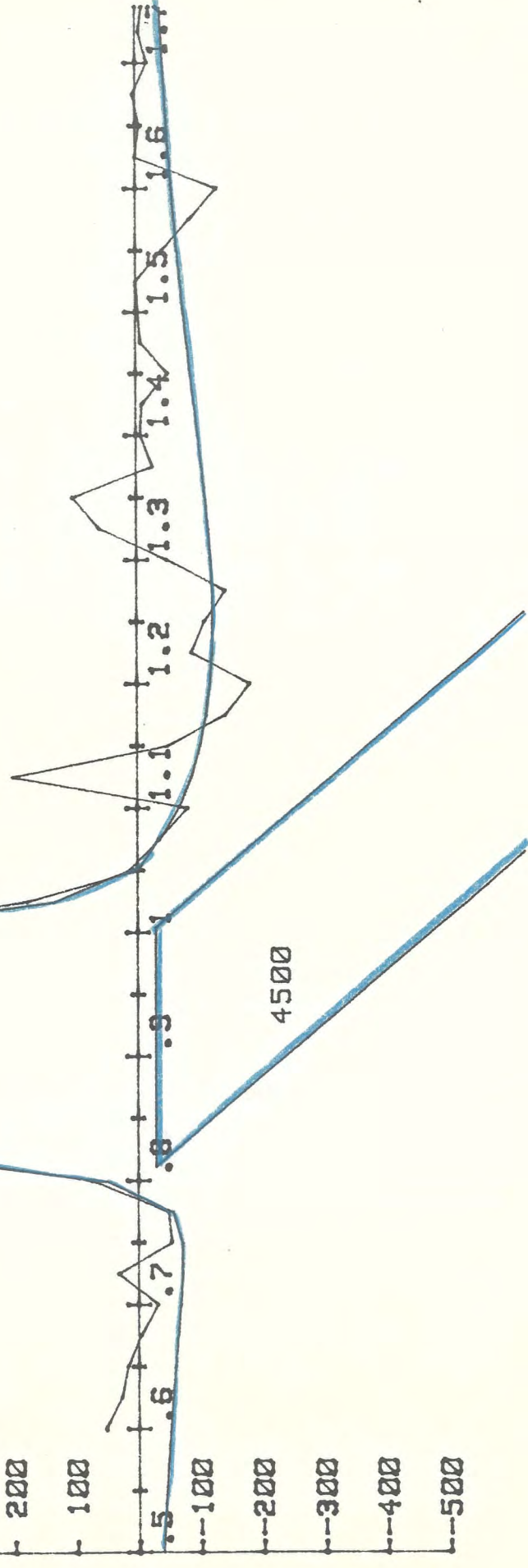
nT

700
600
500
400
300
200
100
0
-100
-200
-300
-400
-500

SUSCEPTIBILITY *10E-5 SI

MEASURED

CALCULATED



Y=6

15213/LÖKKEN SVINSPS

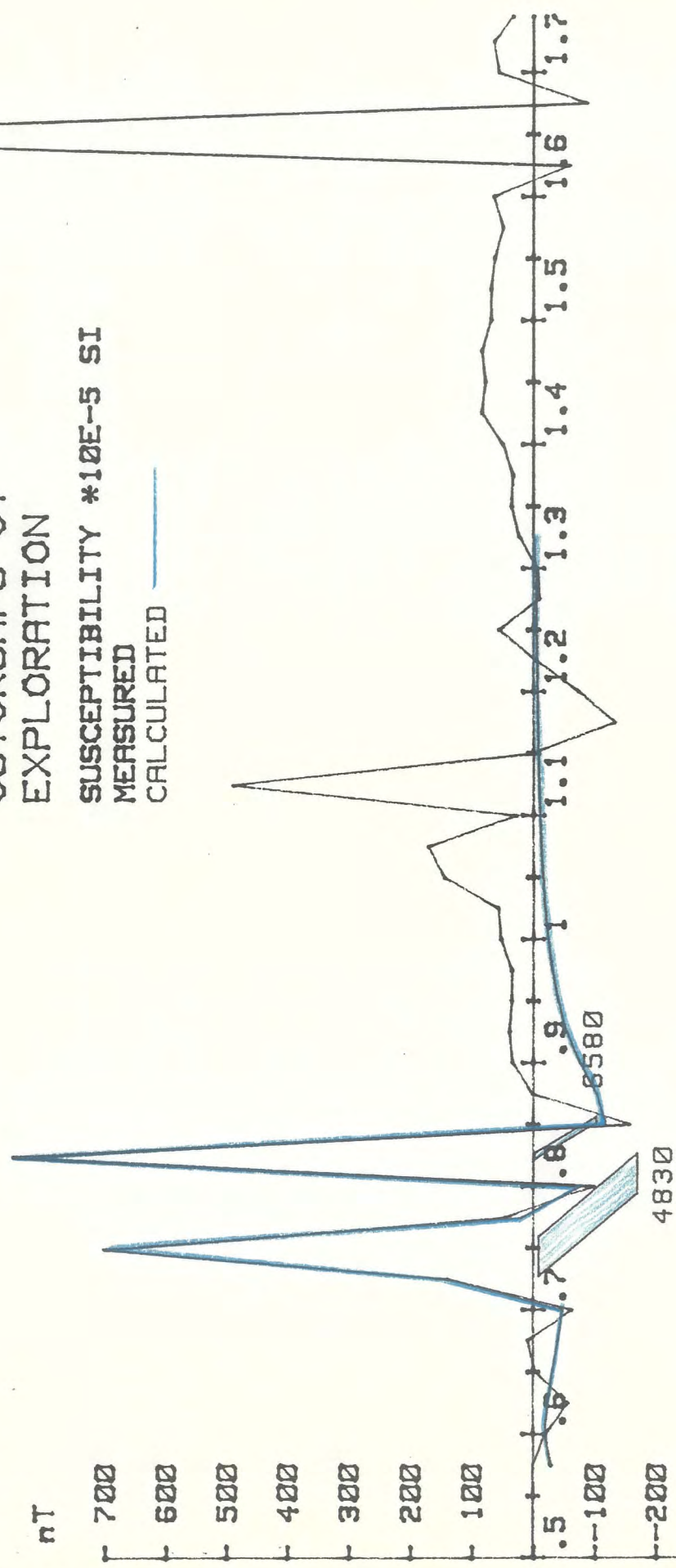
422/50700

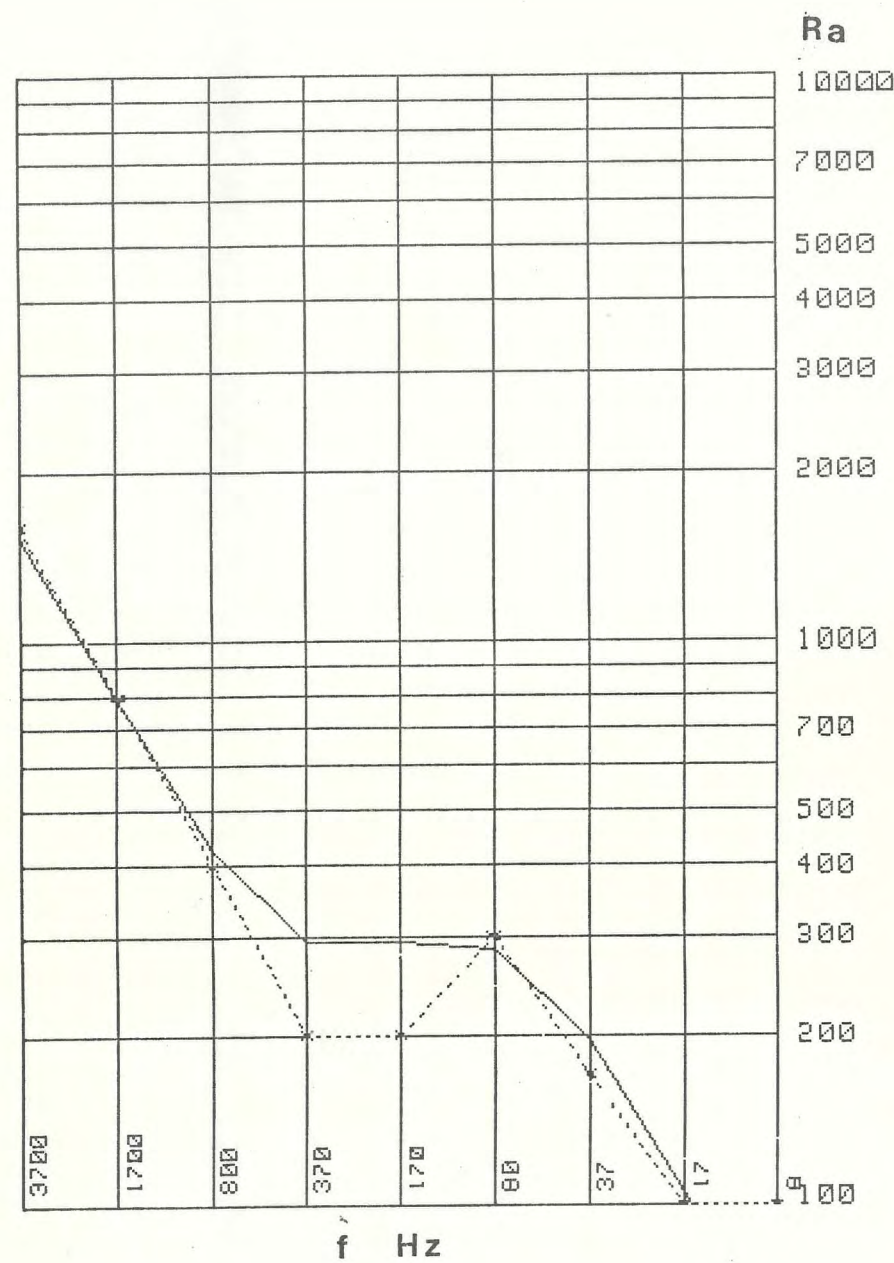
415/1:5000

nT

700
600
500
400
300
200
100
0
-100
-200
-300
-400
-500

MAGNETIC INTERPRETATION
TOTAL FIELD
OUTOKUMPU OY
EXPLORATION
SUSCEPTIBILITY *10E-5 SI
MEASURED
CALCULATED





OUTOKUMPU OY
 Malminetsintä
 AMT-tulkinta
 ECA
 LÖKKEN/korj
 Ø
 25g

i	Z _i	rho _i
1	250	2000
2	2	1
3	600	5000
4	9999	1