Bergvesenet
Postboks 3021, N-7441 Trondheim

Rapportarkivet

Bergvesenet rapport nr	Intern Journal nr	Internt arkiv nr	Rapport lokalisering	Gradering
6891				

Kommer fra ..arkiv	Ekstern rapport nr	Oversendt fra	Fortrolig pga	Fortrolig fra dato:
Grong Gruber AS	NTH 2/87/716.50/HE	Grong Gruber a.s.		

Tittel

Electromagnetic Frequency Soundings Fremstfjell, Grong District, Noway

Forfatter	Dato	År	Bedrift (Oppdragsgiver og/eller oppdragstaker)
Elvebakk, Harald Lile, Ole bernt	25.02	1987	Commission of the European Communities, Dir-Gen for Science, Research and Development

Kommune	Fylke	Bergdistrikt	1: 50 000 kartblad	1: 250 000 kartblad
Røyrvik	Nord-Trøndelag		1924 1	Grong

Fagområde	Dokument type	Forekomster (forekomst, gruvefelt, undersøkelsesfelt)
Geofysikk		Fremstfjell Jomaforekomsten Sølvberg Mofjellet Gruber

Råstoffgruppe	Råstofftype
Malm/metall	Cu,Mo

Sammendrag, innholdsfortegnelse eller innholdsbeskrivelse

Beskrivelse av metode (Melos method)og måleinstrumentering (Syscal EM)
Beskriver først kort bruken ved andre forekomster (Joma, Mofjellet). Disse viser at metoden er velegnet for påvisning av dype, massive malmkropper.
Ledende strukturer knyttet til stockwerk med Cu-Mo mineralisering nær overflaten i Fremstfjell er tydelig indikert. Disse er innenfor en pyritt halo hvor forekomsten ligger. Oppløsningen av metoden er i midlertid for lav til å få gode dyptolkninger av slike forekomster. Den indikerer ikke klart ledende soner mot dypet i Fremstfjell.
Metoden er også følsom for topografiske effekter.

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THE NORWEGIAN INSTITUTE OF TECHNOLOGY
DIVISION OF PETROLEUM ENGINEERING
AND APPLIED GEOPHYSICS

REPORT NO
2/87/716.50/HE

AVAILABILITY
Open

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TITLE OF REPORT	DATE
ELECTROMAGNETIC FREQUENCY SOUNDINGS FREMSTFJELL, GRONG DISTRICT, NORWAY	1987-02-25
	NO. OF PAGES
AUTHOR(S)	RESPONSIBLE
HARALD ELVEBAKK, OLE B. LILE	

CLIENT	CLIENT REF.
Commission of the European Communities, Directorate-General for Science, Research and Development	

EXTRACT

Electromagnetic depth soundings have been executed in Fremstfjell, Joma and Mofjellet in Norway using a French system, SYSCAL EM. The results from Joma and Mofjellet show that the method is very suitable to detect deep massive sulphide ore bodies. In Fremstfjell near surface conductive structures connected to a stockwork type Mo-Cu mineralization were clearly indicated. These structures were inside a pyrite halo surrounding the deposit. However, the resolution of the method is too low to obtain good depth interpretations for such deposits. The method is also very sensitive to topographic effects.

3 KEYWORDS IN NORWEGIAN	KEYWORDS IN ENGLISH
Malmgeofysikk	Mining geophysics
EM dybdesondering	EM depth sounding
CS AMT	CS AMT

NTH-Trykk

CONTENTS

1. Introduction.

Electromagnetic depth sounding with controlled source,CSAMT,is a new geophysical prospecting method in Norway. The method has been tested in a research programme for deep ore prospecting at the Norwegian Institute of Technology,division of petroleum and applied geophysics,since 1984. The purpose of this programme is to do deep ore exploration close to existing sulphide mines in operation. The ore reserves for most of the Norwegian sulphide mines are rapidly decreasing and the mining companies have to find new ore reserves in the near future to extend the lifetime of the mine.

However,we thought that the CSAMT method also should be tested for other prospecting targets like disseminated ores. The resistivity of the rocks is generally very high in Norway,several thousands ohmm,and even weak mineralization would give a resistivity contrast high enough to be detected by EM sounding. When the OGR-programme,Ores associated with granitic rocks,started in 1985,we joined this research programme with the geophysical subproject "Electromagnetic frequency soundings". The geophysical project would be employed in the same area where the geological work would be carried out in the project "Porphyry-type Mo-Cu mineralization in the Norwegian Caledonides". This area was the Fremstfjell deposit in the central Norwegian Caledonides,southeast Grong District.

2. The Melos method, CSAMT.

Electromagnetic depth soundings with different frequencies have been used for many years by help of the technique known as AMT (Audio Magneto Telluric) or MT (Magneto Telluric). The principle of this method is to compute the apparent resistivity ϱ_A by measuring the magnetic ,Hx, and the electric, Ey, component of the natural EM-field at a chosen frequency. Using the equations for plane waves, the apparent resistivity can be derived:

$$\varrho_A = \frac{1}{2\pi f \mu_0} \left| \frac{Ey}{Hx} \right|^2$$

f=frequency

μ_0 =magnetic permeability

The depth penetration can be expressed by the socalled skin depth:

$$\delta = \sqrt{\frac{\varrho_A}{\pi f \mu_0}}$$

According to this expression, the lower the frequency, the deeper the investigation. The EM field is considered as plane waves. A problem in AMT measurements is noise from near field sources (power lines etc.). In some areas the AMT field can have a very low level and combined with noise it can be almost impossible to obtain reliable data. Therefore, J.Duroux in 1967 proposed to use a controlled source as a transmitter where the signal level was much higher than the natural field. This method is called CSAMT (Controlled Source AMT) or Melos (Magneto Electrique par Ondes de Surface) in France. The energy source can either be a horizontal loop on the ground or a long grounded cable. The Melos method is described by P.Valla, BRGM (1982) and in Melos data interpretation manual, BRGM Instruments (1985).

2.1 The SYSCAL EM instrument.

The instrument used in this project is developed by BRGM. It is called SYSCAL EM. The SYSCAL EM equipment uses a horizontal loop (140x140m) on the ground carrying alternating current as an energy source. 12 preset frequencies from 8.75Hz to 17920Hz in steps with factor of 2 can be used. The receiver station consists of 2 coils measuring the radial horizontal, Hx, and vertical, Hz, magnetic field component and an electric dipole measuring the tangential electric field component Ey. (fig.2.1). A microprocessor in the receiver computes the apparent resistivity for each frequency.

A special feature on the SYSCAL EM equipment is that the apparent resistivity also can be computed from the magnetic field components only. The electric field is very sensitive to lateral variations of superficial resistivities. The magnetic field is in a large range independent of such variations, and the apparent resistivity computed from only the magnetic components is therefore used in quantitative depth interpretations.

For each frequency three basic apparent resistivities ϱ_A, ϱ_A' and ϱ_A'' are computed. The theory for these computations is given in SYSCAL EM, Notice d'utilistion, BRGM report 82 SGT 033ELI and in Melos data interpretation manual, BRGM Instruments (1985). The relationship for these resistivities is:

$$\varrho_A = \frac{k}{\omega\mu}\left|\frac{Ey}{Hx}\right| \qquad k \text{ as a function of } Hx/Hz$$

$$\varrho_A' = \frac{k'\omega\mu r^2}{9}\left|\frac{Hz}{Hx}\right|^2 \qquad k' \text{ as a function of } Hx/Hz$$

$$\varrho_A'' = \frac{k''}{\omega\mu}\left|\frac{Ey}{Hx}\right|^2 \qquad k'' \text{ as a function of } Hx/Hz \text{ and } r$$

r=transmitter receiver separation

$\omega=2\pi f$

Experimental results from SYSCAL EM measurements are plotted as sounding curves,resistivity profiles or pseudo sections,fig.2.2. Depth interpretation is done by adjusting theoretical data from a layered model to the measured sounding curve. This is done by an interpretation programme on a HP 9816 microcomputer.

3. The Fremstfjell deposit.

The Fremstfjell deposit is situated in the central parts of the Norwegian Caledonides about 250km north of Trondheim,fig.3.1. This deposit is a porphyry / stockwork type Mo-Cu mineralization. The deposit was discovered early in the 1970's by the Geological Survey of Norway (NGU). Later a Norwegian mining company has investigated the deposit geologically,geochemically and geophysically. The geophysical measurements IP (induced polarization) and RP (resistivity measurements) were carried out by NGU early in the 1980's. The IP and RP measurements indicated the conductive structures in the area. The conductive structures are mostly related to pyrite mineralisation which also occur in the area. There was no good correlation between the Mo-Cu mineralization and these IP-RP measurements. IP and RP measurements only maps the near surface conductive structures (the outcropping) and do not say anything about the mineralization deeper down. It was hoped that the Melos method which is a depth sounding method,could tell us something about the resistivity conditions in the deeper part of the deposit.

The most interesting mineral is molybdenite,MoS_2 ,but the analyses show that the deposit is not of economic significance. The Fremstfjell deposit was chosen for this geophysical project because it was one of the most investigated deposits of this type and because there would be parallell geological mapping of the area.

4. Joma and Mofjellet deposits.

The Joma deposit,owned by Grong Gruber A/S,is a sulphide ore deposit about 70km northeast of Fremstfjell. A Turam survey in 1984 indicated a conductor just outside the known deposit at a depth of 300m. SYSCAL

EM measurements were carried out on the same conductor in 1985-86 and the conductor was clearly indicated. This conductor was later found by drilling to be a thick impregnation zone (sulphide mineralization with Cu).

Sølvberg,Mofjellet Gruber,in the middle of Norway,is also a sulphide ore deposit. It is a thin horizontal plate at a depth of 200-250m. This deposit was well known by drilling. Test measurements were carried out on this deposit in 1986 showing that the Melos method worked very well at this type of deposit.

5. Interpretation and results.

The main objective of this project was to test the Melos method in connection with mineralizations in granitic intrusives. However,the method was new in Norway and in order to get a better understanding of interpretation of data,it was decided to carry out test measurements on deep sulphide ore bodies.

A short presentation of the results from Joma and Mofjellet will first be given,and then more detailed interpretations from Fremstfjell will be presented.

5.1 Results from Joma.

Fig.5.1 shows a pseudo section of ρ_A from Joma. Frequency 1 represents the lowest frequency. This line is crossing a deep Turam anoamly. The conductor was indicated at B 1300-1400 by the Turam measurements. As we can see,there is a very low resistivity zone from 1200-1500 indicating a conductor. An interpretation of ρ_A ' using a layered model is shown in fig.5.2. The apparent resistivity, ρ_A ',based on only the magnetic components,is used. The *-signs indicate the measured resistivity values while the solid line is the calculated sounding curve. We can see that the model curve fits quite well. Two conductors are indicated at 157m and 309m depth. The conductive lower halfspace in the model represents the underlying graphite shale in the area. A drillhole in B 1300 later hit a thick impregnation sulphide zone at a depth of about 300m.

5.2 Results from Sølvberg ,Mofjellet.

Fig.5.3 shows a pseudo section of ρ_A from the Sølvberg deposit, Mofjellet. A conductor is indicated on this profile from 24500X to 24800X. The apparent resistivity is very low at the lowest frquencies at this part of the profile. The sounding curve, ρ_A ', with an interpreted model is shown in fig.5.4. A thin conductor is indicated at 172m depth and a thick and good conductor at 260m depth. The deepest conductor is the Sølvberg deposit. Such interpretations are done at every station along the profile and the results are shown in fig.5.5. The results from 4 drillholes are plotted together with the interpreted depths of the conductor. There is no big difference between the drilling results and the geophysical interpretations. In this case the conductivity-thickness product of the conductor is computed. The σt-product is very high in the conductor and it is decreasing strongly outside the conductor.

The conclusion from the SYSCAL EM measurements in Joma and Mofjellet is that the Melos method is a well suited geophysical method for prospecting deep sulphide ore bodies. The quality of the conductors can be evaluated by the conductivity-thickness product. The measurements have also shown that two conductors at different levels can be detected.

5.3 Results from Fremstfjell.

5.3.1 The field measurements area.

The map in fig.5.6 shows the area where all the SYSCAL EM measurements in Fremstfjell were carried out. This map is a part of the IP contour map made by NGU and shows the results from these measurements. The profiles 4600E to 5500E cover the area investigated by SYSCAL EM. The length of the profiles were 6-700m and measurements were made at every 50 m. The topography is very variable in the area and it was impossible to do all the measurements in the same plane as the transmitter loop. The size of the loop was 140x140m. The loop was moved once during the measurement periode , loop 1 and loop 2.

5.3.2 Field procedure.

Measurements were taken at every 50m. At every station Hx,Hz and Ey were measured at 12 frequencies. Four readings were taken of every component and the three apparent resistivities were computed. Sometimes,in strong wind,it was impossible to get readings at the lowest frequencies. The time used at one station was about one hour. Loop 1,fig.5.6,was used for the measurements on profile 5100E,5000E, 4900E,4800E,4700E and 4600E. The distance between the transmitter and the receiver was in this case varying from 300-975m. Loop 2 was used for profile 5200E,5300E,5400E and 5500E , and the transmitter-receiver spacing was 315-705m.

The topography was varying in the hole area with altitude variations of $\pm$ 50m from the plane of the transmitter loop. The transmitter loop was not horizontal,but dipping with an angle of θ_1=-0.071rad (loop 1),and θ_2=0.143rad (loop 2). The topographic effects are computed and will be described later.

The field measurements were executed during the summer 1985. Most of the field work were done by two students from the Norwegian Institute of Technology , Bernt Holst and Sten Ola Rasch. The weather conditions in the mountains in this part of Norway is usually bad with a lot of rain and wind during the summer and 1985 did not make any exception. Measurements during heavy rain showed that the receiver was not waterproof and there were big problems to take measurements. The display did not work. When this happened, the receiver had to be taken inhouse to dry up. Besides problems with rain and wind there were no other special problems connected to the field measurements.

5.3.3 Data plotting , pseudo sections.

As mentioned,the calculated resistivity values can be plotted in pseudo sections. Pseudo sections of ρ_A , ρ_A' and ρ_A'' for all profiles are shown in fig.5.7-5.36. Contour lines are drawn for 10,50,100,500,1000,2000 and 5000 ohmm. If we look at the ρ_A-sections,fig.5.7-5.16,there is one characteristic pattern on profile 5500E to 5100E. The southern part of the profile has very low resistivities at almost all frequencies. Especially the soundings in 1900N on profile 5300E and 5200E show extreme low resistivities. For the western profiles the resistivities are quite high. The low resistivities in the north on profile 4900E and 4800E are caused by problems with the electrodes measuring the electric field. The lowest frequencies (1 and 2) show very low resistivities on all profiles. This is topographic effects and the phenomenon can be observed on all profiles and all three resistivities. These data can not be used. The low resistivity zones observed on the ρ_A-sections are observed at all frequencies. This is caused by lateral variations of superficial resistivities and the electric field is very sensitive to such variations. ρ_A and ρ_A'',which use Ey,can be used for a quality study of conductors. This will be shown later.

The ρ_A' pseudo sections,fig.5.17-5.26,is different from ρ_A and ρ_A''. However the main pattern is the same. In the north there are high resistivities. From 18-1900N to the south on profile 5500E to 5100E there are fairly low resistivities at low and middle frequencies. This can be interpreted to be a conductor at depth in this area (southeast). The western part of the area has high resistivities.

5.3.4 Conductive conditions of the near surface rocks.

Another way to plot data is to make a resistivity (or conductivity) map of the area (horizontal section). This is done by plotting the resistivities on one certain frequency for all stations. Fig. 5.37 shows ρ_A at 17920Hz (f=12). Some data are missing on line 4900E and 4800E (problems with electrodes). Fig.5.38 shows ρ_A for 4480Hz (f=10). This is one of the most interesting results from the measurements at Fremstfjell. The low resistivity zones are clearly indicated (yellow and red zones). Fig.5.39 and 5.40 show the conductivity and IP map from the NGU measurements. The SYSCAL EM measurements indicate the same structures as the RP/IP measurements. The best conductive structure is indicated along 1900N from 5100E to 5400E. The good conductive structure along 1900N probably indicates a small vein of greenstone coming from the eastern part of the area. The eastern part of the area consists of greenstones with some pyrite and magnetite.

Fig.5.41 to 5.44 show the conductivity (RP) and IP along profile

5100E,5200E,5300E and 5400E compared with the SYSCAL EM results. There is good correlation between the low resistivity SYSCAL zones and the high conductivity RP zones. Profile 5200E,fig.5.42,shows this clearly. As mentioned,these zones represent shallow conductive structures and it is clear that it is the electic field component that indicates these zones. The question then is how these zones correlate to the mineralization in the area. It is no good correlation to the Mo-mineralization (NGU,Rønning 1984) so the conductive zones are probably connected to the pyrite mineralization (halo).

Fig.5.45 shows where the mineralization occur in the area and fig.5.46 is a geological map of the same area. These maps are results of the geological project on the Fremstfjell deposit worked out by M. Martinsen,Sintef. The stockwork in fig.5.45 is the main MoS_2 and FeS_2 mineralization. Outside this stockwork there are several small MoS_2 mineralizations. A pyrite halo is surruonding the deposit. Outside this halo there is no occurence of pyrite. As can be seen from the geological map in fig.5.46 and the resistivity map in fig.5.38,the alternating acid and alkalic volcanites in the central part of the area seem to have lower apparent resistivity than the surrounding greenstones and trondhjemites.

The main part of the deposit ,the stockwork in fig.5.45,4800E to 5100E , 2200N,2100N,is not clearly indicated on the horizontal section by the SYSCAL measurements. Unfortunately some data are missing on profile 4800E and 4900E. On the other hand the stockwork is situated in a central area where the conductive structures also are situated. The south-eastern part of the stockwork is inside a low resistivity area on the map in fig.5.37 (ρ_A-17920Hz). All the indicated conductive structures are inside the pyrite halo in which the stockwork also occurs. Most of the SYSCAL EM measurements are made inside this halo,but the IP and RP measurements cover a large area outside the halo without indicating conductive structures like those inside the halo.

Fig.5.47 and 5.48 show the ρ_A' horizontal sections at 17920Hz and 280Hz. The zones which are indicated by ρ_A are not indicated by ρ_A'. There are variations in the resistivities but there are no good conductors indicated at the 17920Hz section. A weak conductive zone is indicated on profile 4800E and 4900E ,2200N. This zone correlates quite well with the north-eastern part of the stockwork. Another weak conductive zone at 4600E,2300N is also a MoS_2 mineralization. The other indicated zones do not seem to have any connection to outcropping mineralization.

The 280Hz map, fig.5.48, indicates a conductor in the southeast, 5100E to 5500E, 1800N. Since the frequency is only 280Hz (f=6), this means that it is a deep conductor. The depth of the conductor can not be interpreted directly from a pseudo section. For a quantitative study of deep conductive structures the ρ_A' sounding curves have to be interpreted. This can be done by adjusting theoretical data from a layered model to the measured sounding curve.

5.3.5 Depth interpretation and topographic effects.

Depth interpretations have been done for profile 5500E to 4800E. The ρ_A' sounding curves are all decreasing with decreasing frequency indicating a conductor in the depth. With the strong variation in topography, these conductors could be topographic effects or ghost conductors. Fig.5.49 shows the sounding curve and the interpreted model in 1750N, 5500E. A weak conductor is indicated at 229m depth and a good one at 340m depth. At 1800N, 5500E, fig.5.50, the same conductors are indicated at 240m and 350m. At 1800N, 5400E, fig.5.51, the conductors are indicated at 220m and 300m depth. The conductor at 220-240m is indicated at the highest frequencies and does not seem to be a ghost conductor. The deepest conductor, however, seem to be a typical ghost conductor. The depth of a ghost conductor, z, can be computed from the formula:

$$z = 0.5r/\sqrt{|3\phi-2\theta|}$$

r is the transmitter-receiver separation. θ is the angle of the plane of the loop with the horizontal plane and ϕ is the angle of the transmitter-receiver axis with the same horizontal plane. For loop 1 $\theta=-0.071$rad and for loop 2 $\theta=0.143$rad. ϕ depends on the altitudes and the transmitter-receiver separation. Fig.5.52 shows both the depth of the interpreted conductors and the depth of the ghost conductor (red marks) for profile 5500E and 5400E. If the interpreted depth from the measured curve is bigger than the depth of the ghost conductor, the measured data have to be excluded from the interpretation. In this case, profile 5500E and 5400E, the ghost conductor is deeper than the interpreted conductor, specially in the southern part of the profiles.

However, the difference is not big and the measured sounding curve follows a -2 slope asymptote in the bilogaritmic diagram like the curve of a ghost conductor would do. This means that the deepest conductor probably is induced by topographic effects. The other conductor at 230-240m depth is rather weak with a σt-product of only 0.1-0.2.

The soundings at 1800N,5300E and 1800N,5200E are shown in fig.5.53 and 5.54. The interpreted model is a 2-layered model and the indicated conductor is induced by topographic effects. The interpretations of all stations on profile 5300E and 5200E are shown in fig.5.55. For both the interpreted conductor and the ghost conductor the depth increases from 1750N to 2000N and then it decreases to 2200N. This is due to the topography in the area and to the transmitter-receiver separation. The centre of loop 2 was at 2100N,4900E and r will have a minimum value in 2100N on the eastern profiles. It must be said that the transmitter-receiver separation for some profiles was too small. It is important that r is big in rough terrain to minimize the topographic effect.

Fig.5.56 shows the sounding curve and interpretation model for station 1900N,5100E. The conductor is induced by topographic effect. At profile 5000E a conductor is indicated at higher frequencies at 2200N and 2350N ,fig.5.57 and 5.58. The depth is 275-300m and the σt-product is 0.20-0.25. The interpreted depth and the ghost conductor depth for profile 5000E and 5100E are shown in fig.5.59. On the southern part of profile 5100E it is probable that the interpreted conductors from the measured sounding curves are induced by topographic effects. This is suggested by the parallell behaviour of the two curves.

The interpretations on profile 4900E and 4800E are shown in fig.5.60. A fairly weak conductor is also on these profiles indicated at 2200-2300N. The sounding curve in 2300N,4800E ,fig.5.61, clearly indicates 2 conductors. The ghost conductor is at a depth of 625m.

On profile 4700E and 4600E there are no conductors indicated except the ghost conductor. The 17920Hz map in fig.5.47,however, indicates a shallow weak conductor at 2450N,4700E.

The conductors indicated at the higher frequencies are fairly weak. It is only at the two highest frquencies,17920Hz and 8960Hz,that the sounding curves are decreasing indicating a conductor. At 17920Hz the current in the transmitter loop was only 0.25amp. From frequency 8 (1120Hz) the current was decreasing from 3amp. to 0.50amp. at 8960Hz and 0.25amp. at 17920Hz. It is not advisible to do measurements when the current is below 1.0amp. For this reason the data on 17920Hz and 8960Hz should be excluded.

5.3.6 Conclusion of the depth interpretations.

Most of the indicated conductors seem to be induced by topographic effects. In some cases the transmitter-receiver separation has been too small. The depth of investigation depends not only on the frequency but also on the transmitter-receiver separation. In many cases the influence of the topographic effects occurs at all frequencies up to 1120Hz (f=8) and 2240Hz (f=9). This is rather surprising because this influence is expected only at the lowest frquencies (8.75Hz , 17.5Hz).Because the resistivity of the rock is very high,we did not need to use the lowest frequencies. For that reason we thought that the Melos method would be well suited for the rough terrain at Fremstfjell.

However,a flat conductive structure is indicated on profile 5500E and 5400E at 1750-1800N,fig.5.52. The depth is 220-240m. The ρ_A horizontal section (17920Hz) indicated a high conductive structure at 1900N on the same profiles In the western part of the area a conductor is indicated at 2200N and 2300N on profile 5000E,4900E and 4800E ,fig.5.59 and 5.60. The depth is 250-300m.

6. Conclusions and comments.

The SYSCAL EM measurements in Fremstfjell indicated the near surface conductive structures in the area. The measurements showed good correlation to the IP and RP measurements carried out by NGU. It is clear that the conductive zones are most sensible to the electrical field. It is also clear that the method has some important limitations:

The resolution of the method is too low to get good depth interpretations for such deposits.

The method is more sensible to topographic effects than expected.

On the other hand the Melos method is very suitable to detect deep massive sulphide ore bodies. This is shown by the results from Joma and Mofjellet.

It is difficult to say if the method is suitable for mineralization connected to granitic intrusives. This project has shown that near suface conductive structures can be detected,but this can also be done by other methods. Even if the main deposit,the stockwork,was not clearly indicated,the surrounding conductive structures inside the pyrite halo were detected. This was the main objective of this project.

We also think that the Melos method would be suitable and helpful in prospecting for deposit without outcrops under thick overburden. The measurements did not clearly indicate any conductive zones at depth in the Fremstfjell area. The geological investigations can neither say anything about the possible existence of a deep deposit. The drillholes in the area only show weak mineralization.

The total costs of this project were reduced by 30%. Because of this, the field work which was planned for 1986 could not be fullfilled.

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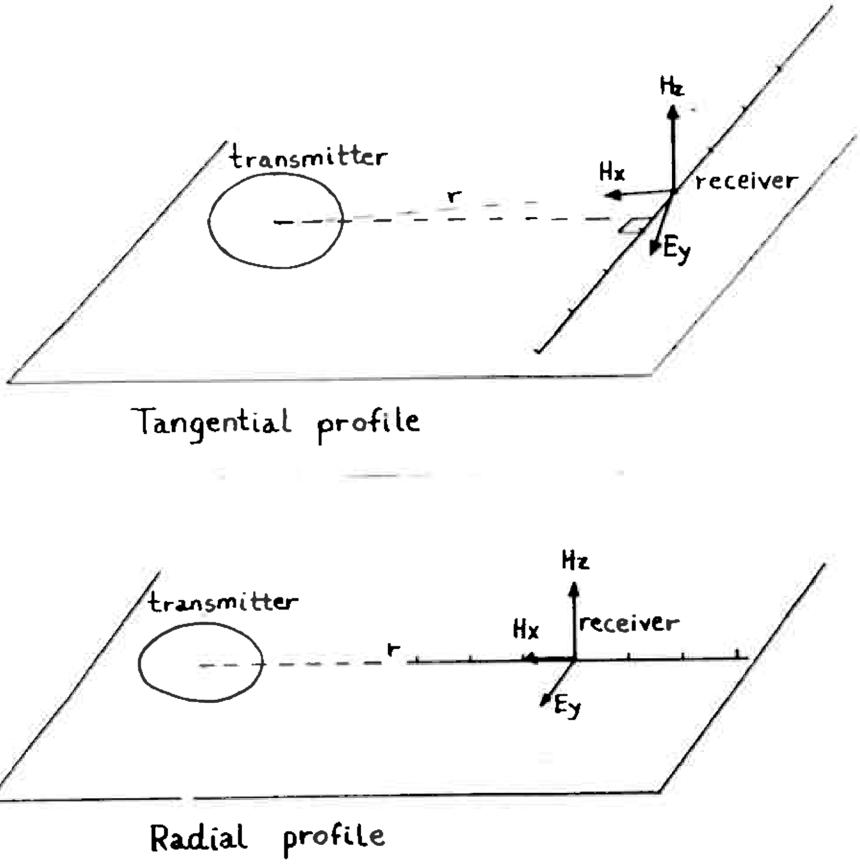


Fig.2.1

SYSCAL EM : DATA PLOTTING

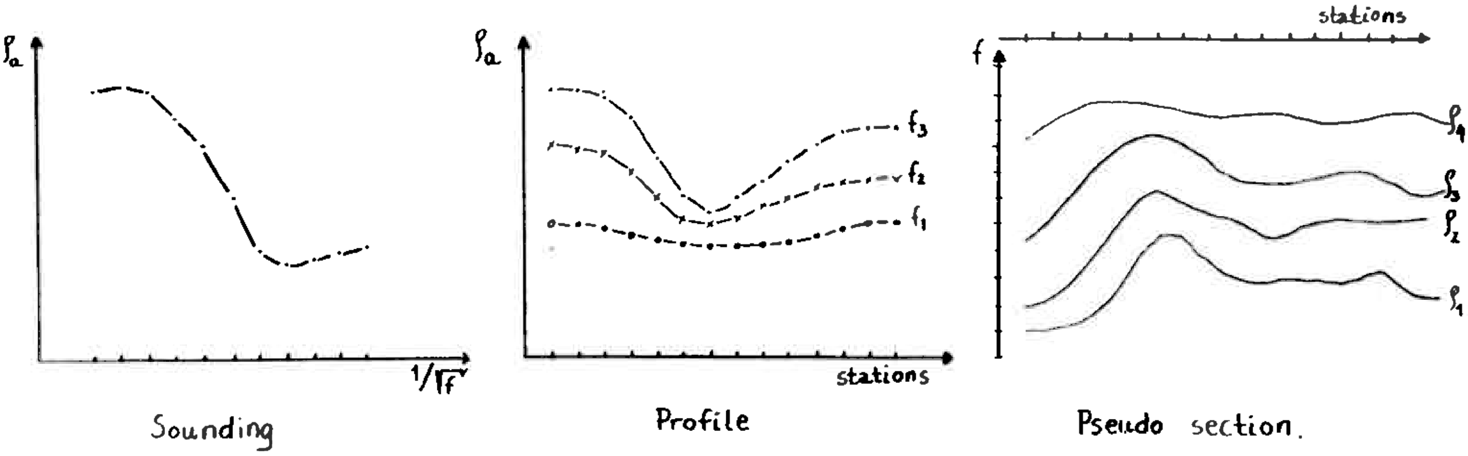


Fig.2.2

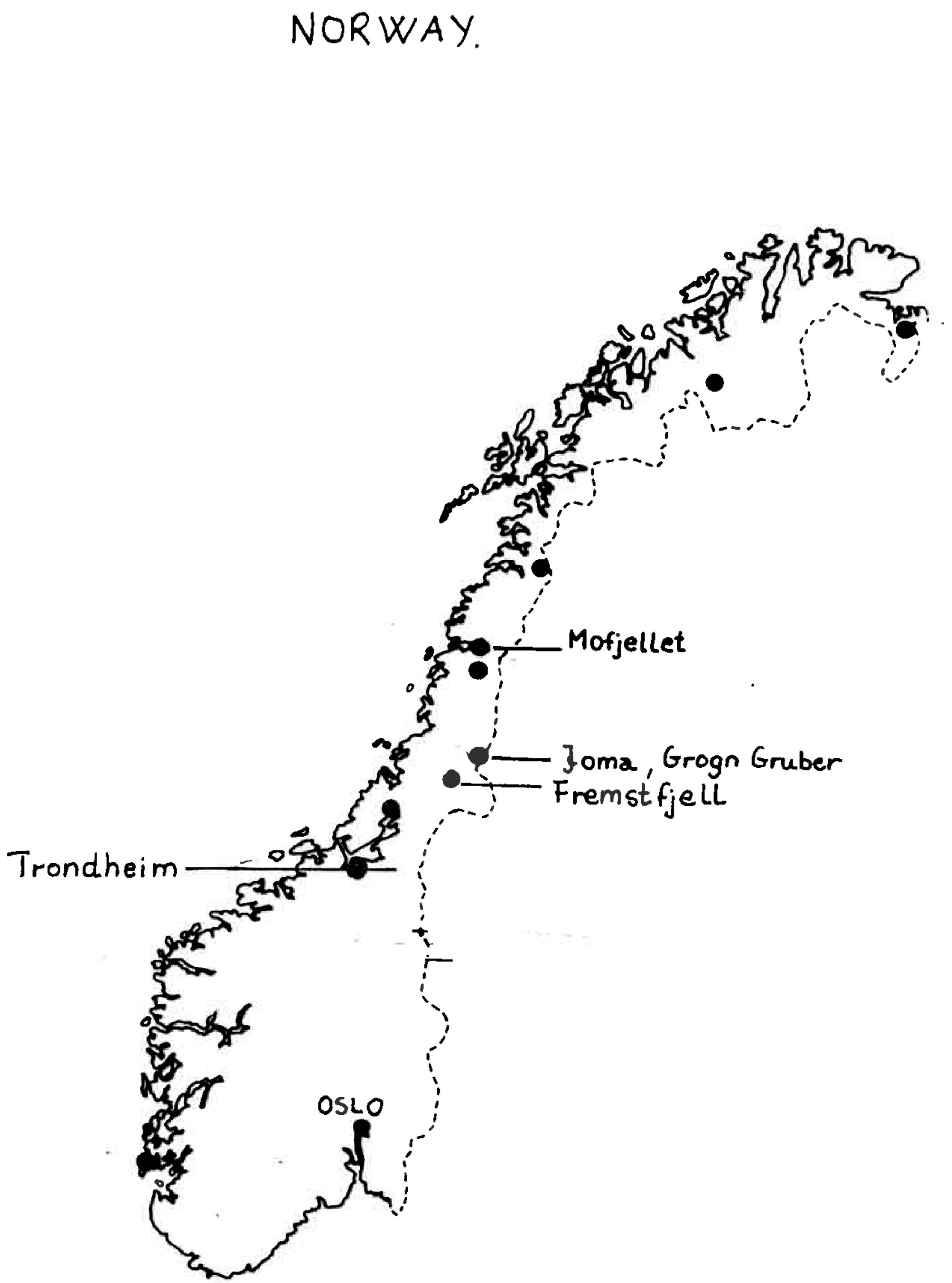
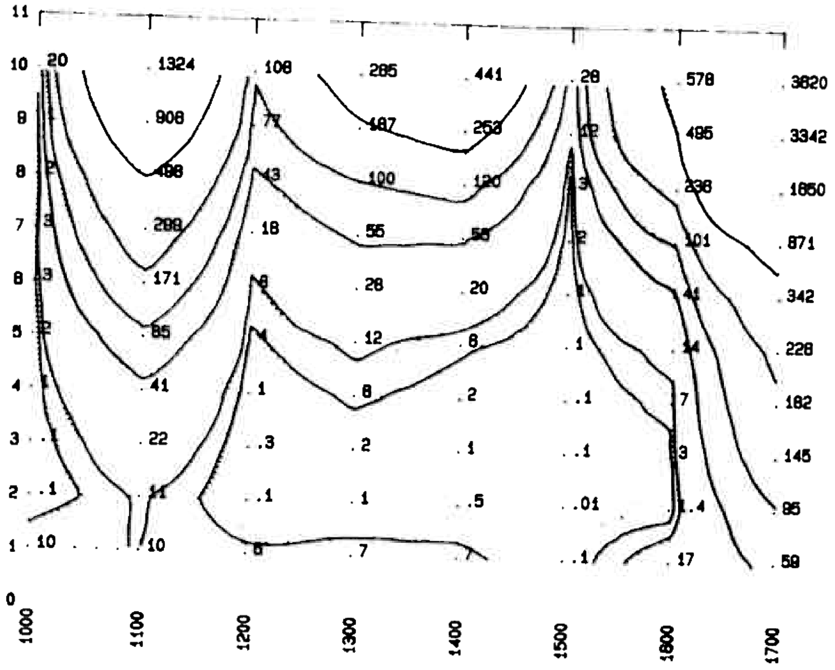

NORWAY.
Mofjellet
Joma, Grogn Gruber
Fremstfjell
Trondheim
OSLO

Fig.3.1



SYSCAL EM
PLOTT AV ROa
STED: JOMA
PROFIL: B
DATO: 26.6.1985

Fig.5.1

NORGES TEKNISKE HØGSKOLE

JOMA B 1985

	Resistivity (ohm.m)	Depth (m)
	oo	
1		0.000
	1200.000	
2		157.430
	1.500	
3		159.774
	2000.000	
4		309.451
	11.855	
5		330.322
	2000.000	
6		380.322
	5.000	

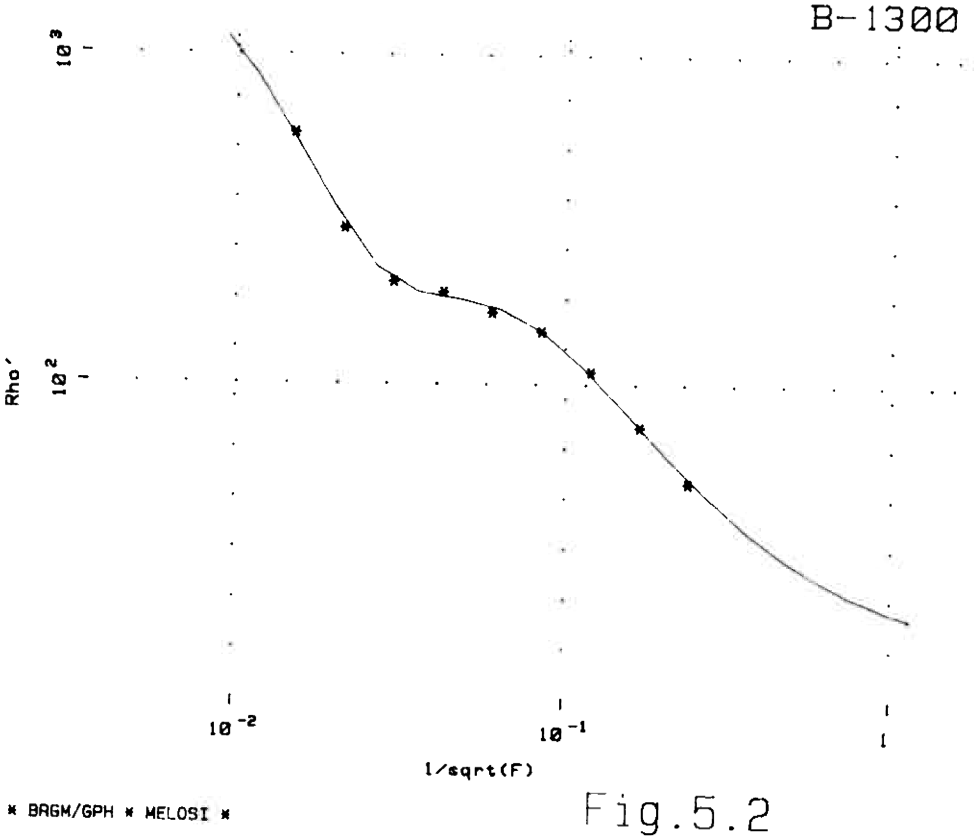


Fig.5.2

SYSCAL EM
PLOTT AV ROa
STED: SØLVBERGSONEN
PROFIL: 46200Y
DATO: 20.08.1986 HE

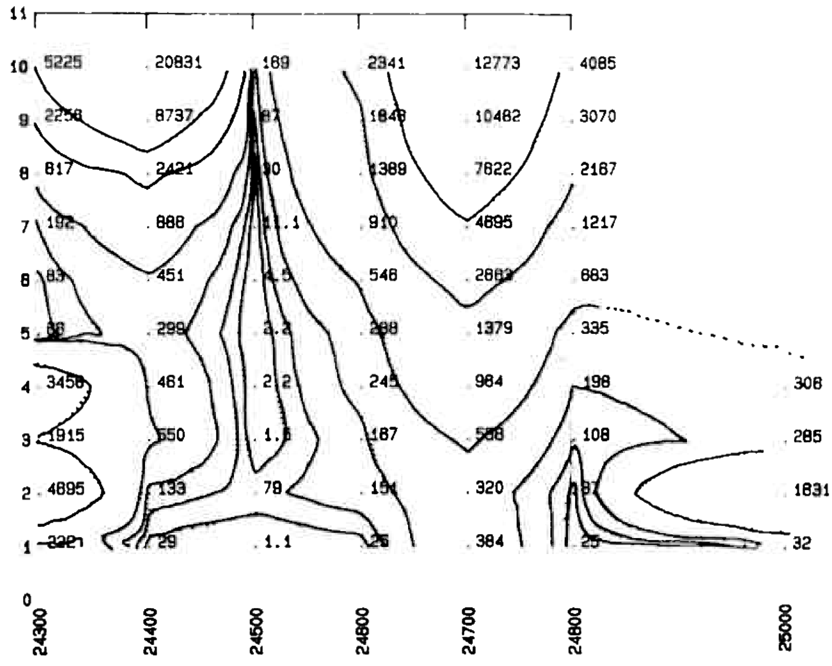


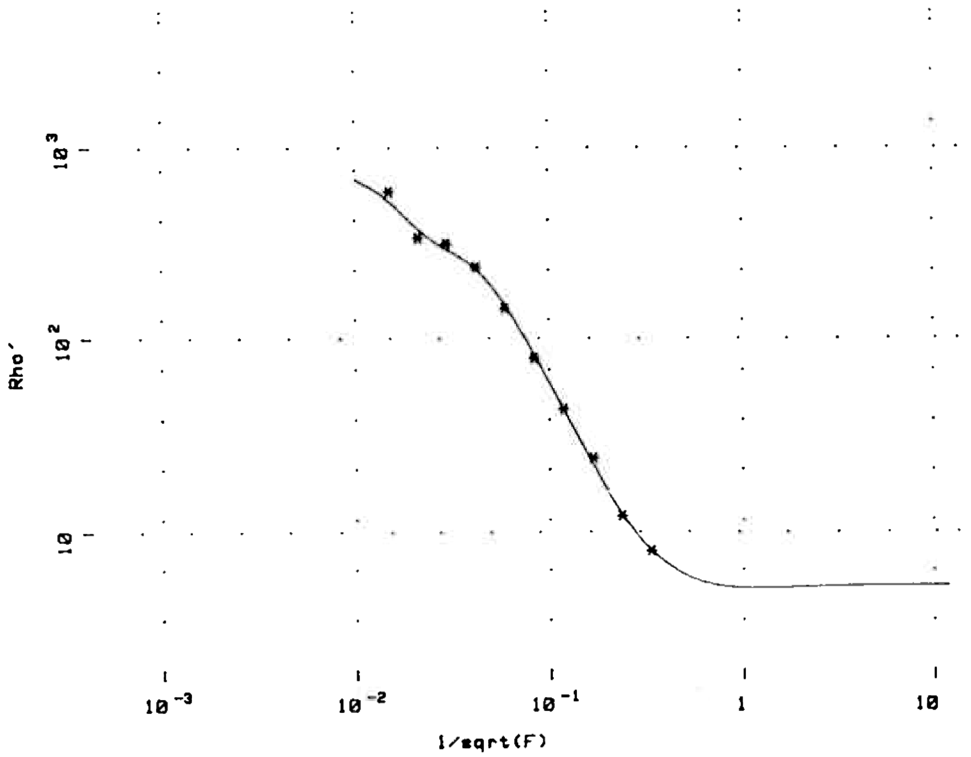
Fig.5.3

NORGES TEKNISKE HØGSKOLE

MOFJELLET 1986

	Resistivity (ohm.m)	Depth (m)
	oo	
1		0.000
	600.000	
2		172.328
	1.000	
3		173.773
	2000.000	
4		259.933
	.100	
5		273.531
	2000.000	

24500X



* BRGM/GPH * MELOSI *

Fig.5.4

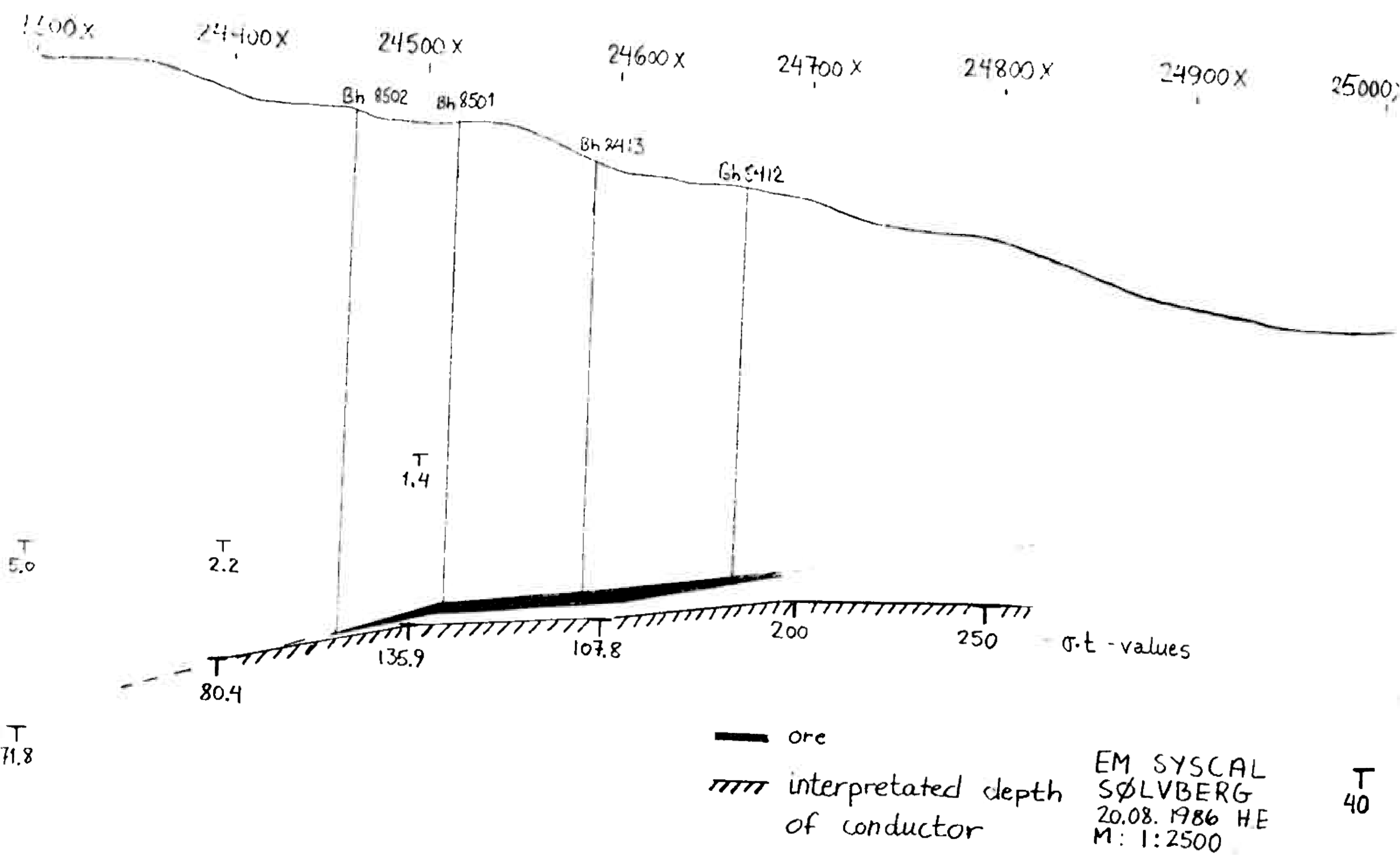
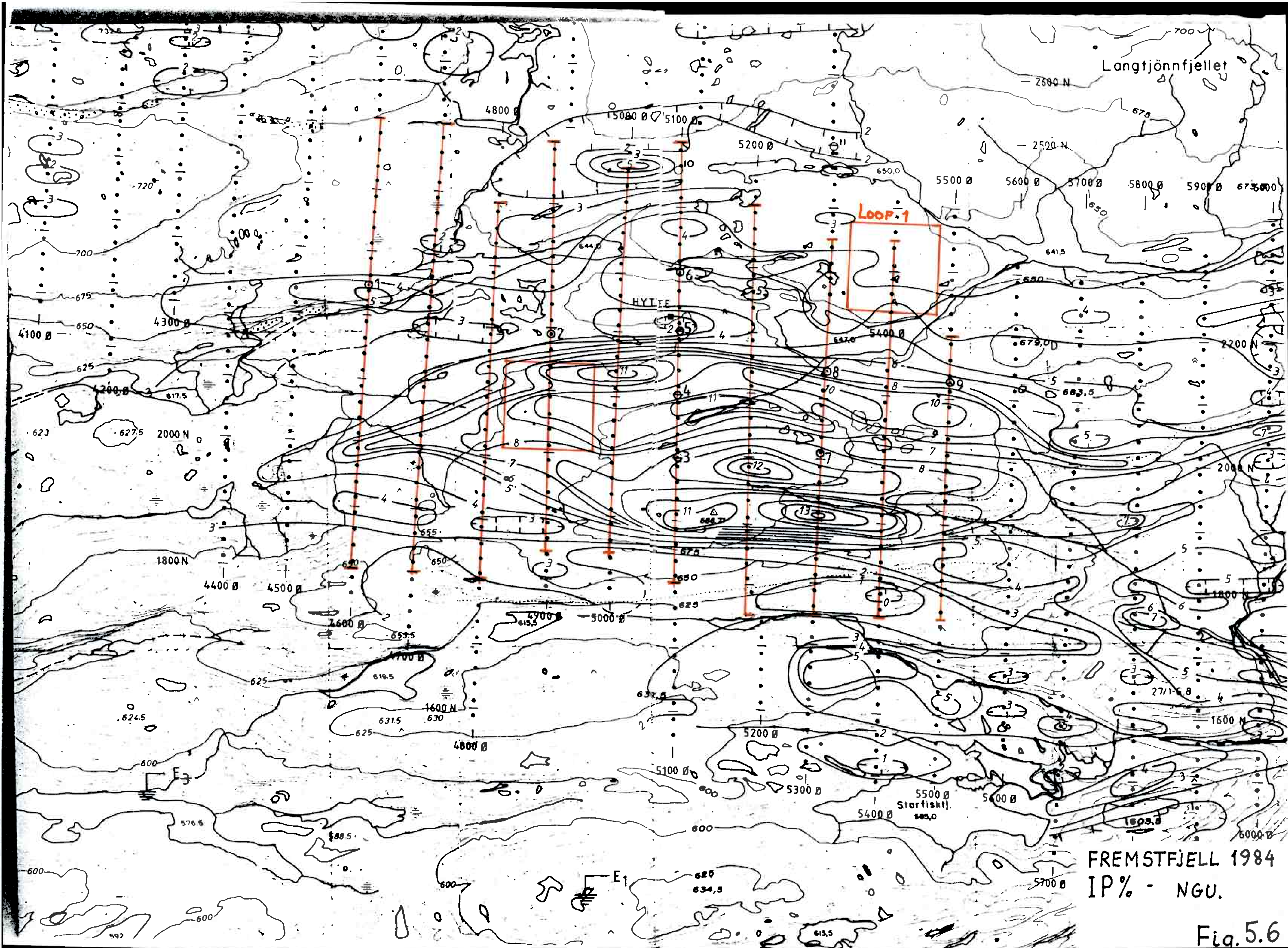
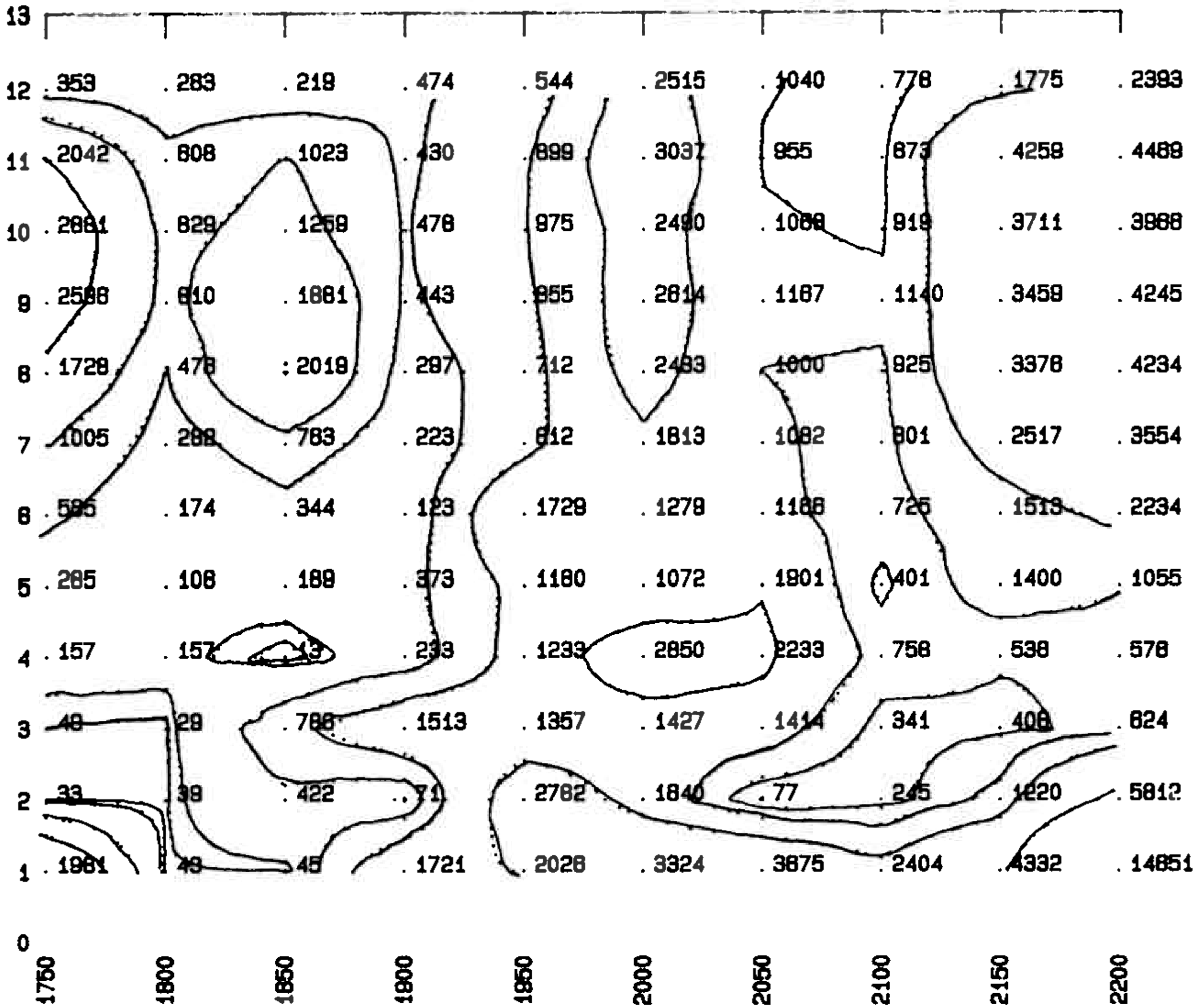

24400 X
24500 X
24600 X
24700 X
24800 X
24900 X
Bh 8502
Bh 8501
1.4
5.0
2.2
135.9
107.8
200
250
σ·t - values
80.4
ore
interpretated depth of conductor
EM SYSCAL
SØLVBERG
20.08. 1986 HE
M: 1:2500
40

Fig.5.5



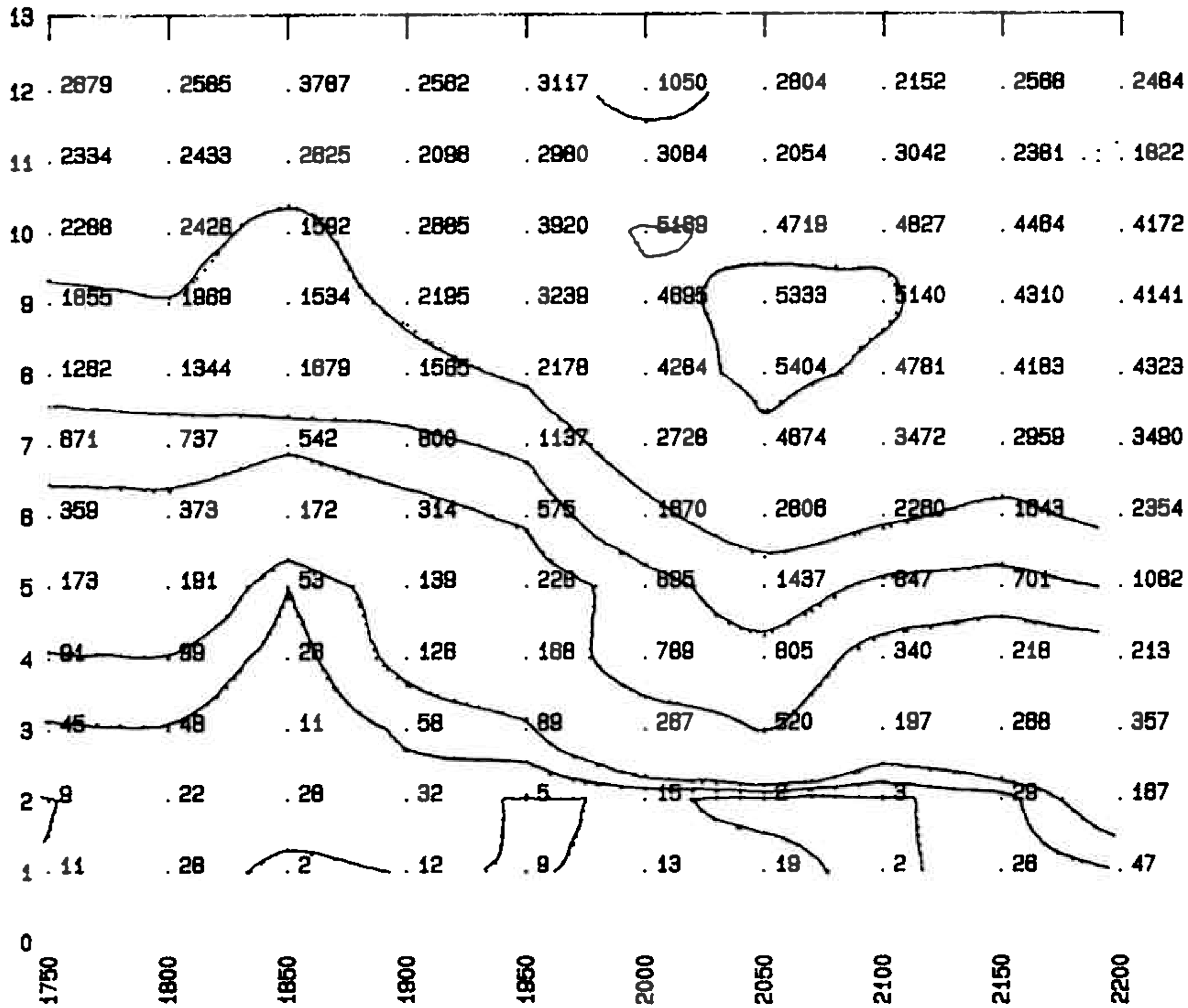
FREMSTFJELL 1984
IP% - NGU.

Fig. 5.6



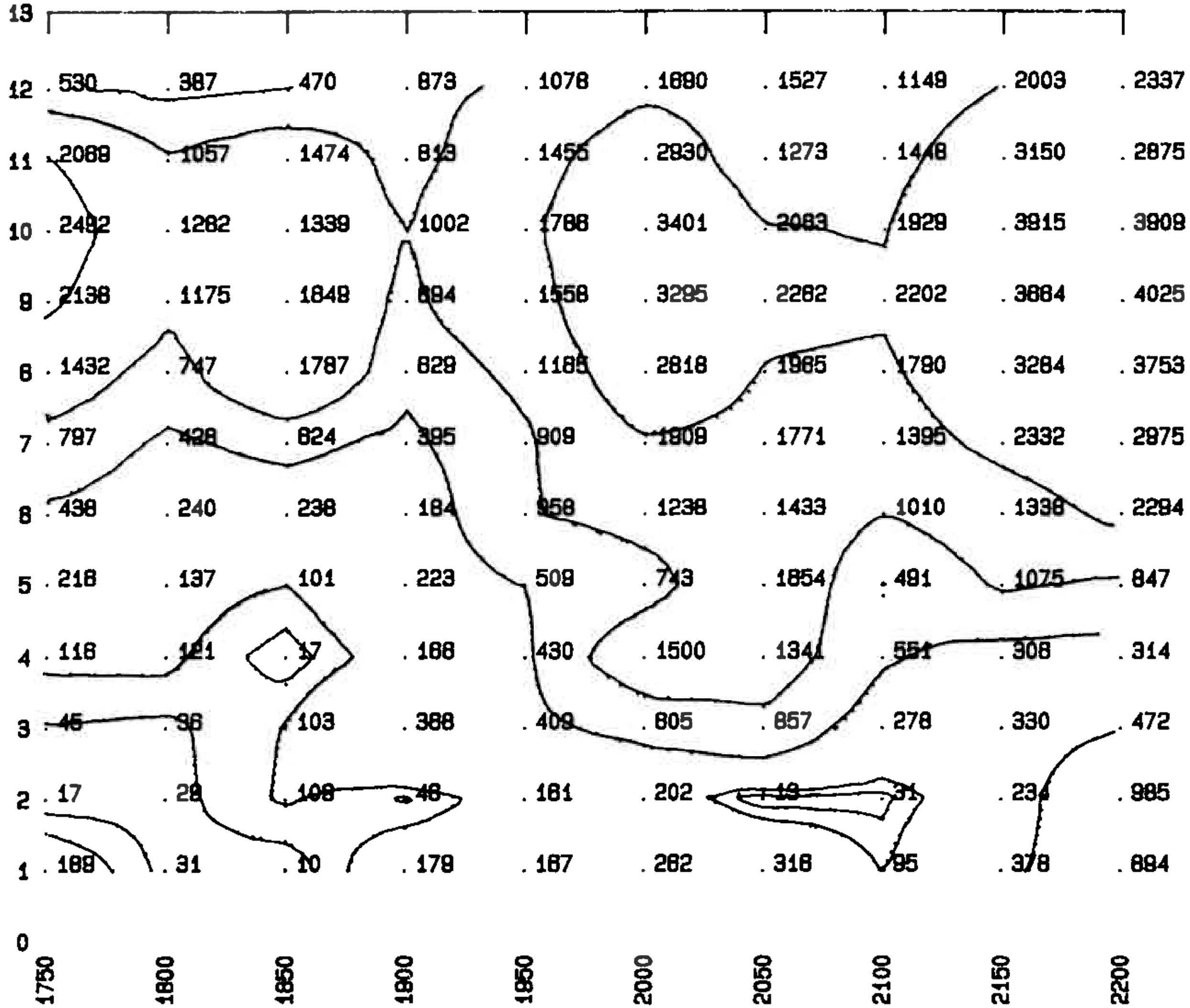
SYSCAL EM
PLOTT AV ROa
STED: FREMSTFJELL
PROFIL: 5500E
DATO: 23.8.85 HE/BH/SOR

Fig.5.7



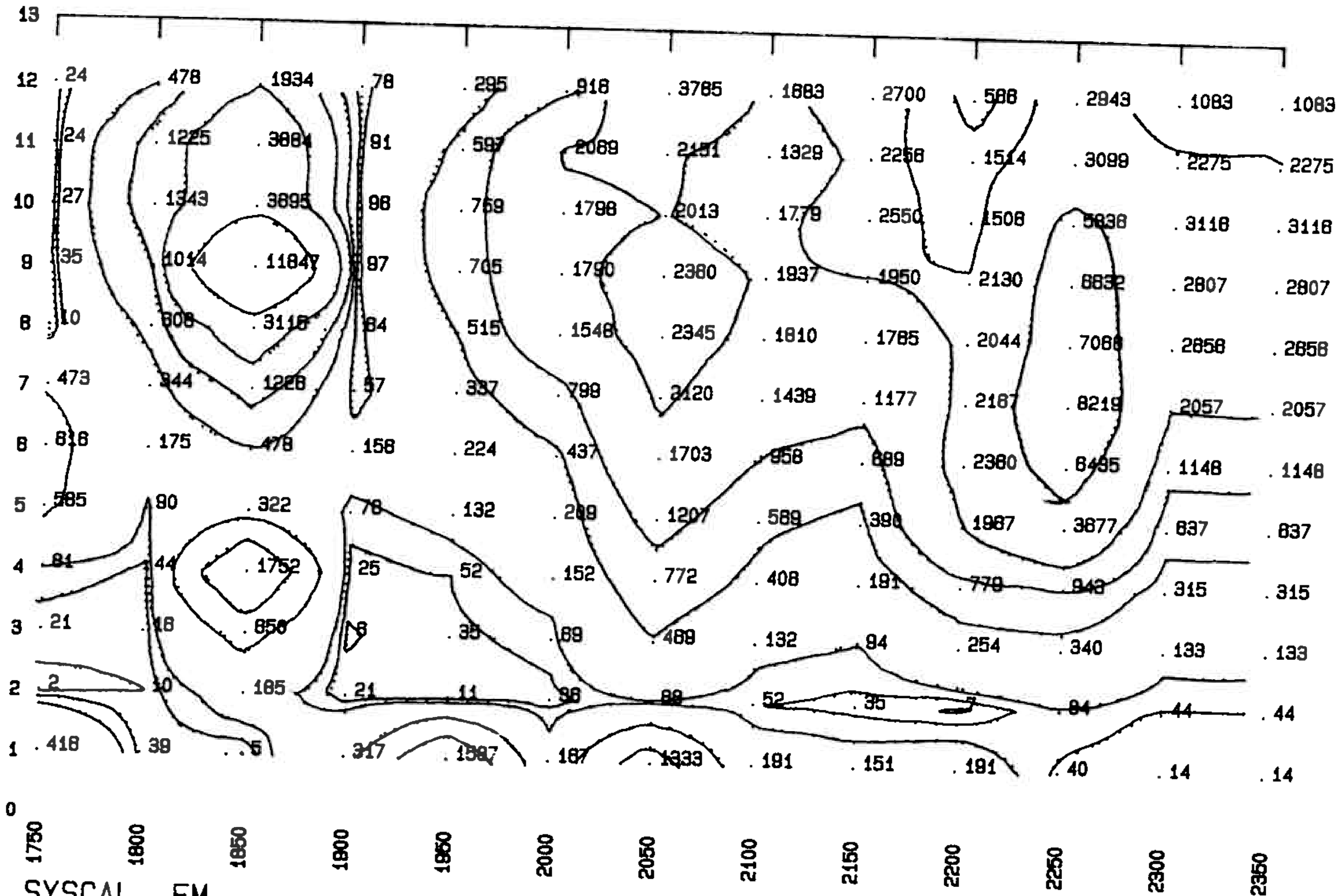
SYSCAL EM
PLOTT AV ROa'
STED: FREMSTFJELL
PROFIL: 5500E
DATO: 23.8.85 HE/BH/SOR

Fig.5.8



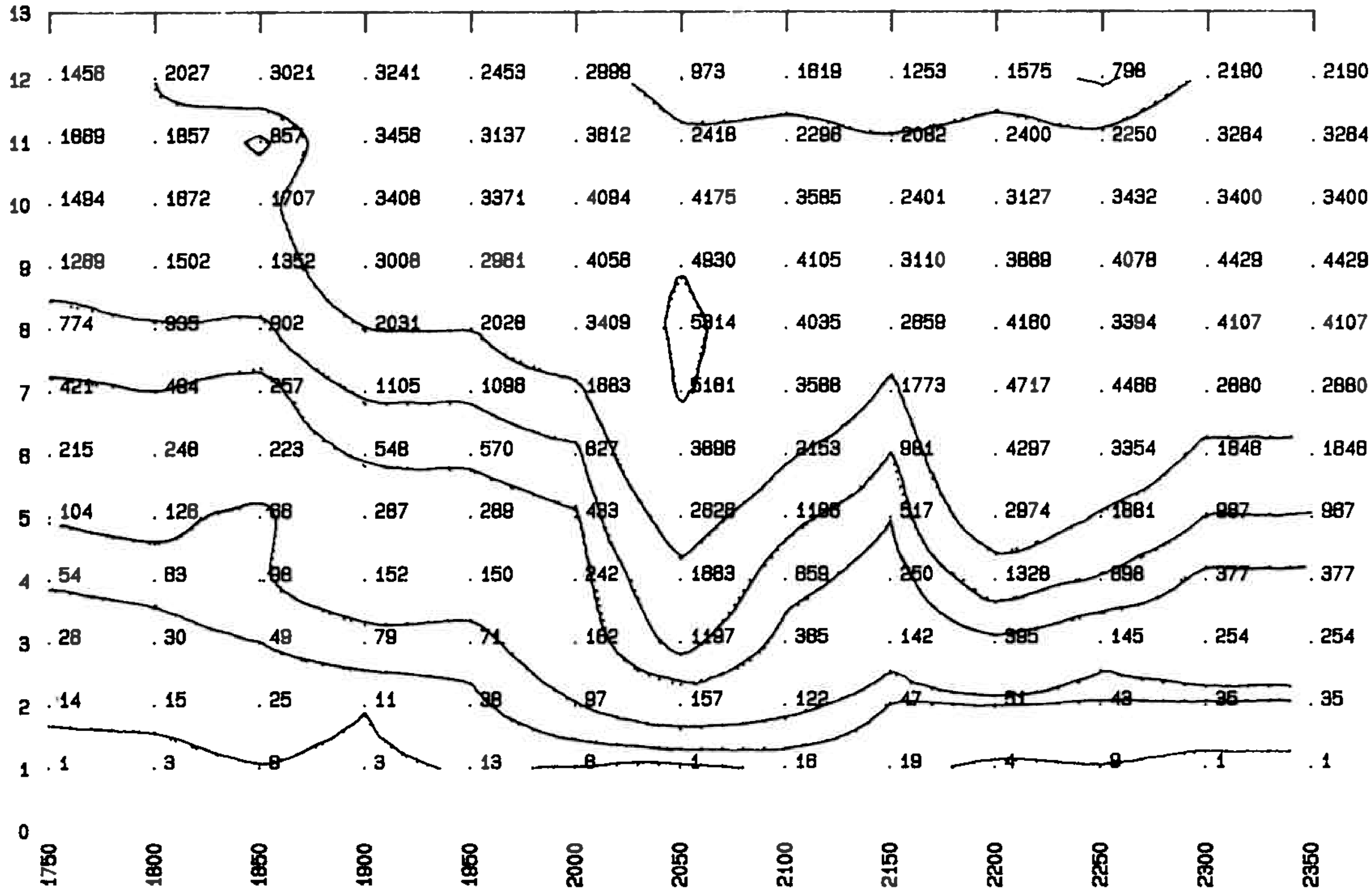
SYSCAL EM
PLOTT AV ROa''
STED: FREMSTFJELL
PROFIL: 5500E
DATO: 23.8.85 HE/BH/SOR

Fig.5.9



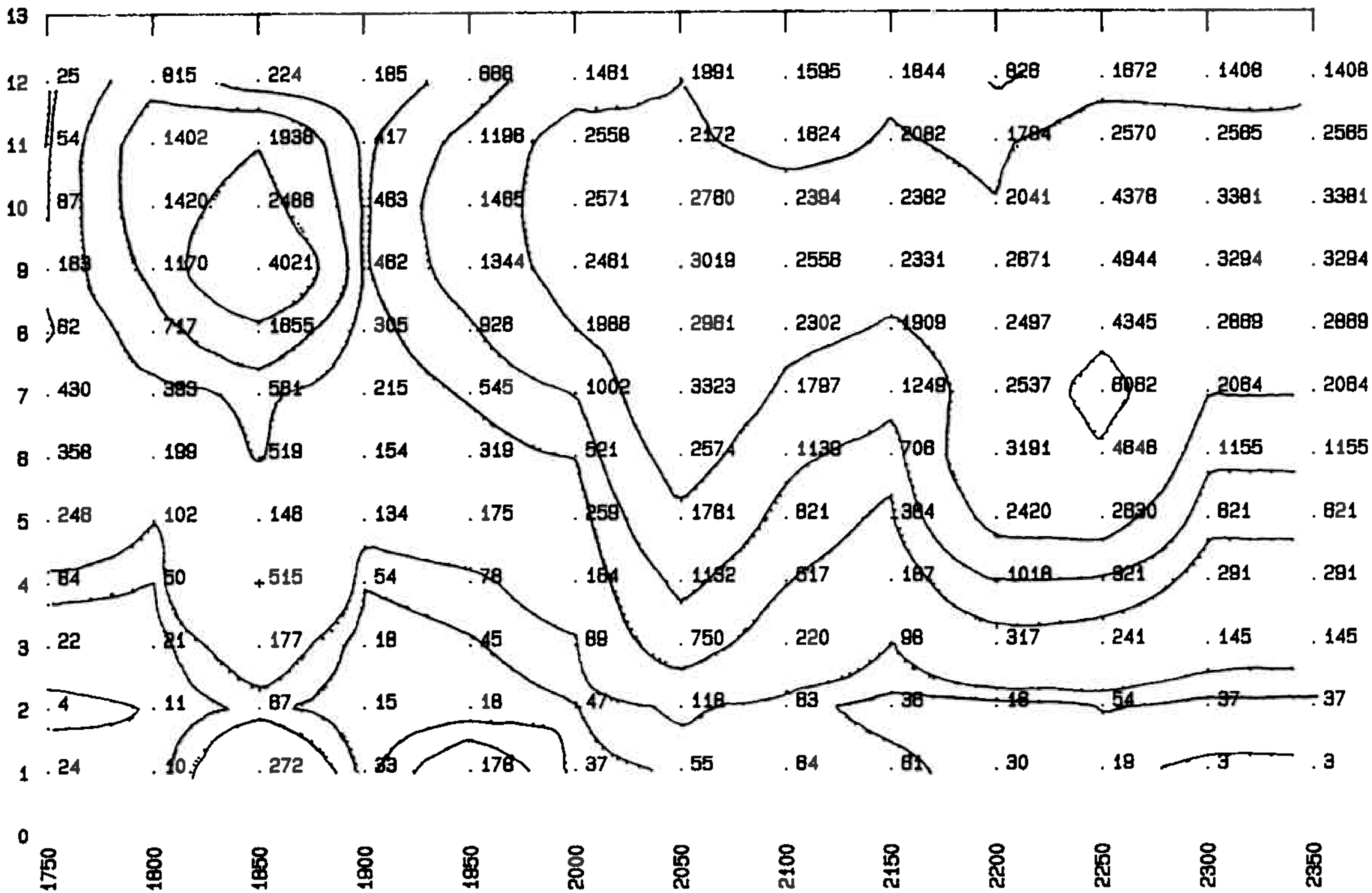
SYSCAL EM
PLOTT AV ROa
STED: FREMSTFJELL
PROFIL: 5400E
DATO: 21.8.85 HE/BH/SOR

Fig.5.10



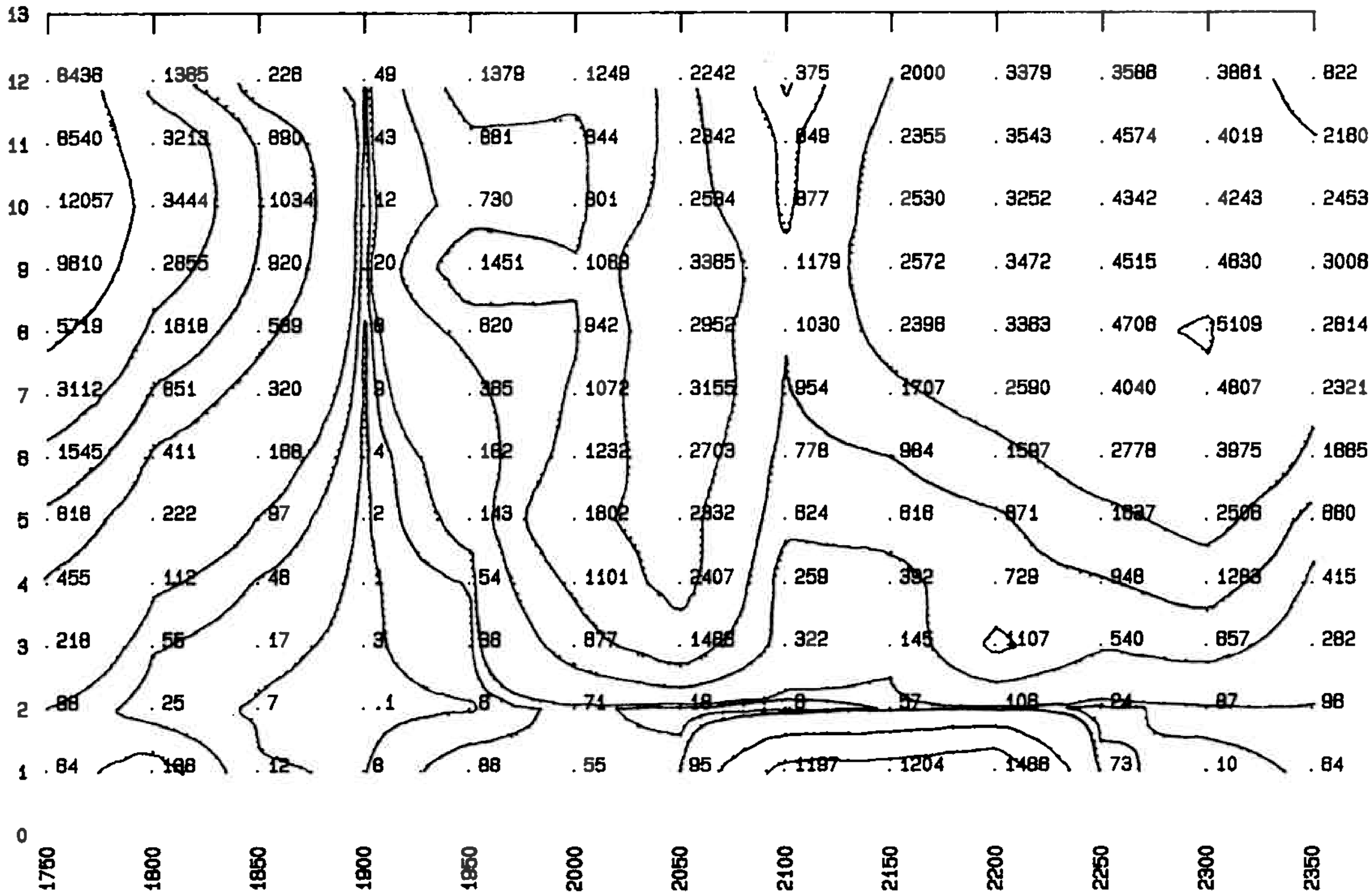
SYSCAL EM
PLOTT AV ROa'
STED: FREMSTFJELL
PROFIL: 5400E
DATO: 21.8.85 HE/BH/SOR

Fig.5.11



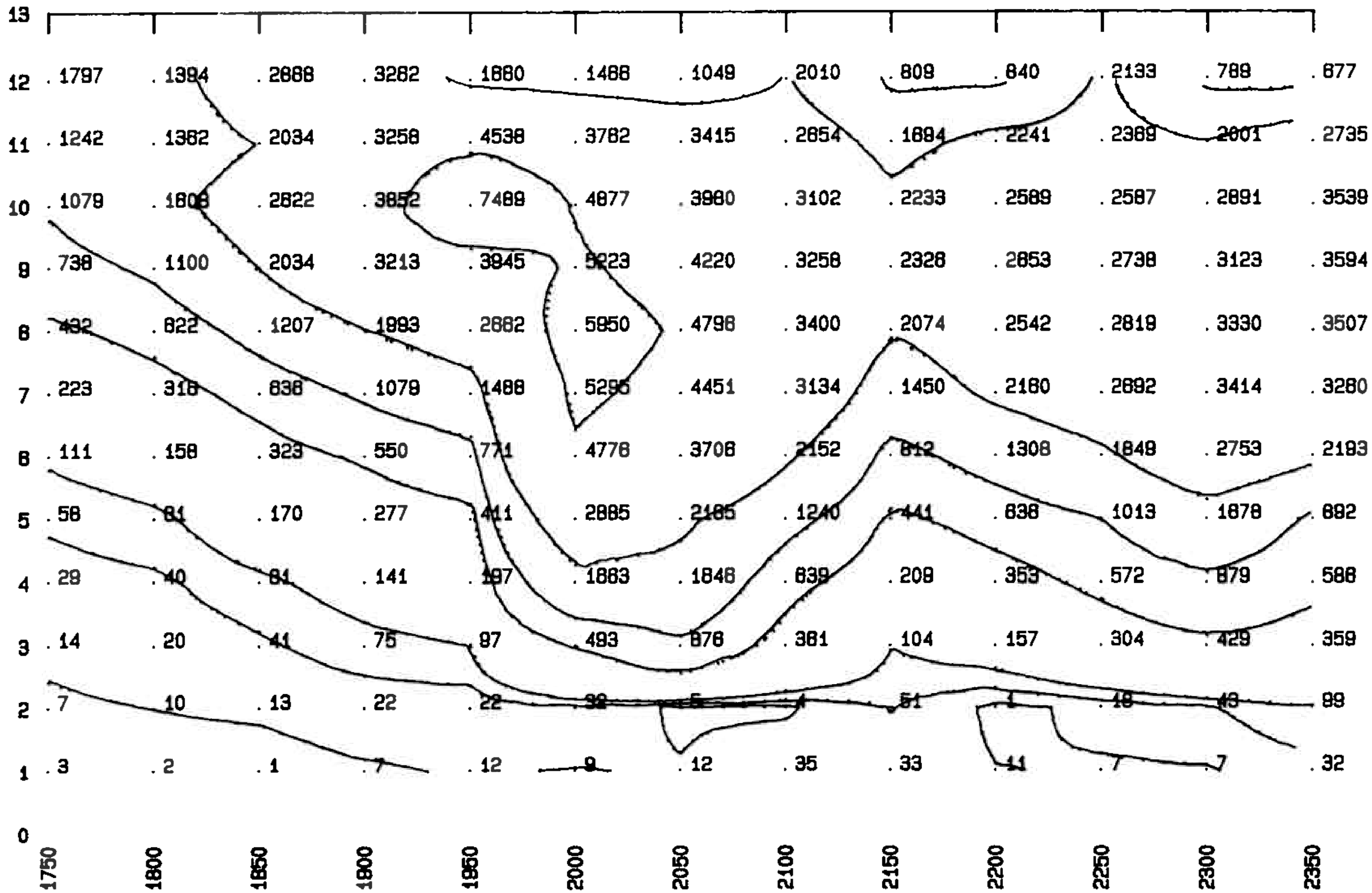
SYSCAL EM
PLOTT AV ROa''
STED: FREMSTFJELL
PROFIL: 5400E
DATO: 21.8.85 HE/BH/SOR

Fig.5.12



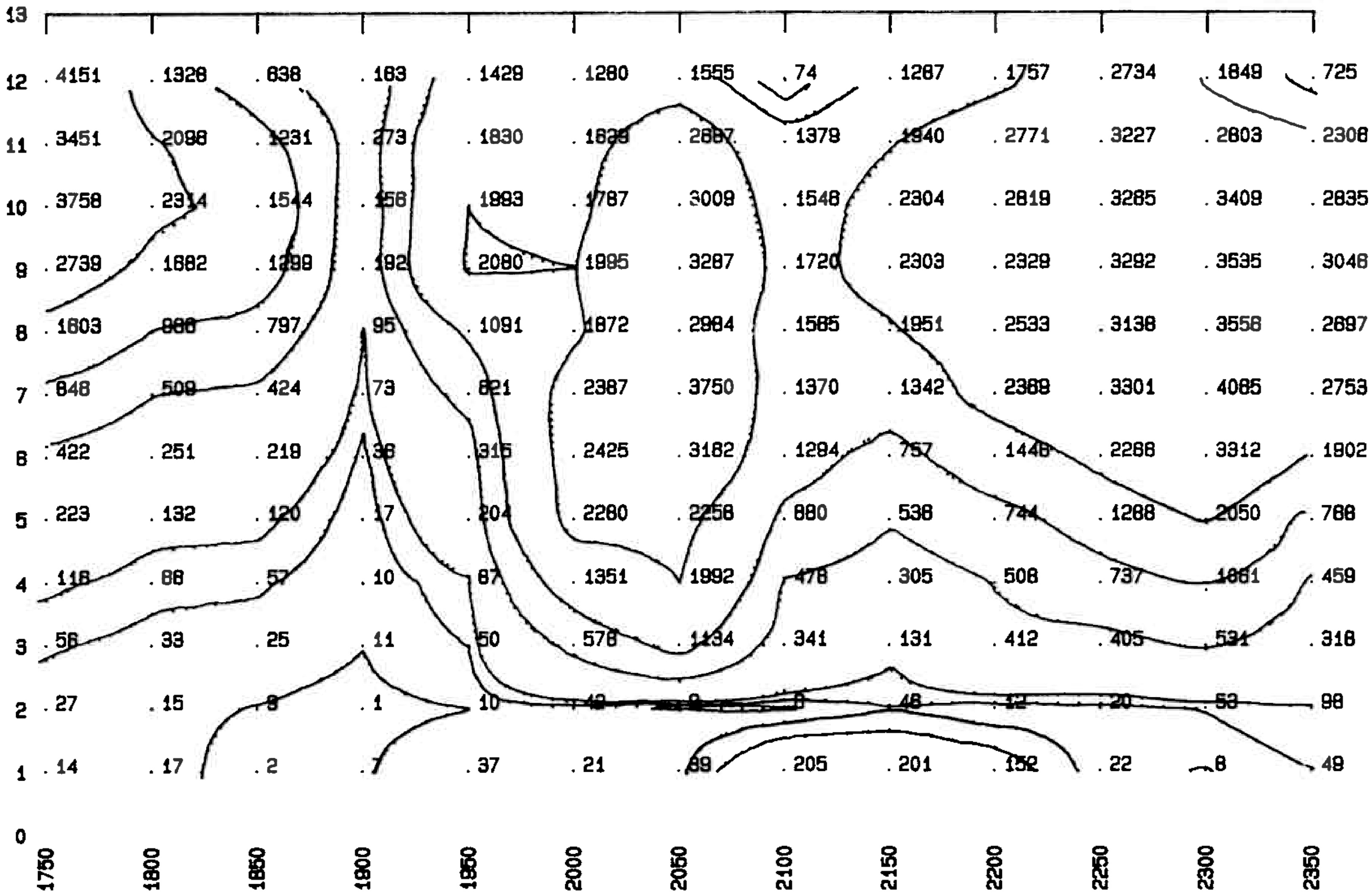
SYSCAL EM
PLOTT AV ROa
STED: FREMSTFJELL
PROFIL: 5300E
DATO: 21.8.85 HE/BH/SOR

Fig.5.13



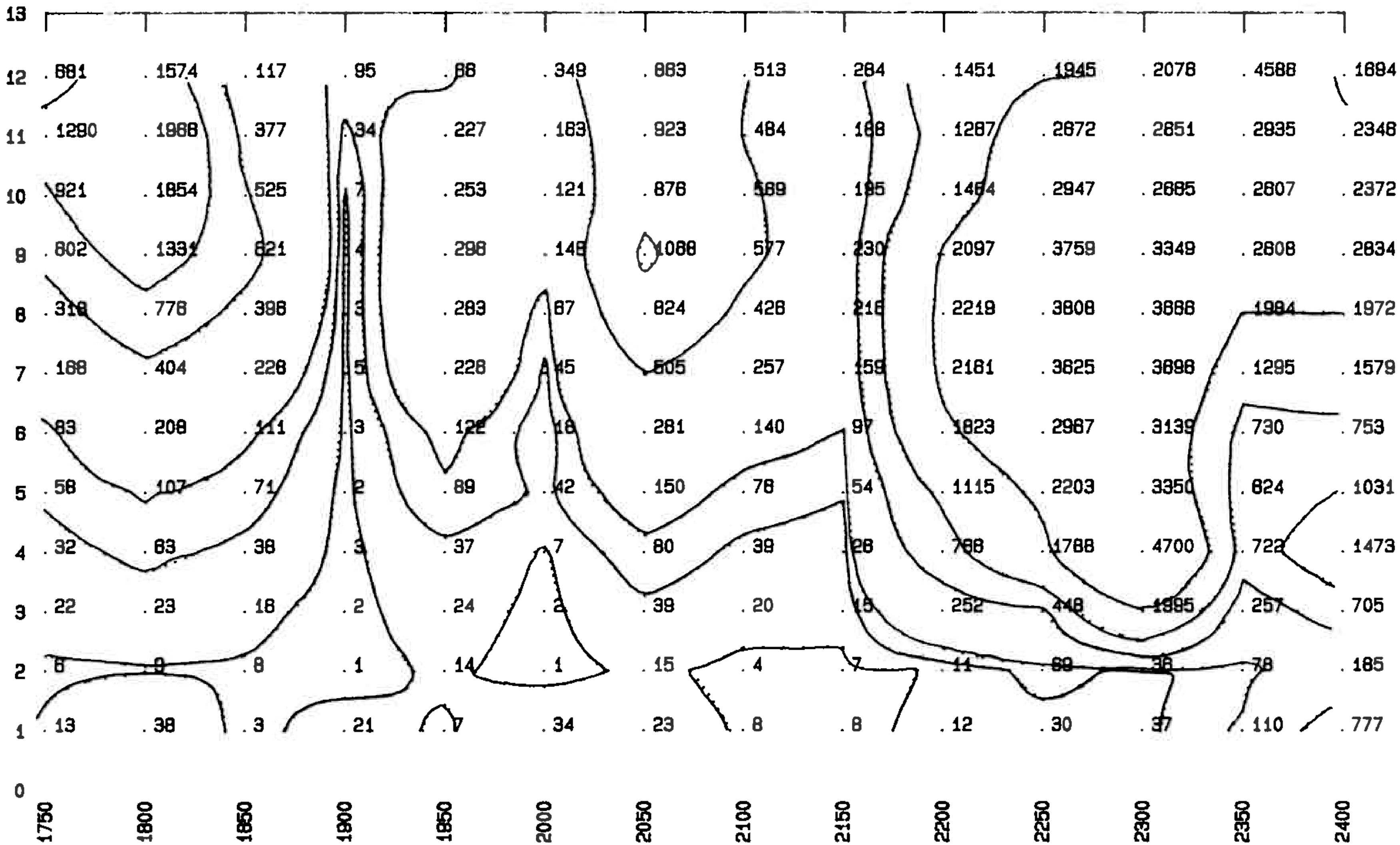
SYSCAL EM
PLOTT AV ROa'
STED: FREMSTFJELL
PROFIL: 5300E
DATO: 21.8.85 HE/BH/SOR

Fig.5.14



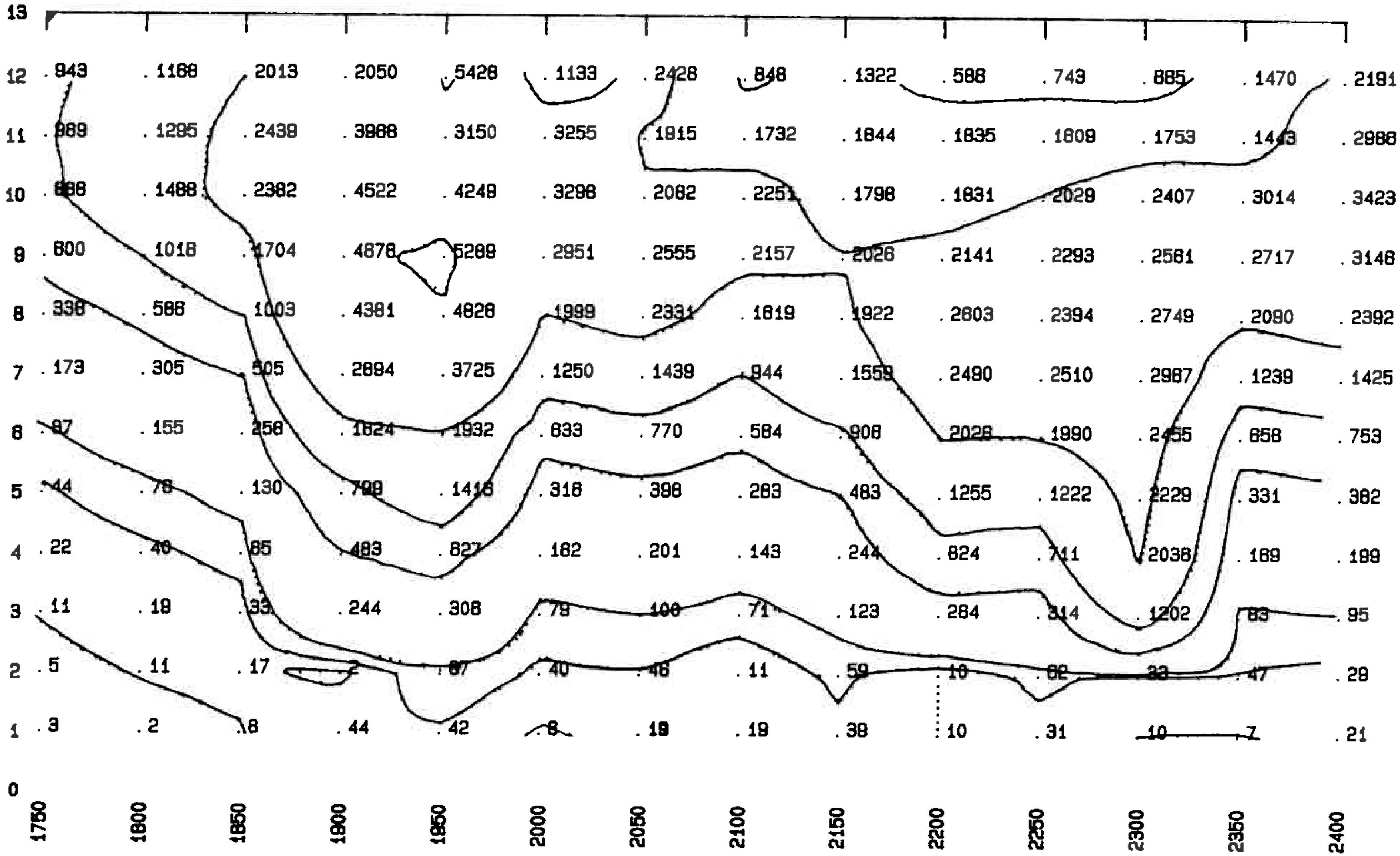
SYSCAL EM
PLOTT AV ROa''
STED: FREMSTFJELL
PROFIL: 5300E
DATO: 21.8.85 HE/BH/SOR

Fig.5.15



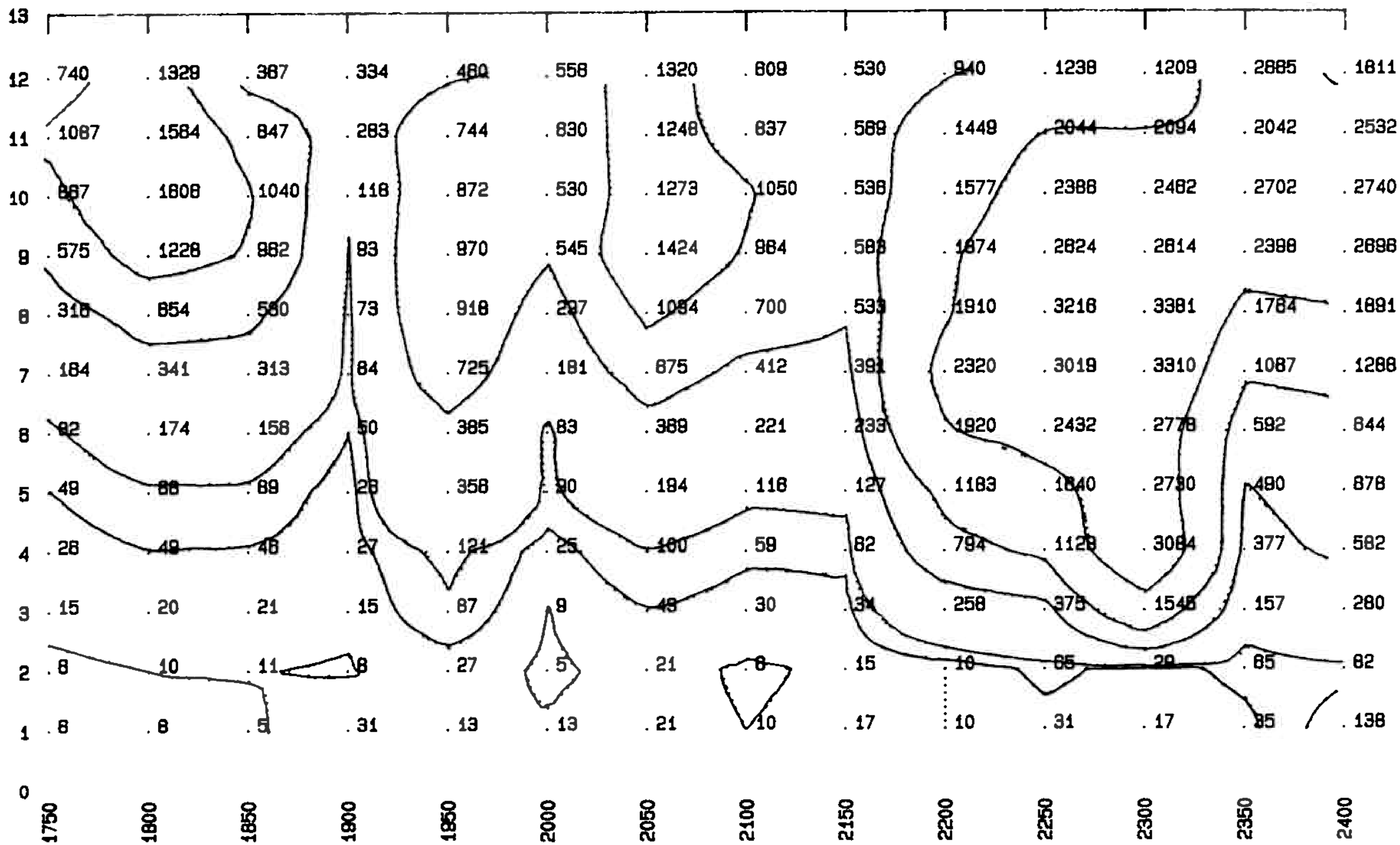
SYSCAL EM
PLOTT AV ROa
STED: FREMSTFJELL
PROFIL: 5200E
DATO: 14.8.85 HE/BH/SOR

Fig.5.16



SYSCAL EM
PLOTT AV ROa'
STED: FREMSTFJELL
PROFIL: 5200E
DATO: 14.8.85 HE/BH/SOR

Fig.5.17



SYSCAL EM
PLOTT AV ROa''
STED: FREMSTFJELL
PROFIL: 5200E
DATO: 14.8.85 HE/BH/SOR

Fig.5.18

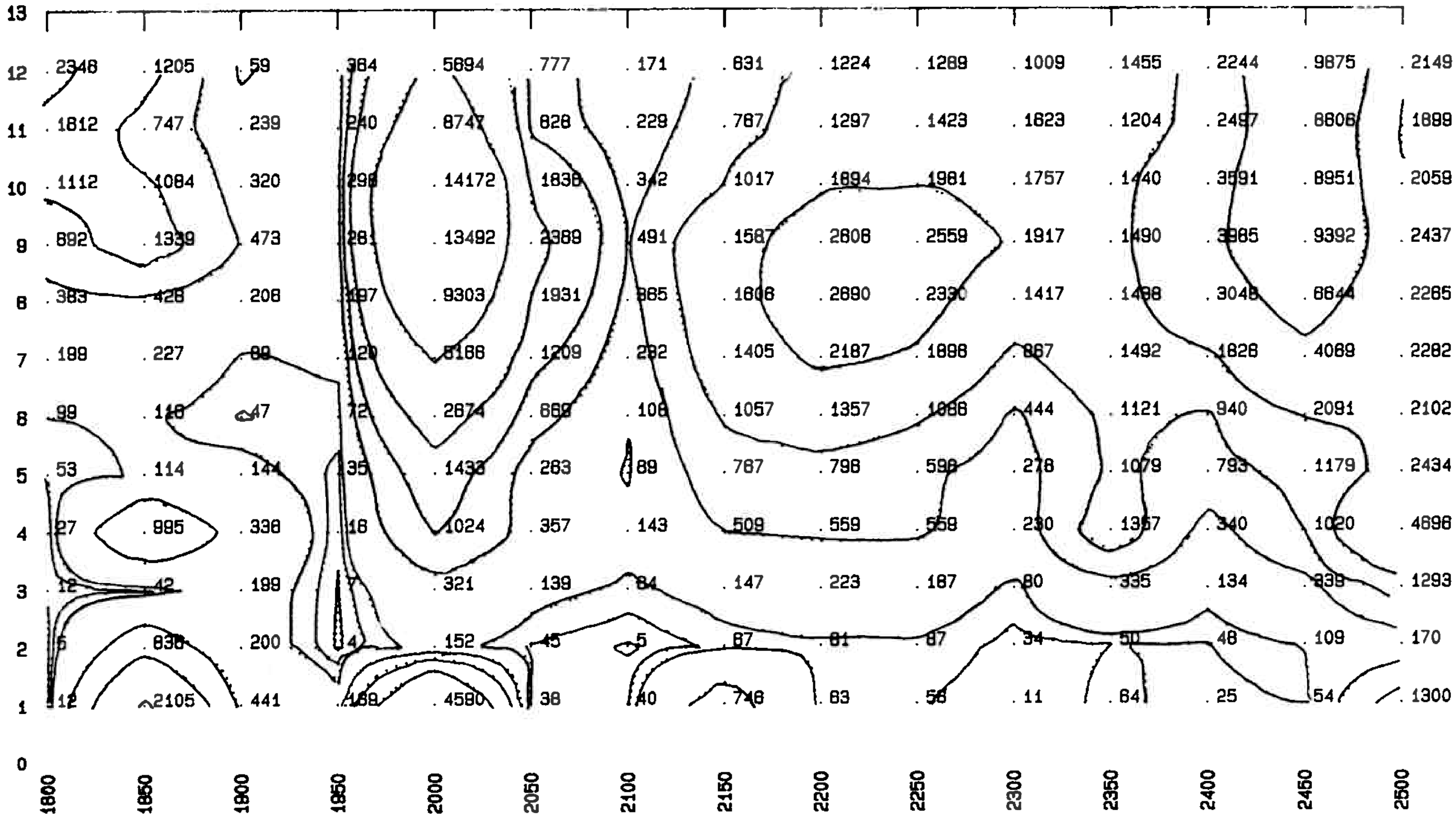
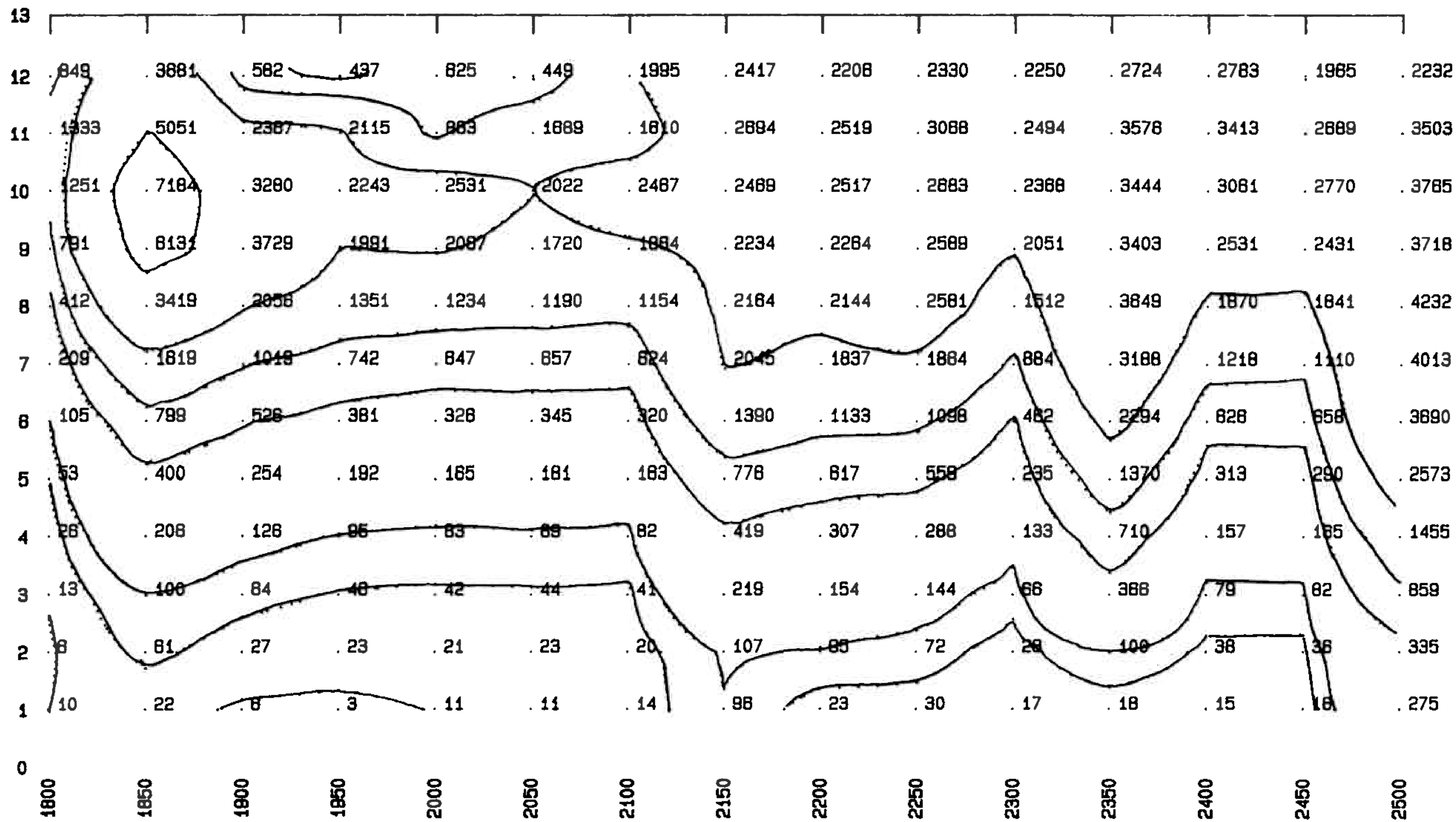


Fig.5.19

SYSCAL EM
PLOTT AV ROa
STED: FREMSTFJELL
PROFIL: 5100E
DATO: 8.8.85 HF/BH/SOR



SYSCAL EM
PLOTT AV ROa'
STED: FREMSTFJELL
PROFIL: 5100E
DATO: 8.8.85 HE/BH/SOR

Fig.5.20

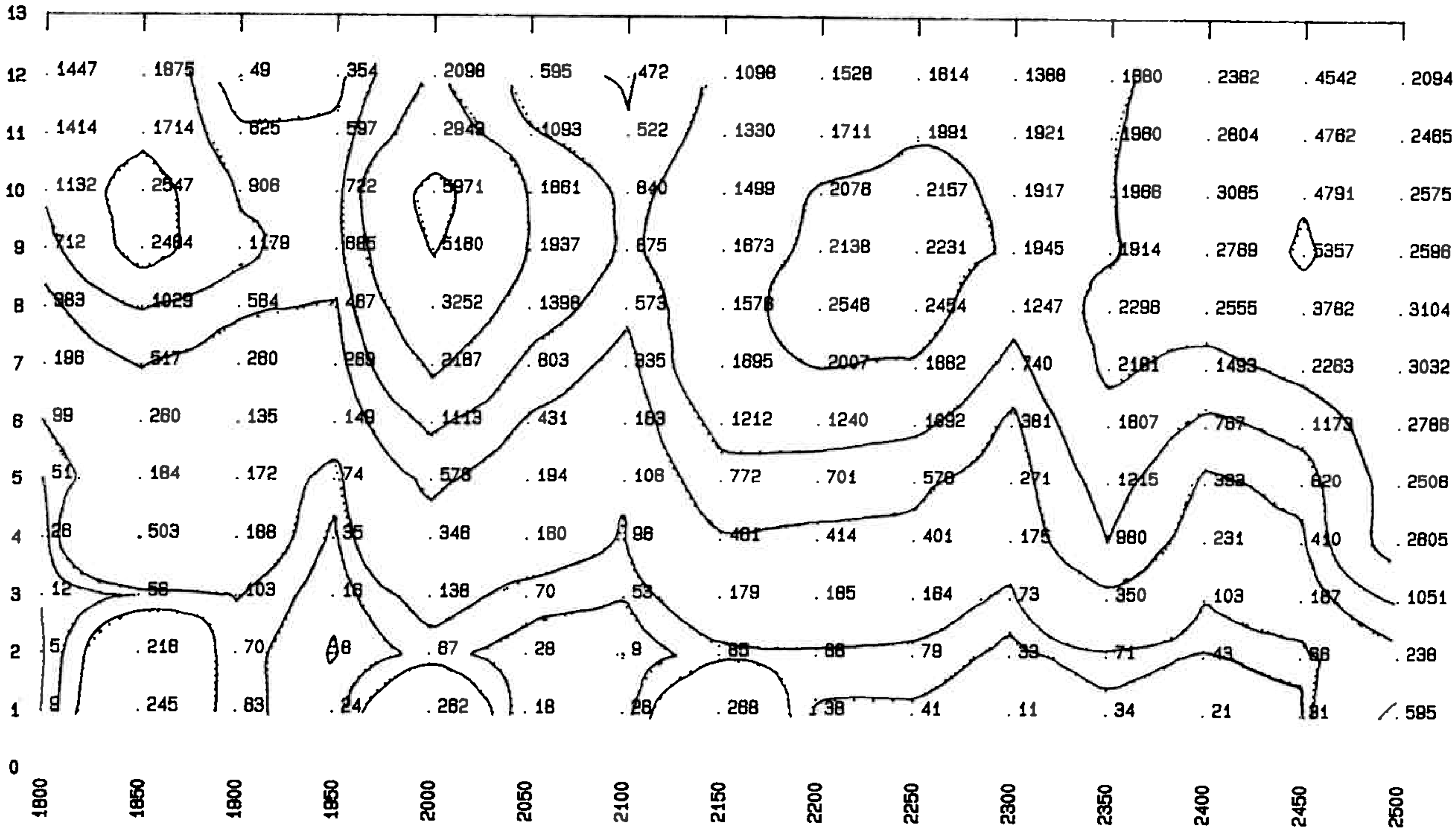
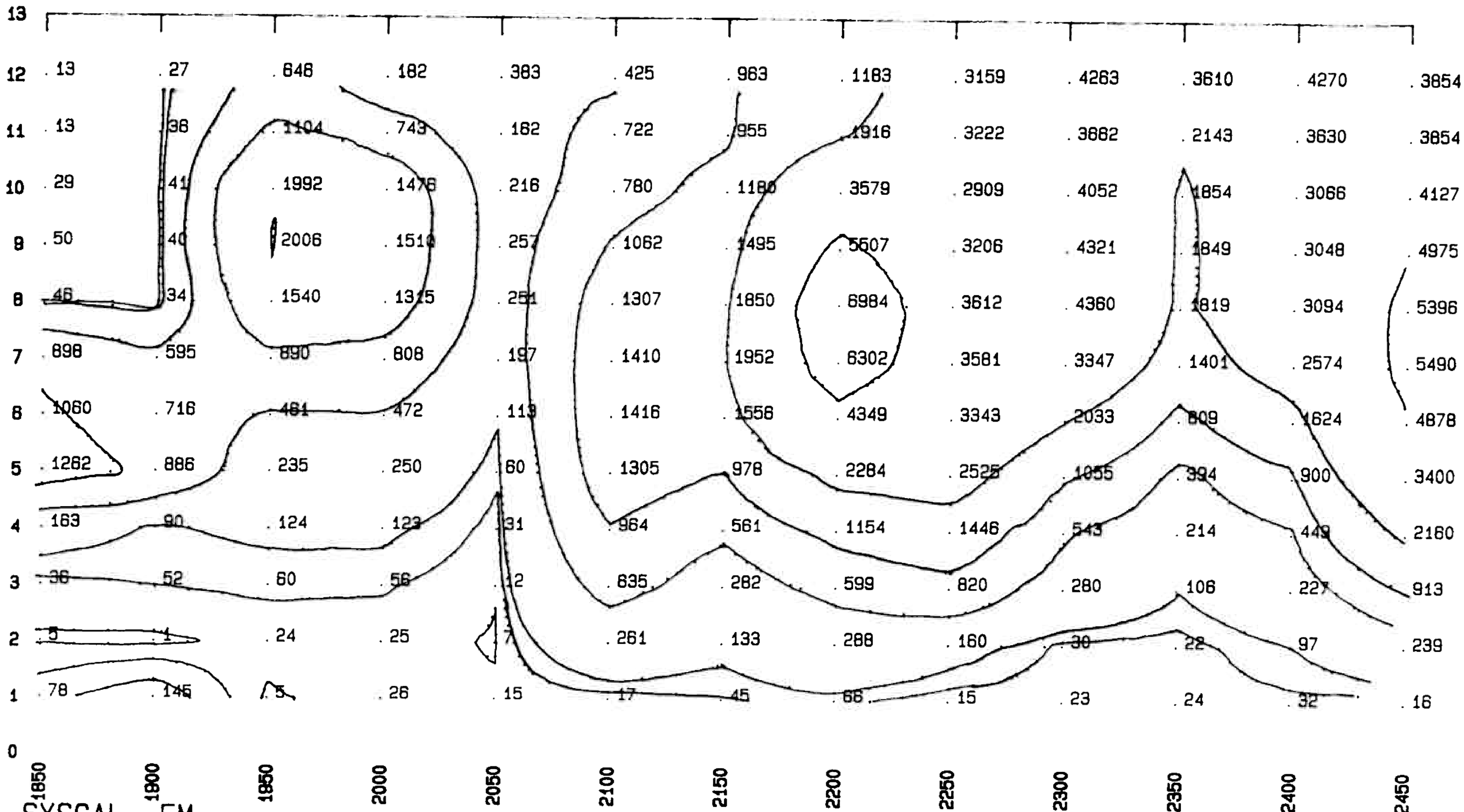


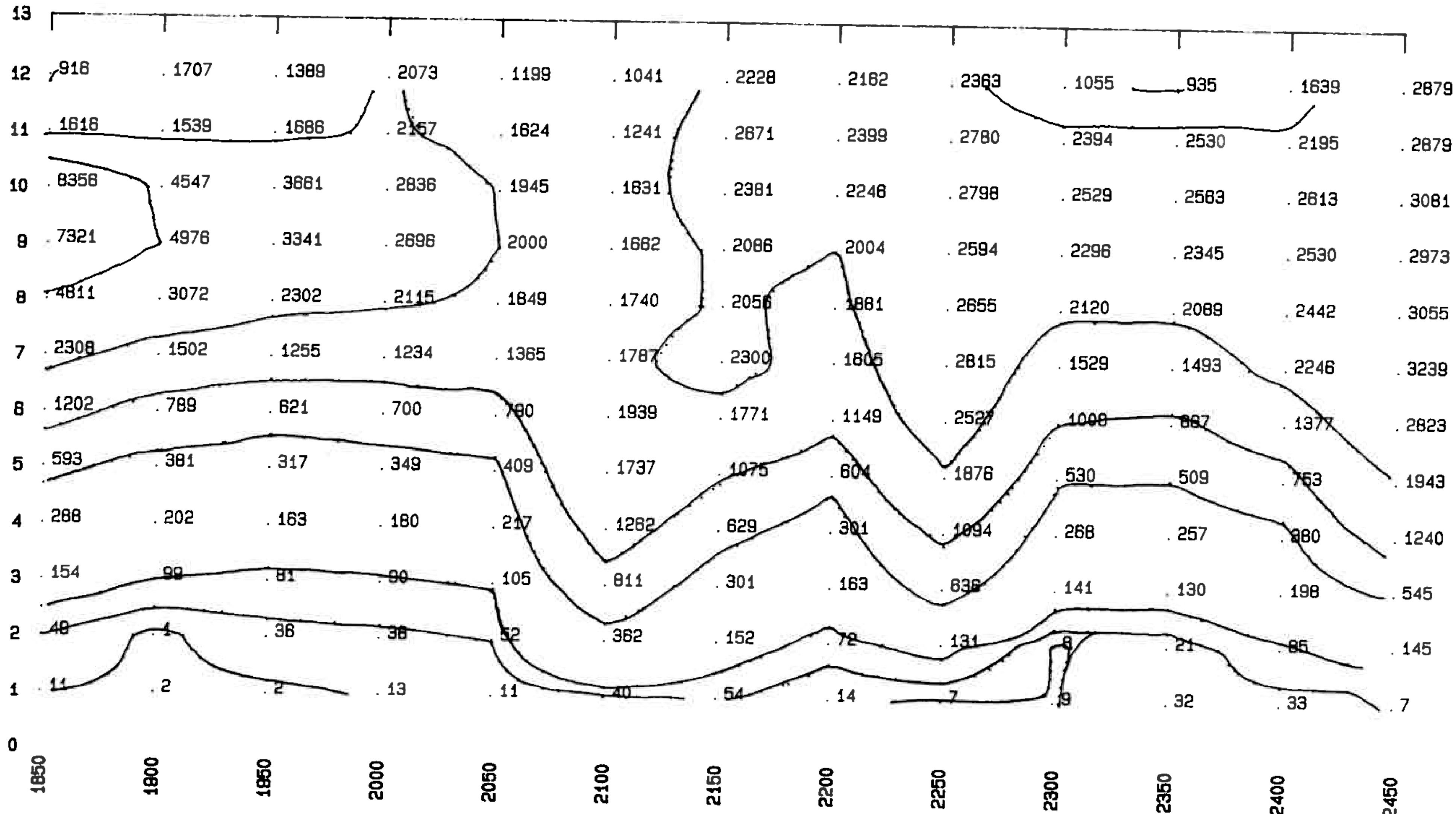
Fig.5.21

SYSCAL EM
PLOTT AV ROa''
STED: FREMSTFJELL
PROFIL: 5100E
DATO: 8.8.85 HE/BH/SOR



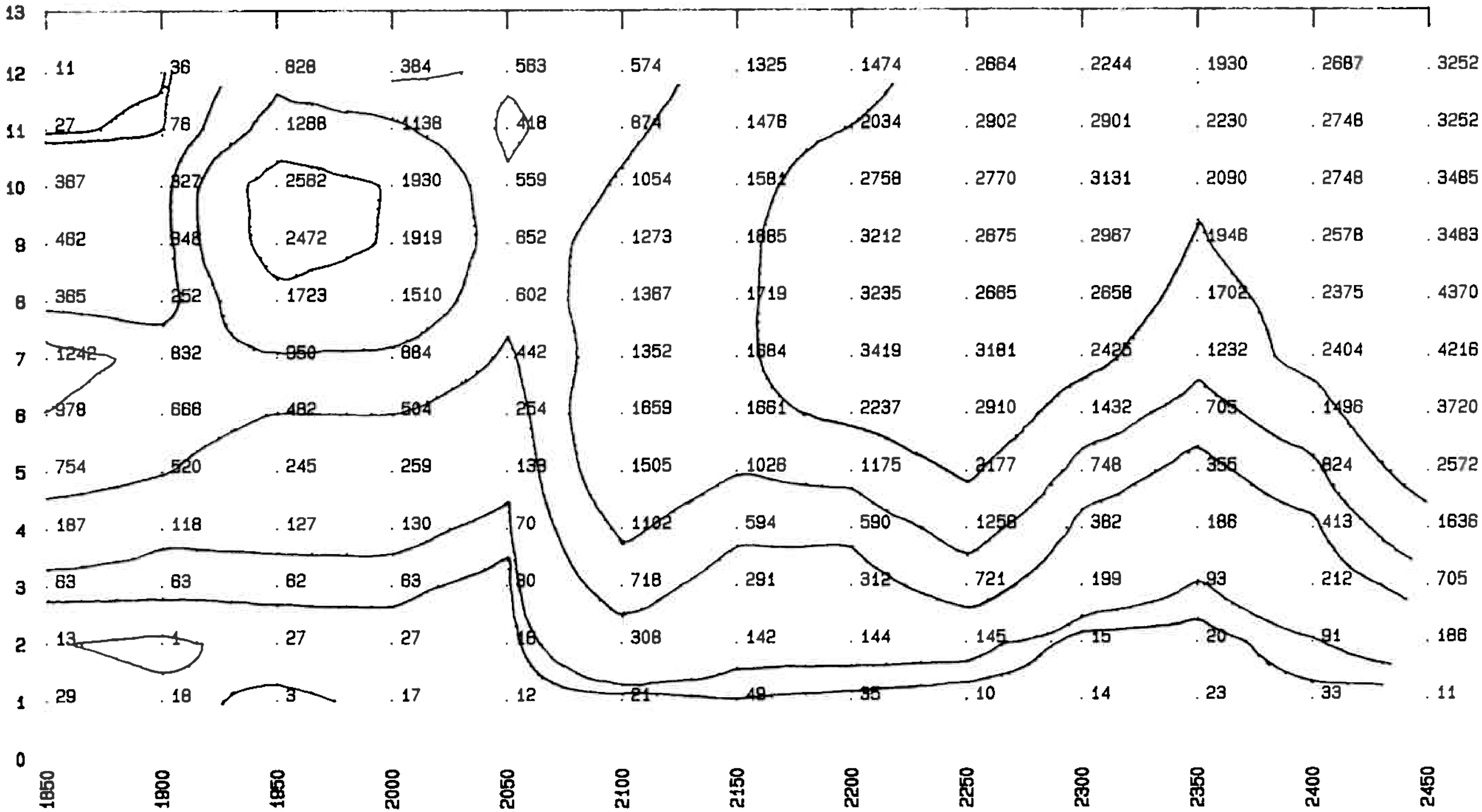
SYSCAL EM
PLOTT AV ROa
STED: FREMSTFJELL
PROFIL: 5000E
DATO: 3.7.1985 HE/BH

Fig.5.22



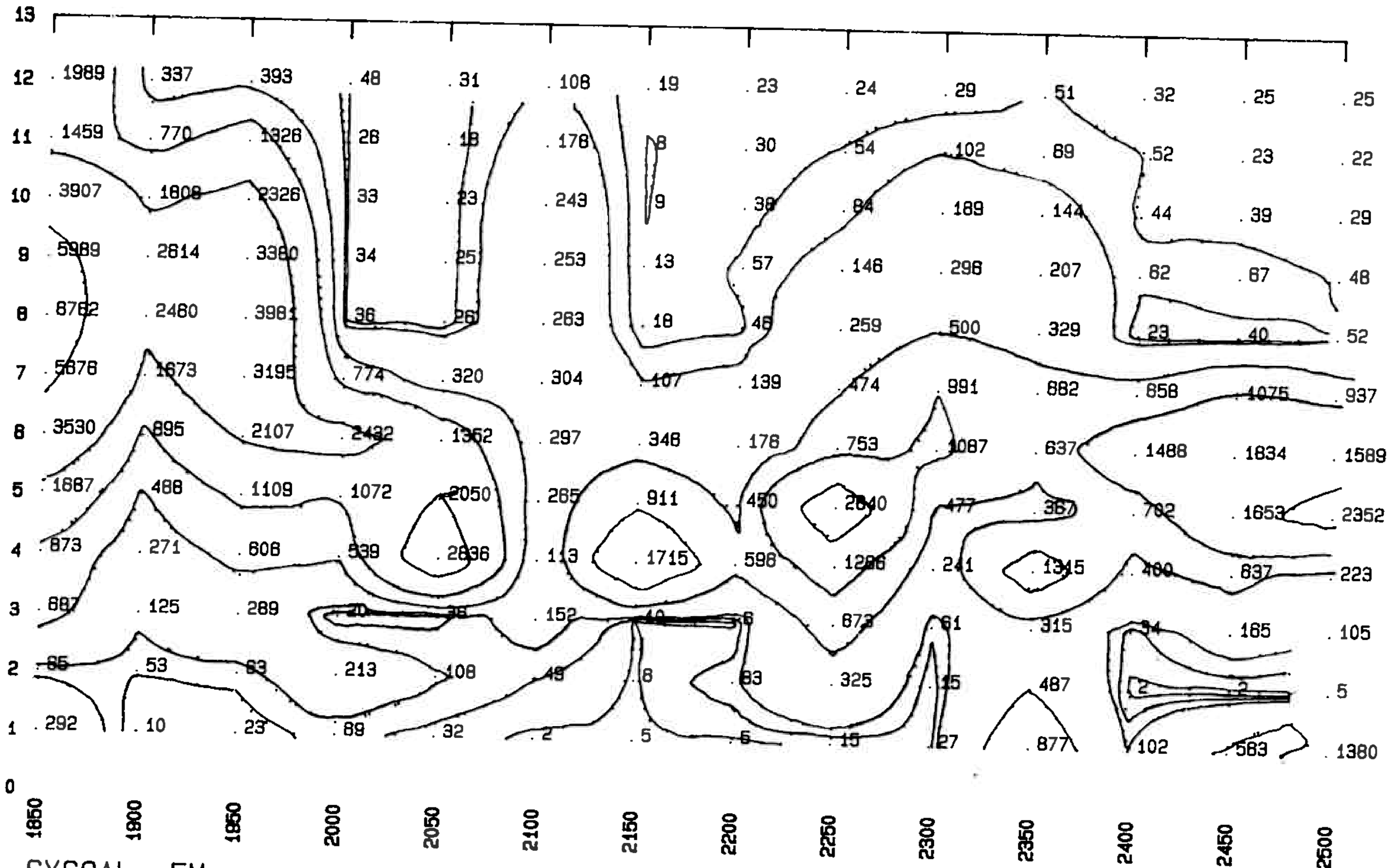
SYSCAL EM
PLOTT AV ROa'
STED: FREMSTFJELL
PROFIL: 5000E
DATO: 3.7.1985 HE/BH

Fig.5.23



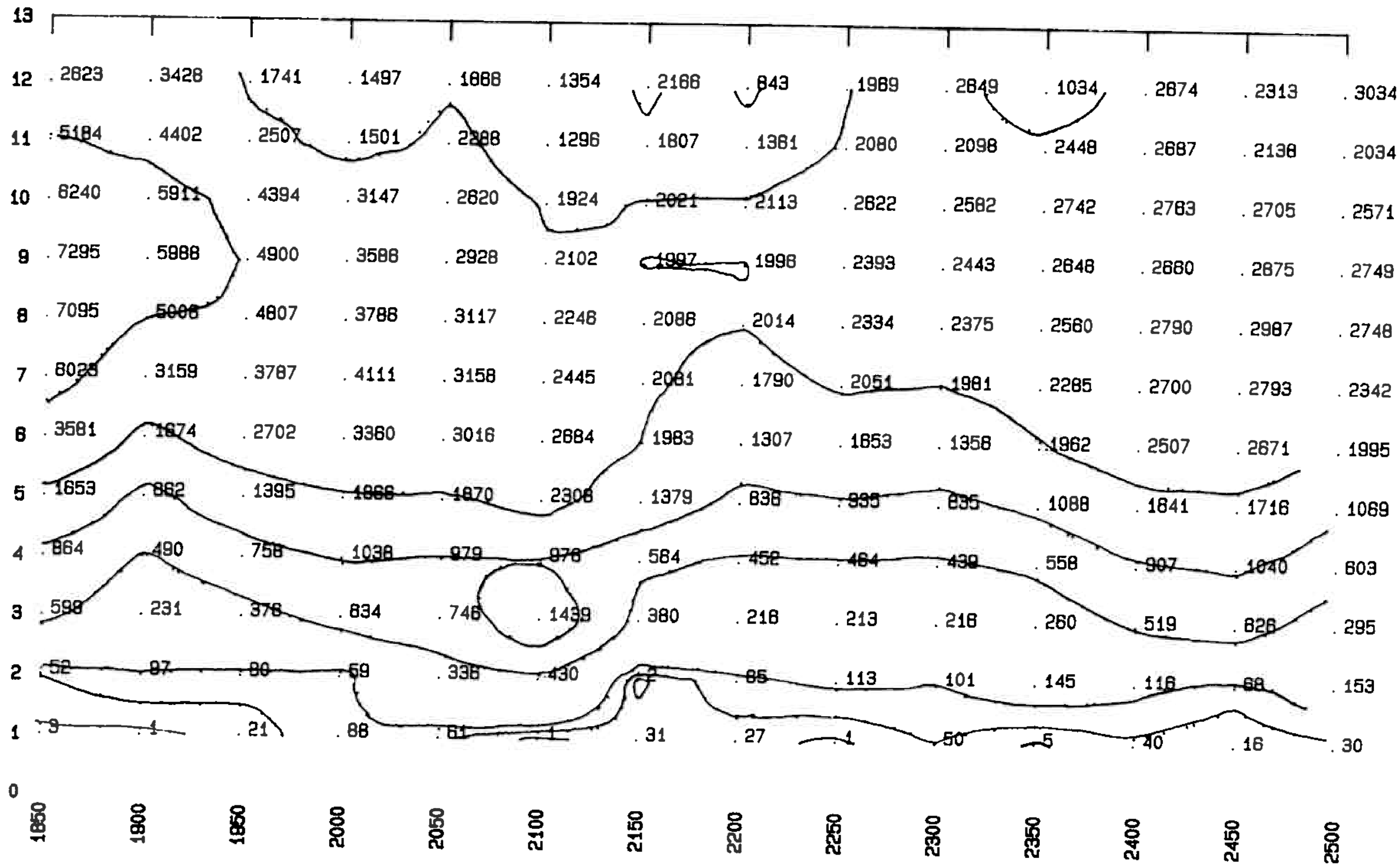
SYSCAL EM
PLOTT AV ROa''
STED: FREMSTFJELL
PROFIL: 5000E
DATO: 3.7.1985 HE/BH

Fig. 5.24



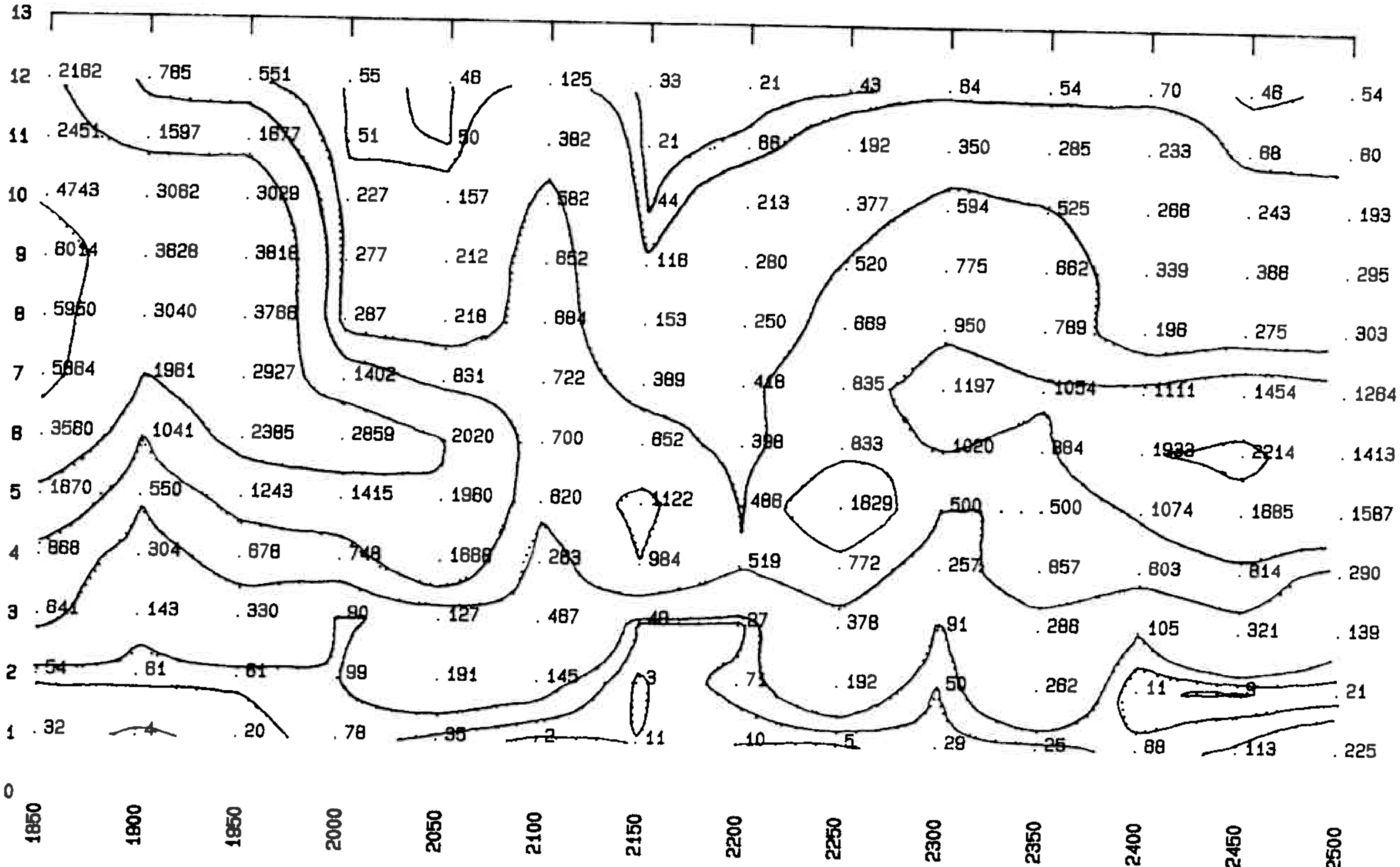
SYSCAL EM
PLOTT AV ROa
STED: FREMSTFJELL
PROFIL: 4900E
DATO: 13.7.85 HE/BH/SOR

Fig.5.25



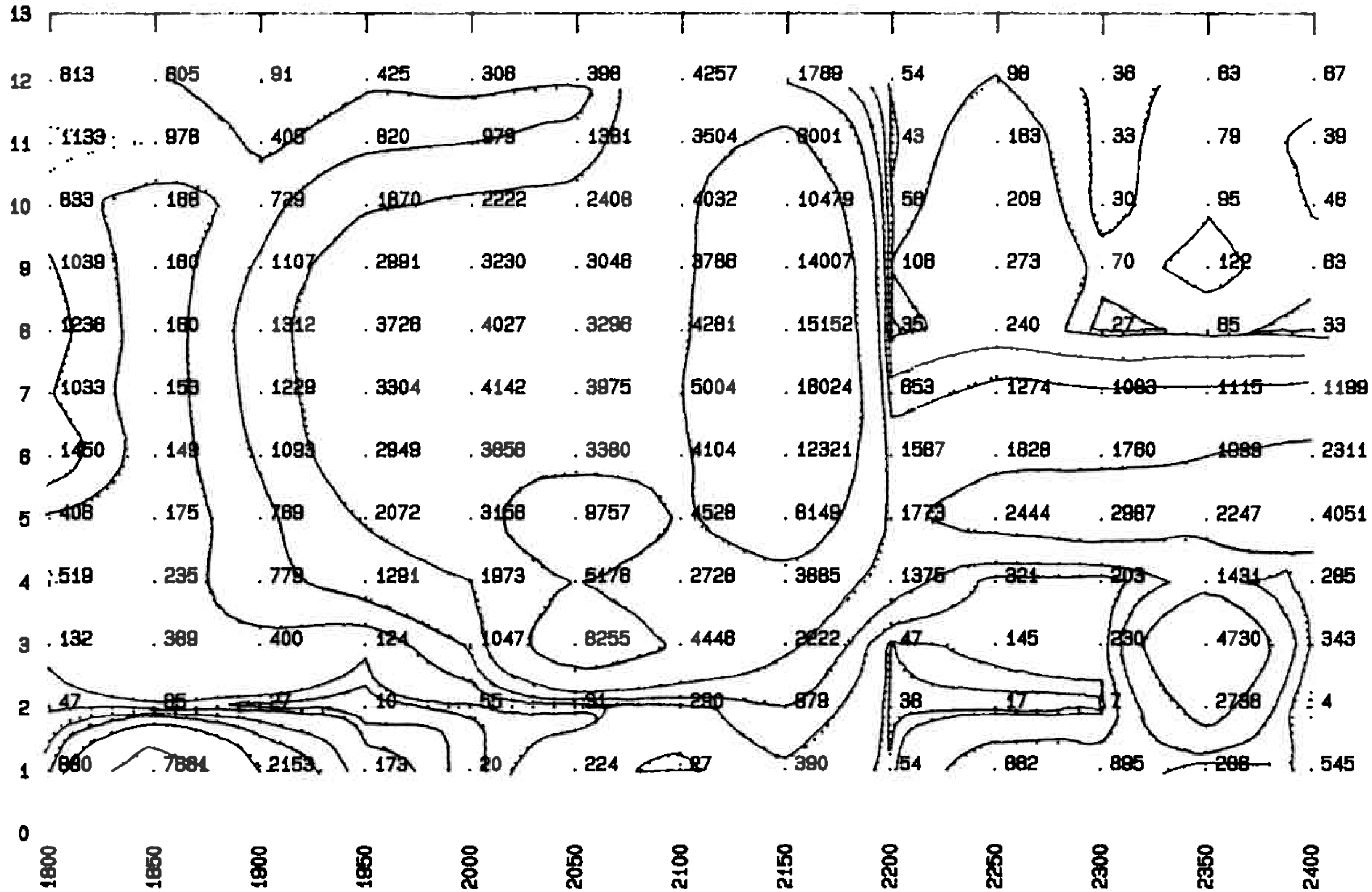
SYSCAL EM
PLOTT AV ROa'
STED: FREMSTFJELL
PROFIL: 4900E
DATO: 13.7.85 HE/BH/SOR

Fig.5.26



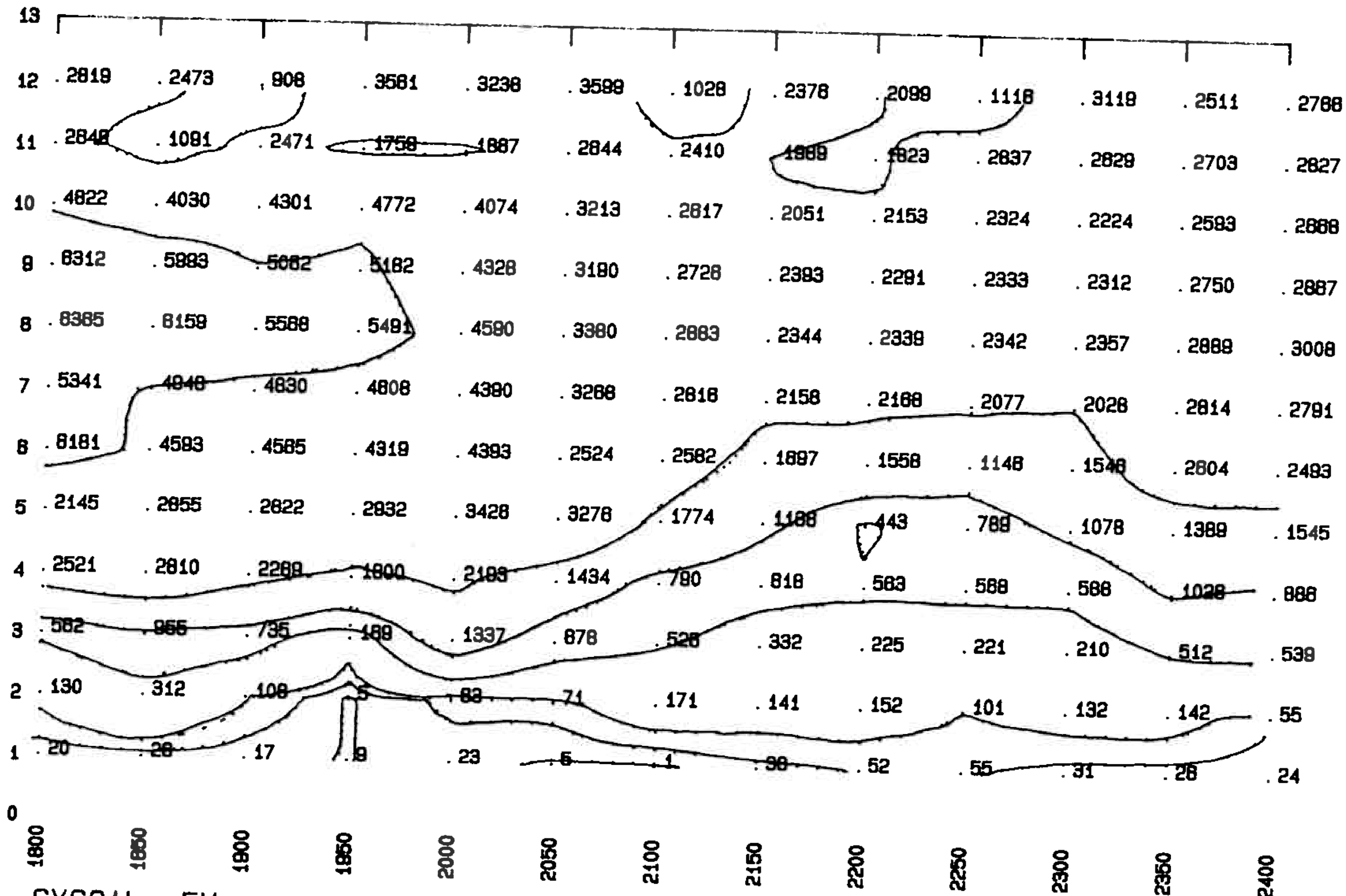
SYSCAL EM
PLOTT AV ROa''
STED: FREMSTFJELL
PROFIL: 4900E
DATO: 13.7.85 HE/BH/SOR

Fig.5.27



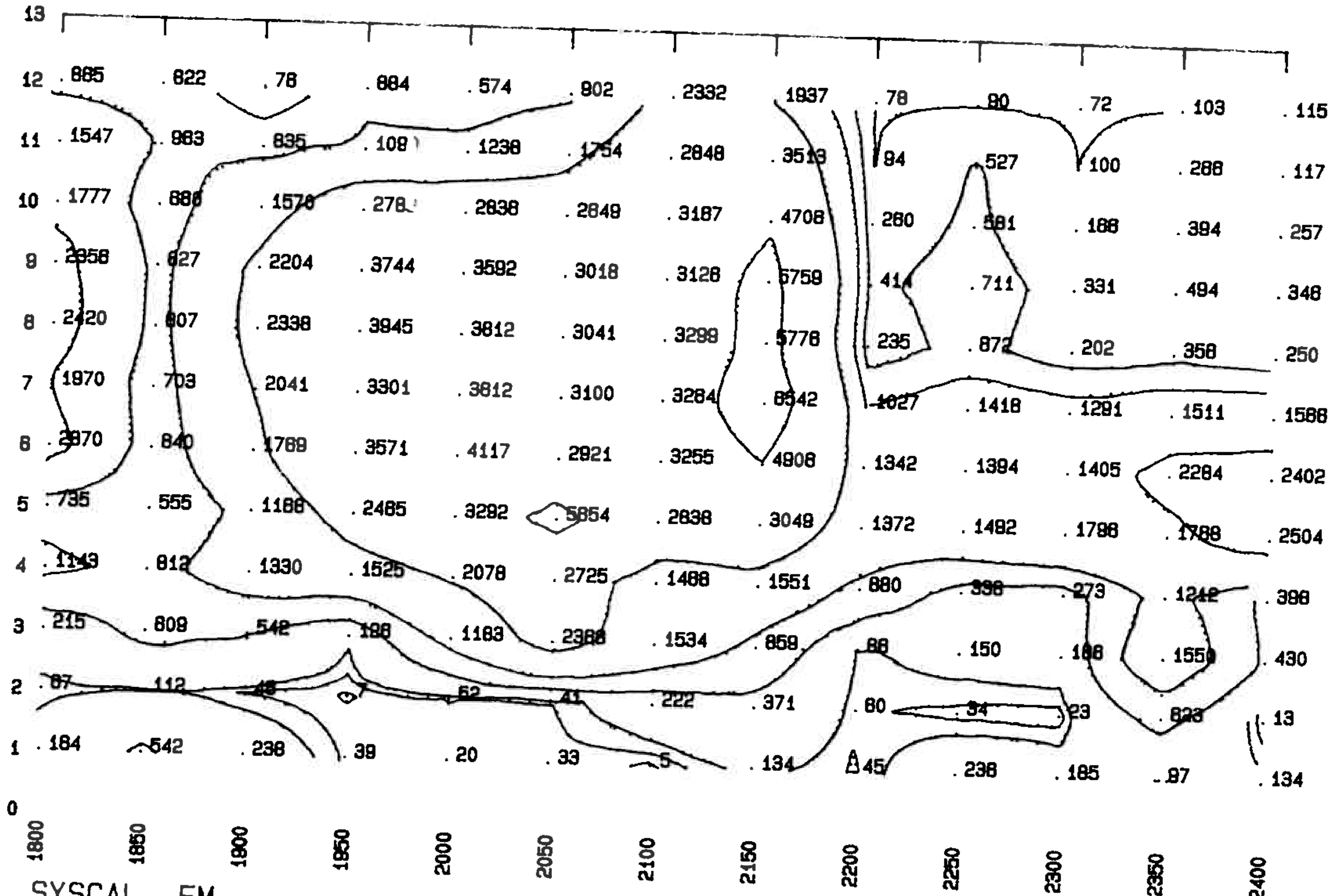
SYSCAL EM
PLOTT AV ROa
STED: FREMSTFJELL
PROFIL: 4800E
DATO: 25.7.85 HE/BH/SOR

Fig.5.28



SYSCAL EM
PLOTT AV ROa'
STED: FREMSTFJELL
PROFIL: 4800E
DATO: 25.7.85 HE/BH/SOR

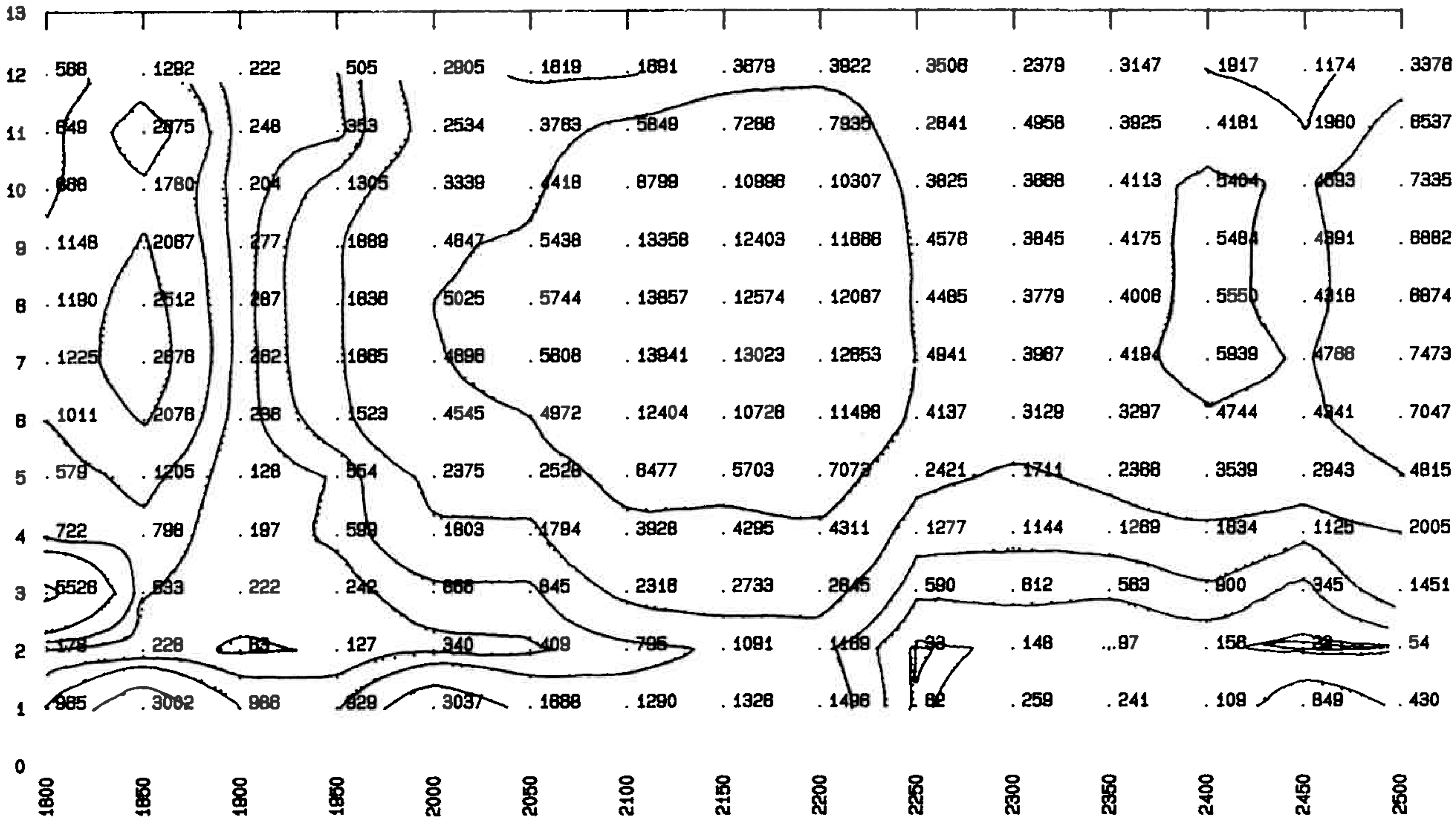
Fig.5.29



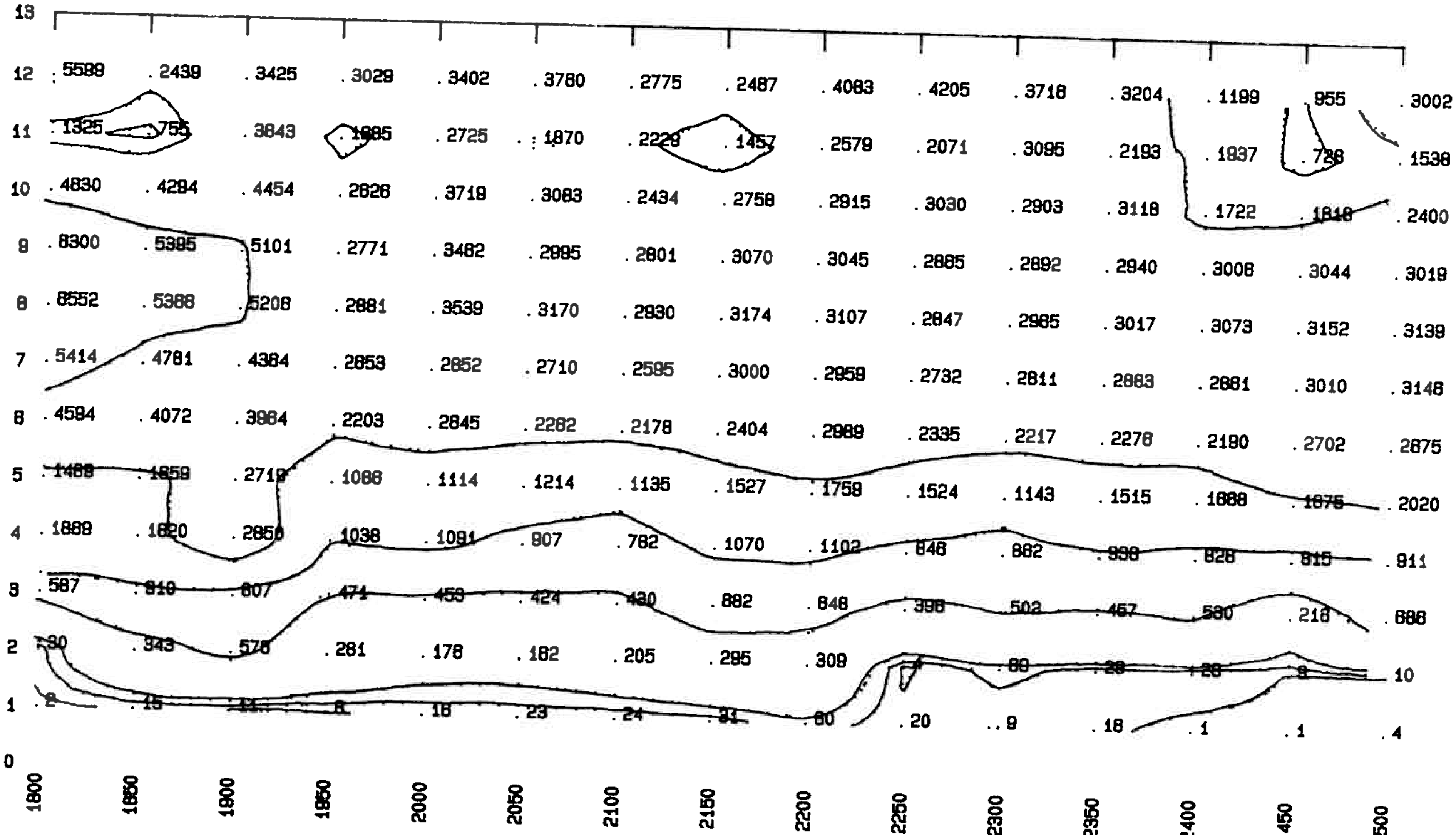
SYSCAL EM
PLOTT AV ROa''
STED: FREMSTFJELL
PROFIL: 4800E
DATO: 25.7.85 HE/BH/SOR

Fig.5.30

Fig.5.31

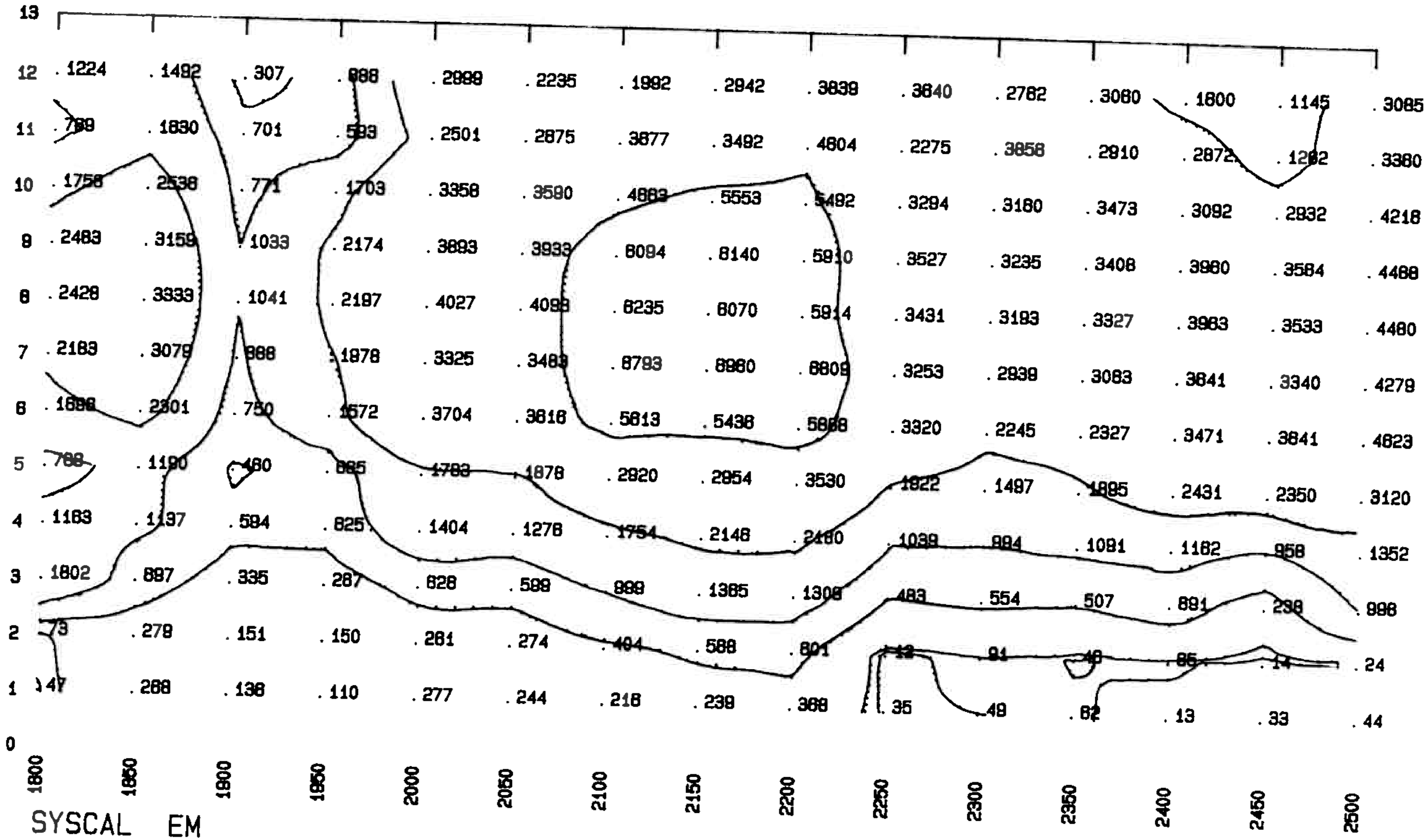


SYSCAL EM
PLOTT AV ROa
STED: FREMSTFJELL
PROFIL: 4700E
DATO: 28.7.85 HE/BH/SOR



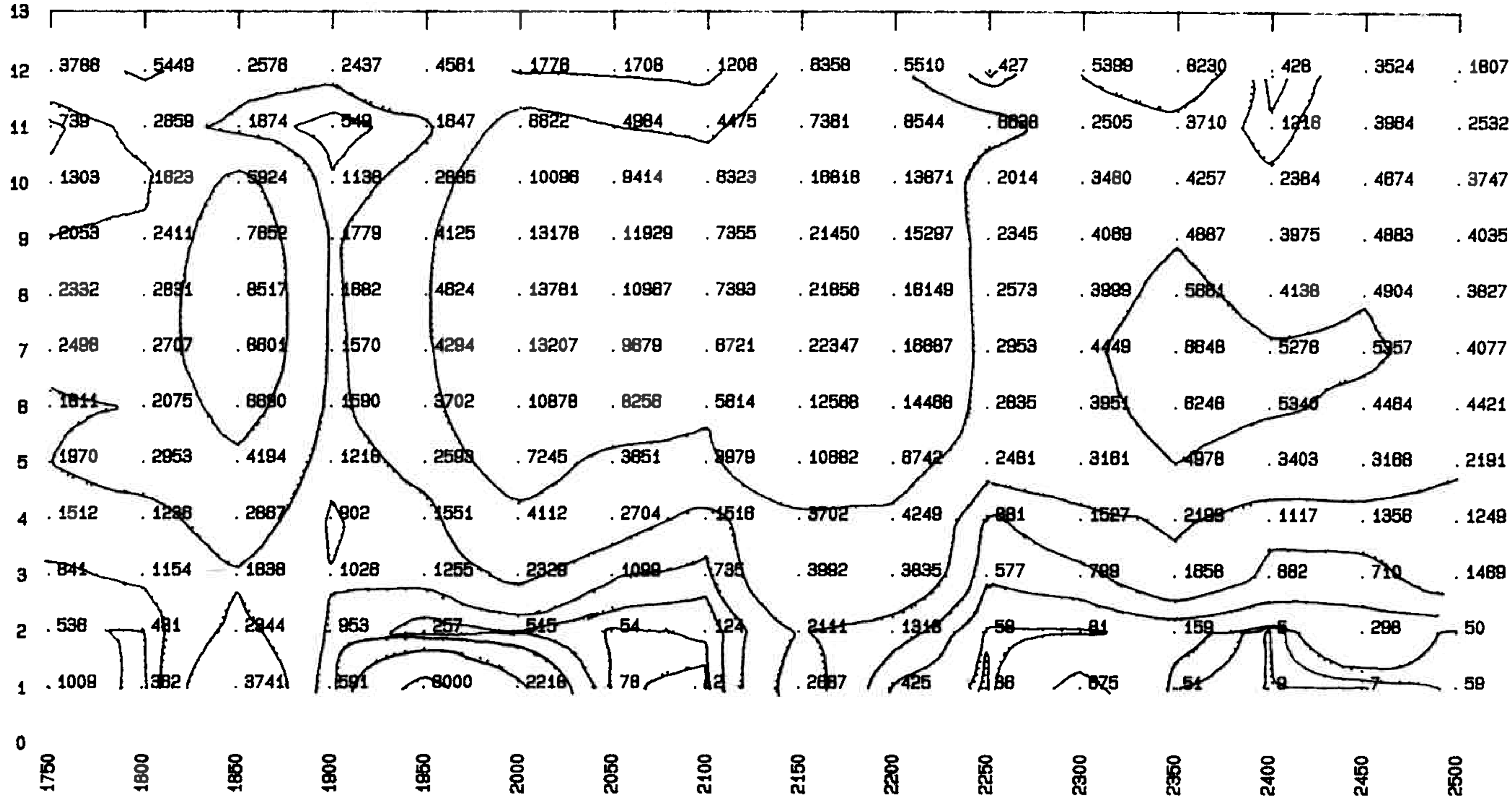
SYSCAL EM
PLOTT AV ROa'
STED: FREMSTFJELL
PROFIL: 4700E
DATO: 28.7.85 HE/BH/SOR

Fig.5.32



SYSCAL EM
PLOTT AV ROa''
STED: FREMSTFJELL
PROFIL: 4700E
DATO: 28.7.85 HE/BH/SOR

Fig.5.33



SYSCAL EM

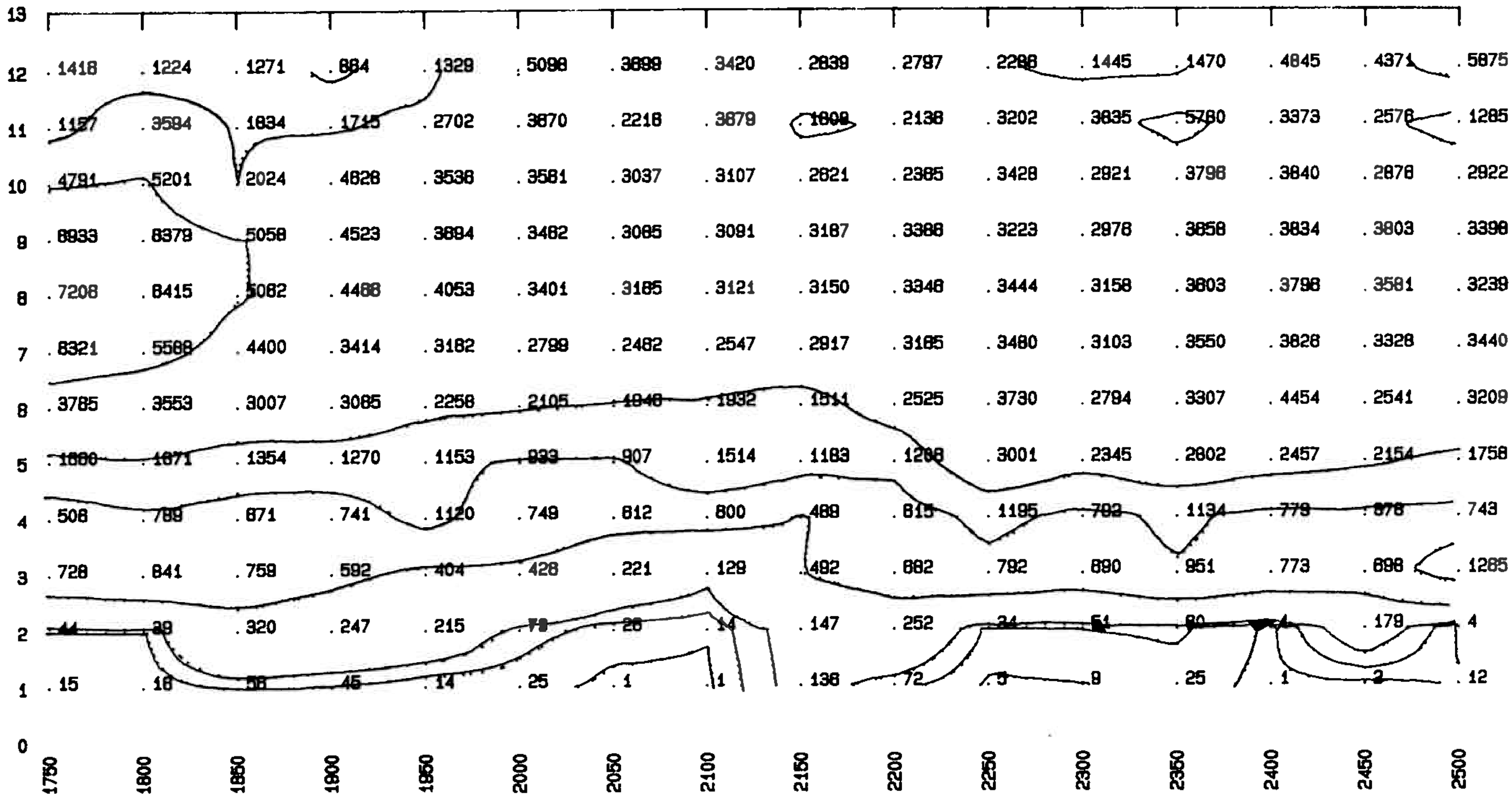
PLOTT AV ROa

STED: FREMSTFJELL

PROFIL: 4600E

DATO: 29.7.85 HE/BH/SOR

Fig.5.34



SYSCAL EM
PLOTT AV ROa'
STED: FREMSTFJELL
PROFIL: 4600E
DATO: 29.7.85 HE/BH/SOR

Fig.5.35

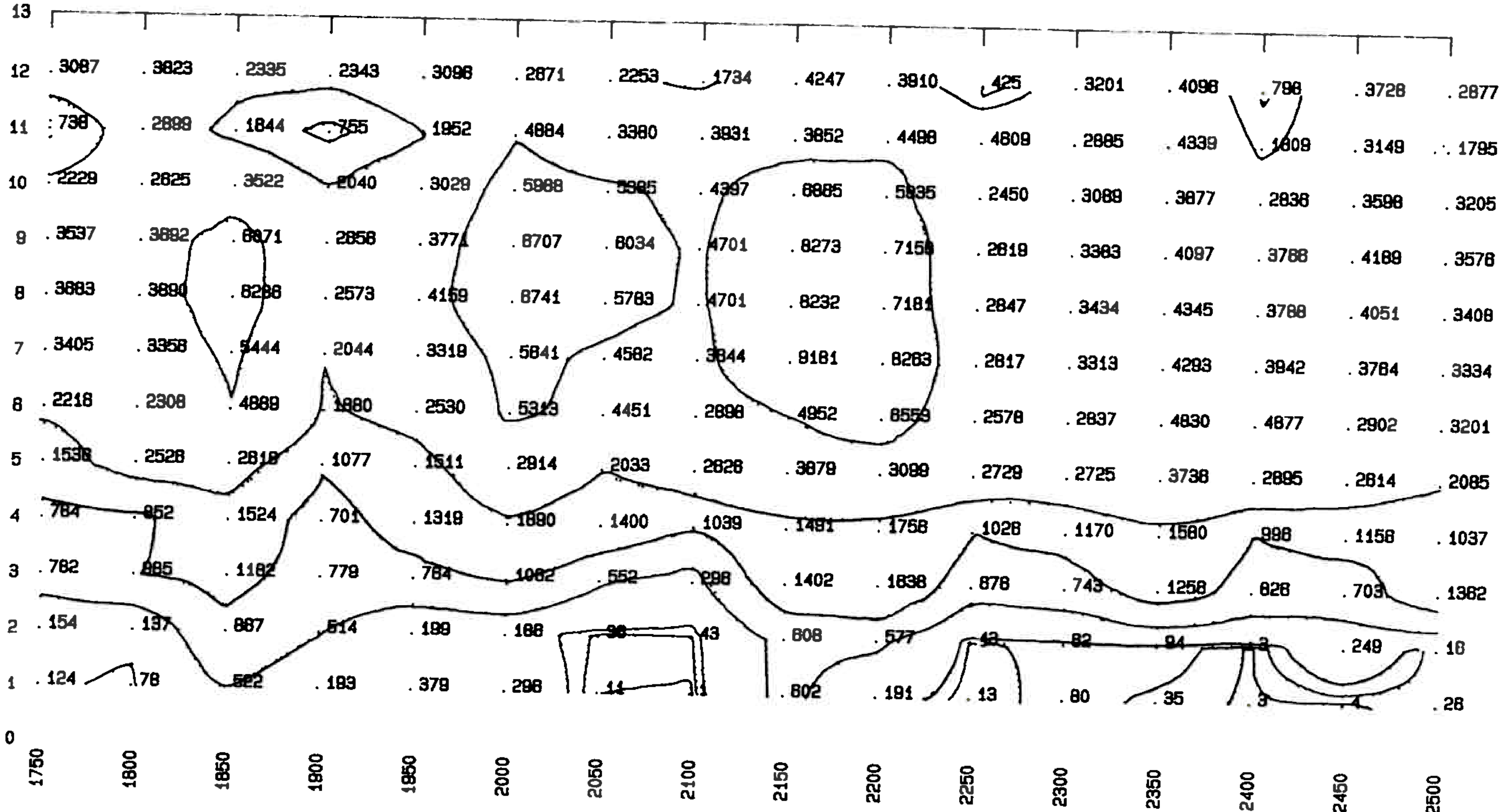


Fig.5.36

SYSCAL EM
PLOTT AV ROa''
STED: FREMSTFJELL
PROFIL: 4600E
DATO: 29.7.85 HE/BH/SOR

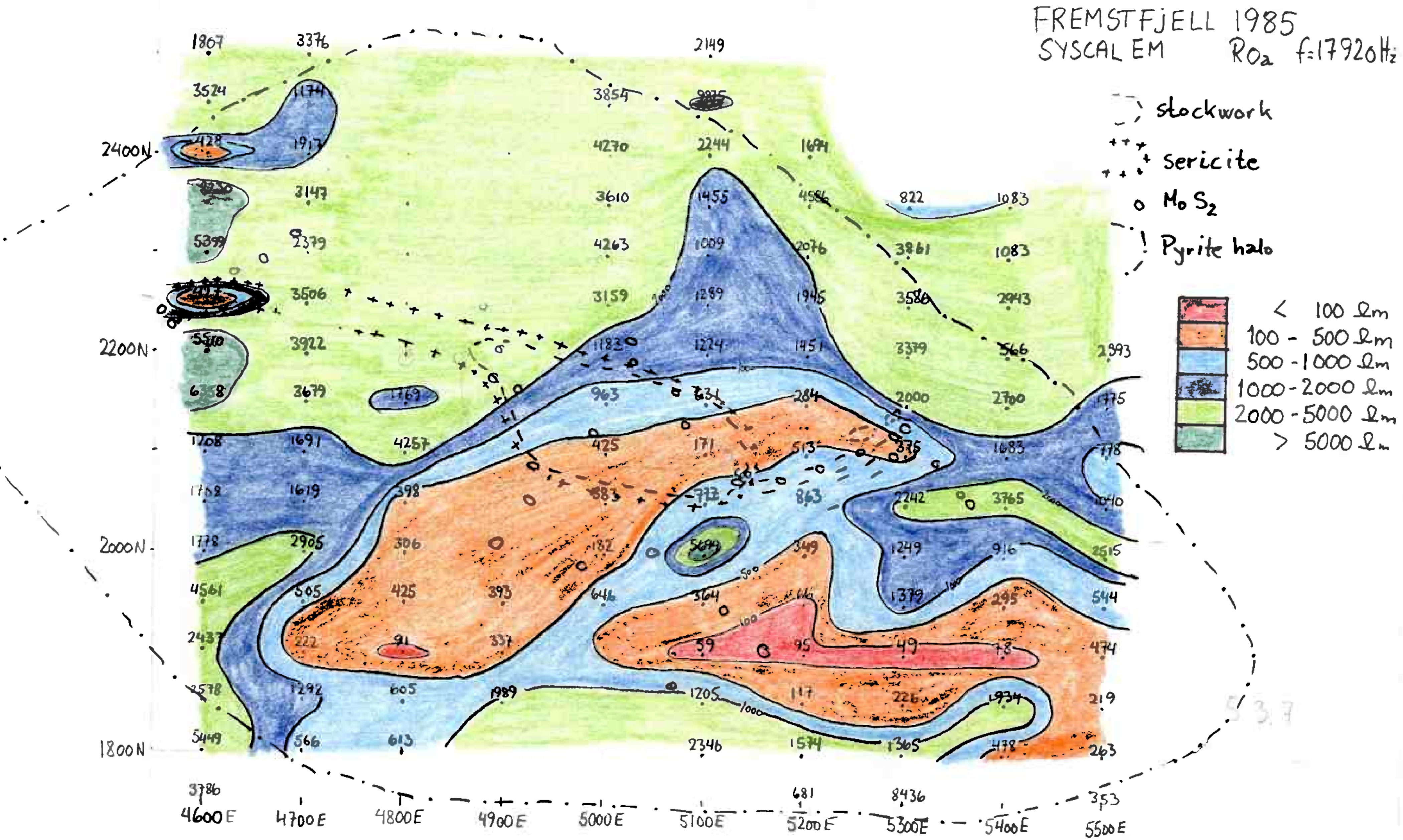

FREMSTFJELL 1985
SYSCAL EM
ROa f:17920Hz
stockwork
sericite
MoS_2
Pyrite halo
< 100 Ωm
100 - 500 Ωm
500 - 1000 Ωm
1000 - 2000 Ωm
2000 - 5000 Ωm
> 5000 Ωm
2400N
2200N
2000N
1800N
4600E
4700E
4800E
4900E
5000E
5100E
5200E
5300E
5400E
5500E

Fig. 5.37

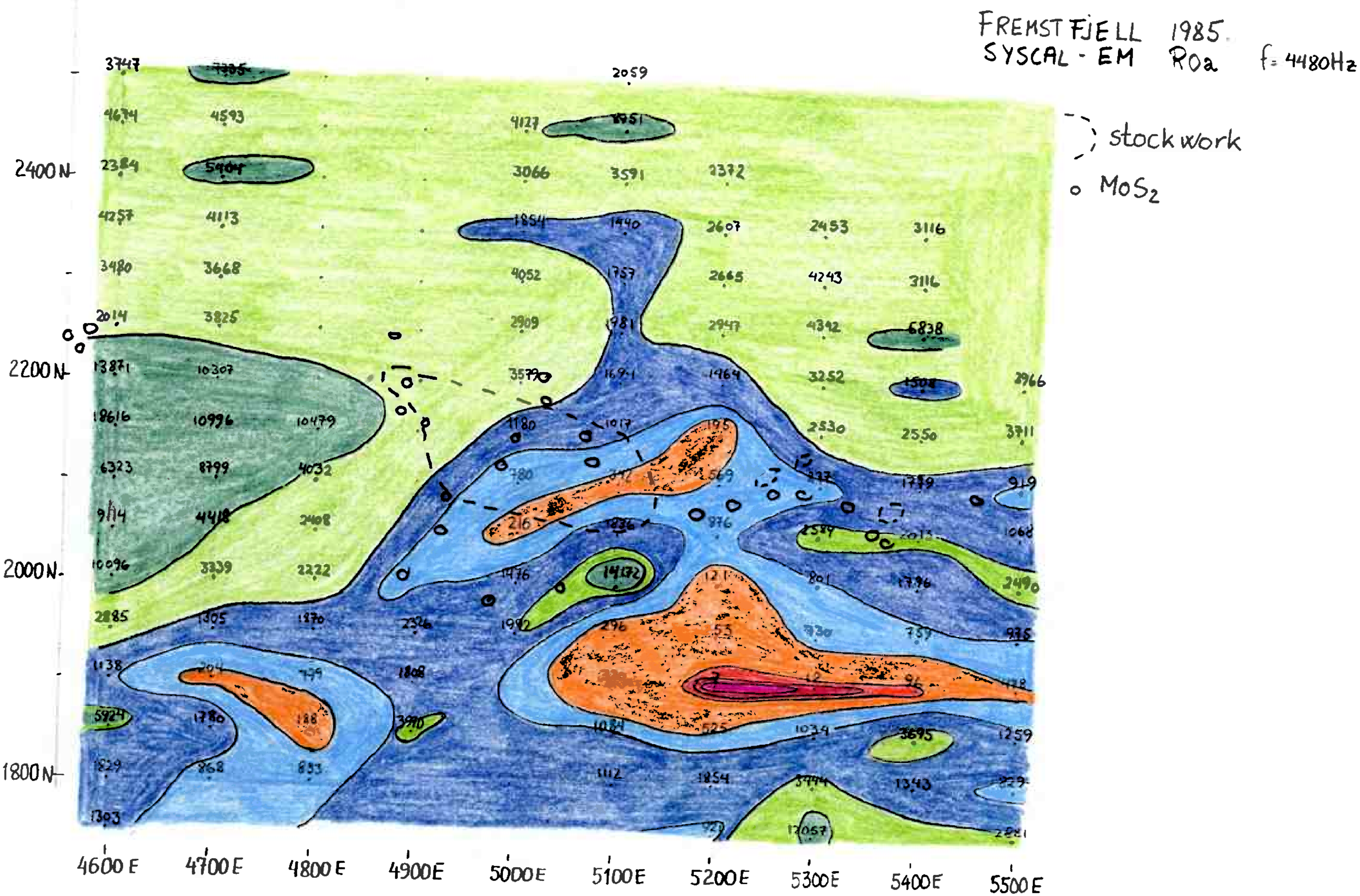

FREMSTFJELL 1985
SYSCAL - EM ROa f= 4480Hz
stockwork
MoS_2
2400N
2200N
2000N
1800N
4600E
4700E
4800E
4900E
5000E
5100E
5200E
5300E
5400E
5500E

Fig. 5.38

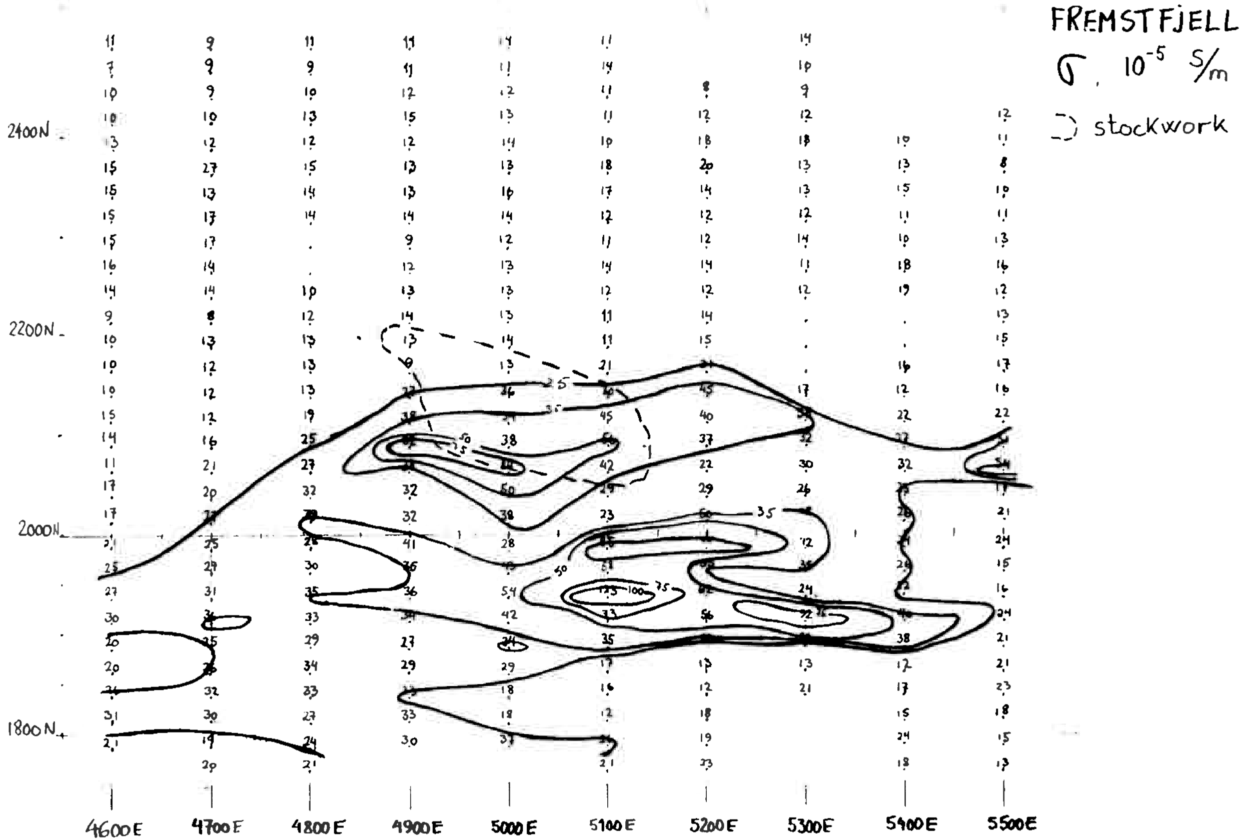
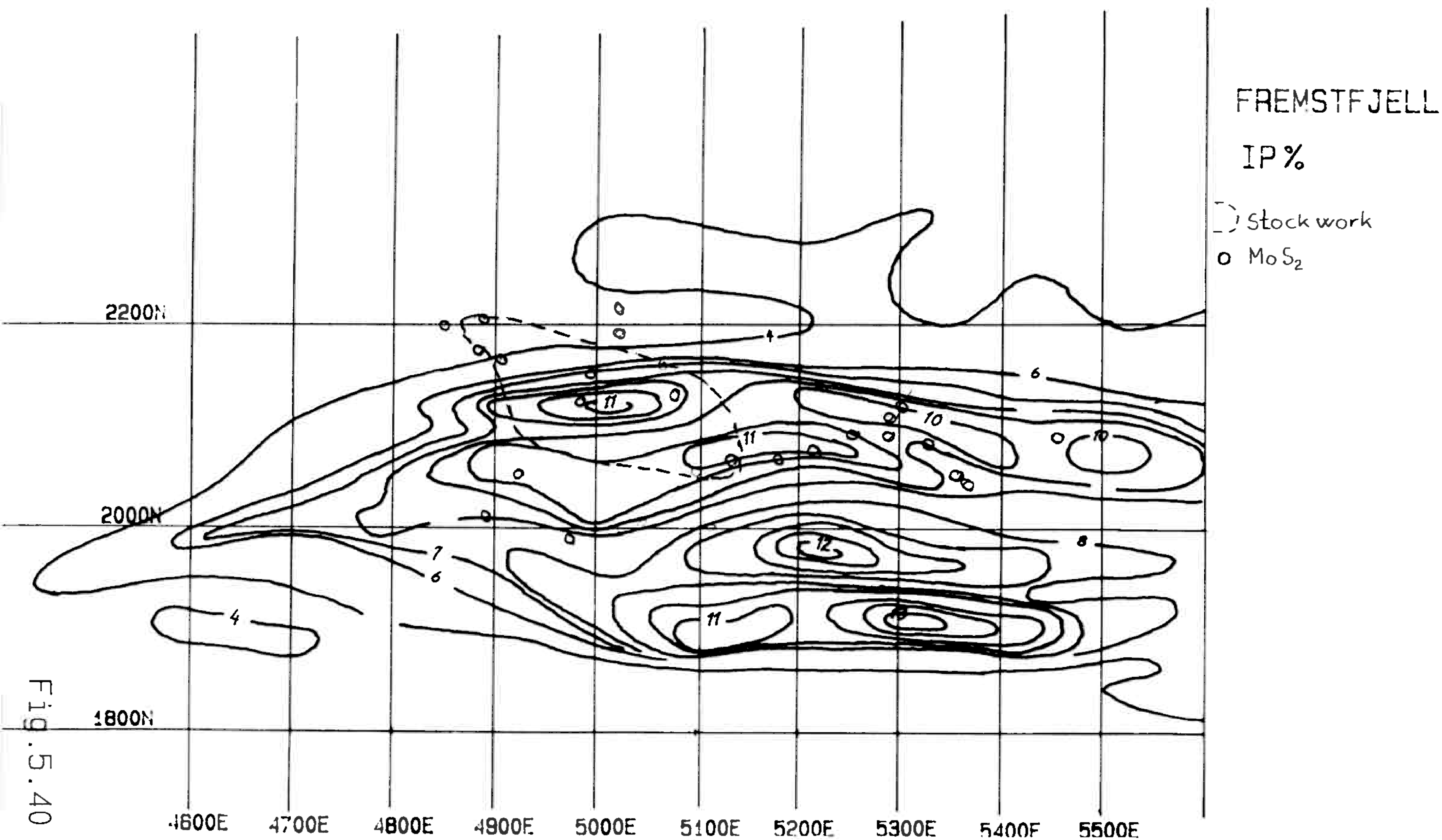
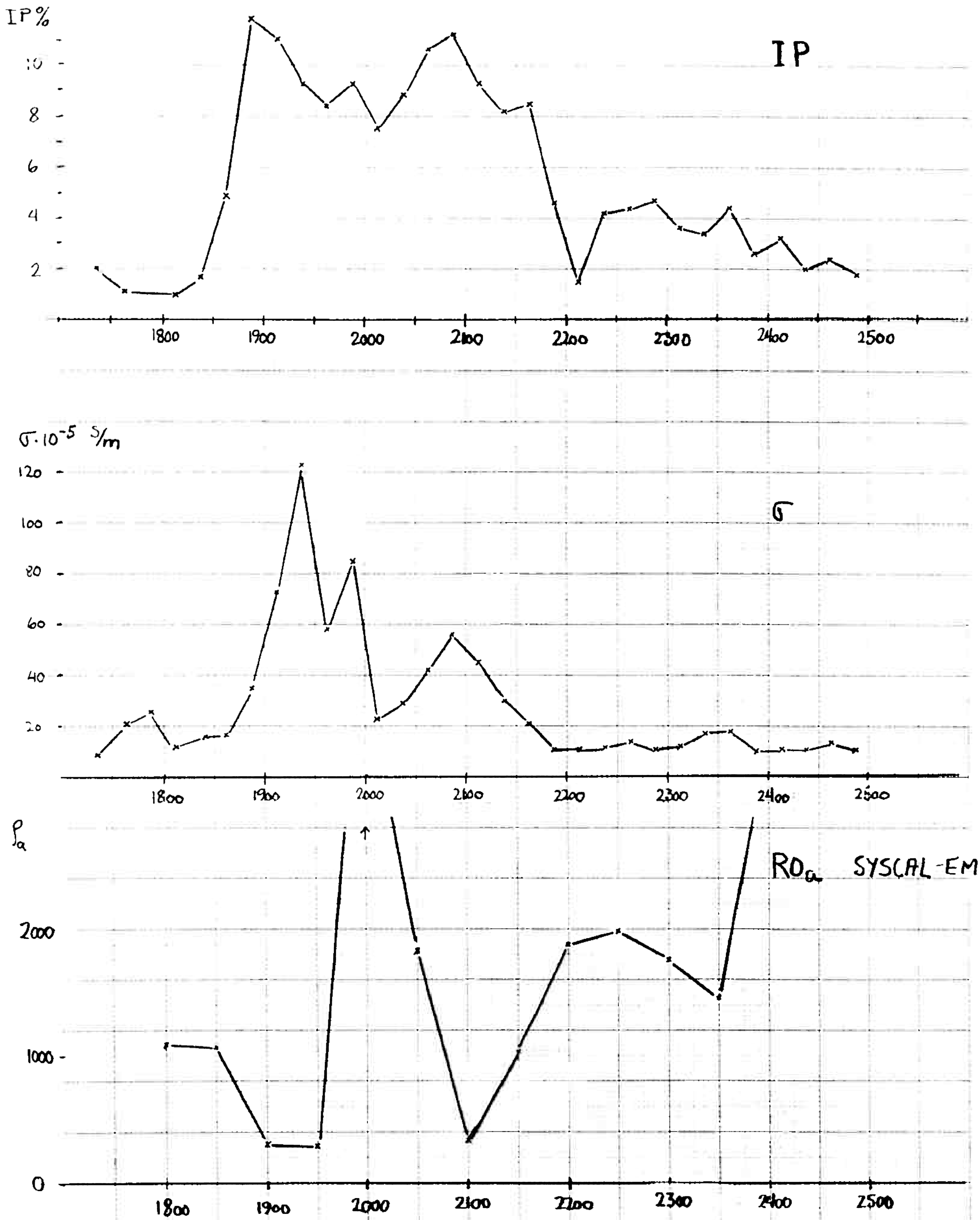

FREMSTFJELL
σ, 10⁻⁵ S/m
stockwork
2400N
2200N
2000N
1800N
4600E
4700E
4800E
4900E
5000E
5100E
5200E
5300E
5400E
5500E

Fig.5.39



FREMSTFJELL
IP%
Stock work
o MoS_2
2200N
2000N
1800N
4600E
4700E
4800E
4900E
5000E
5100E
5200E
5300E
5400E
5500E
4
6
7
8
10
11
12

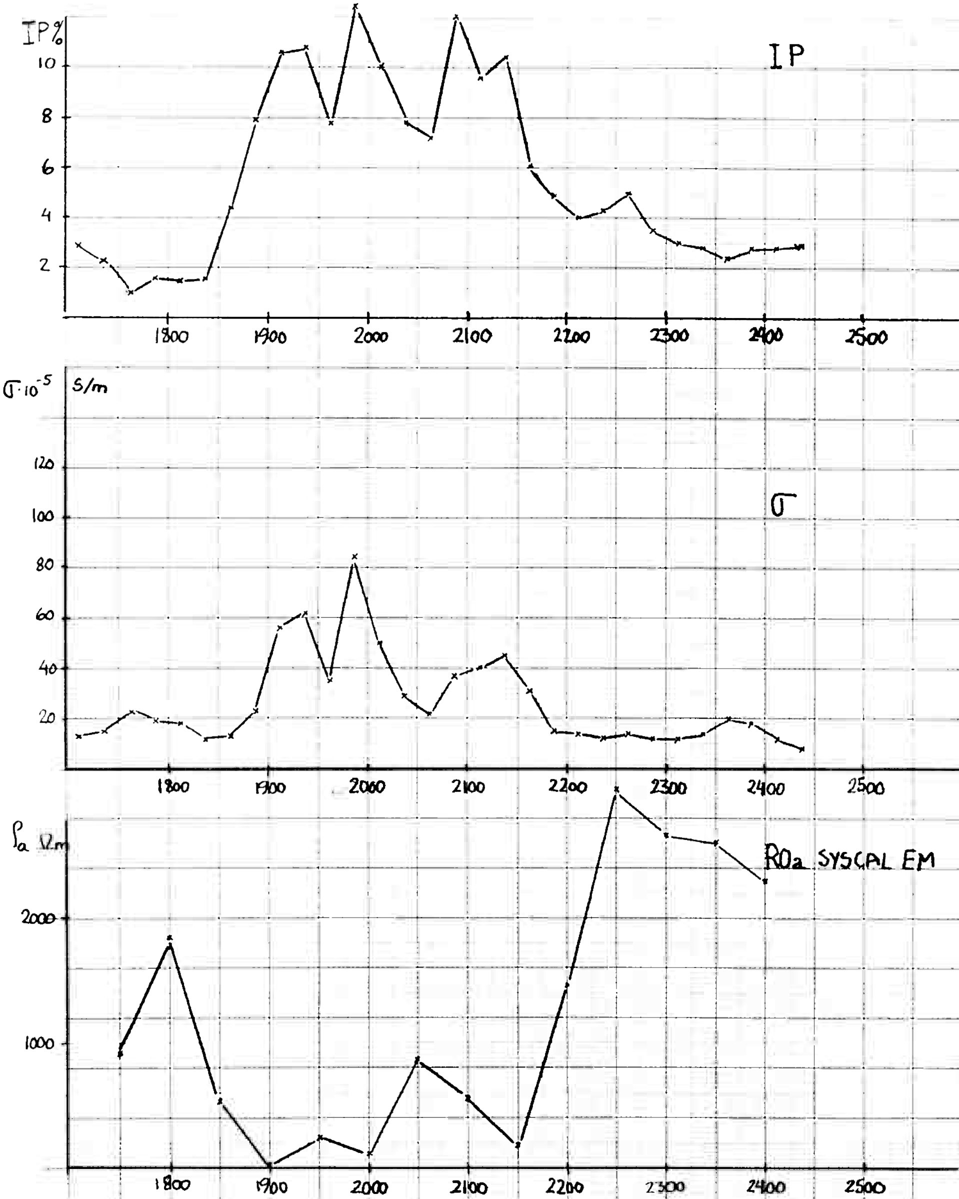
Fig. 5.40



FREMSTFJELL

PROFIL 5100 E

Fig.5.41



FREMSTFJELL

PROFIL 5200E

Fig.5.42

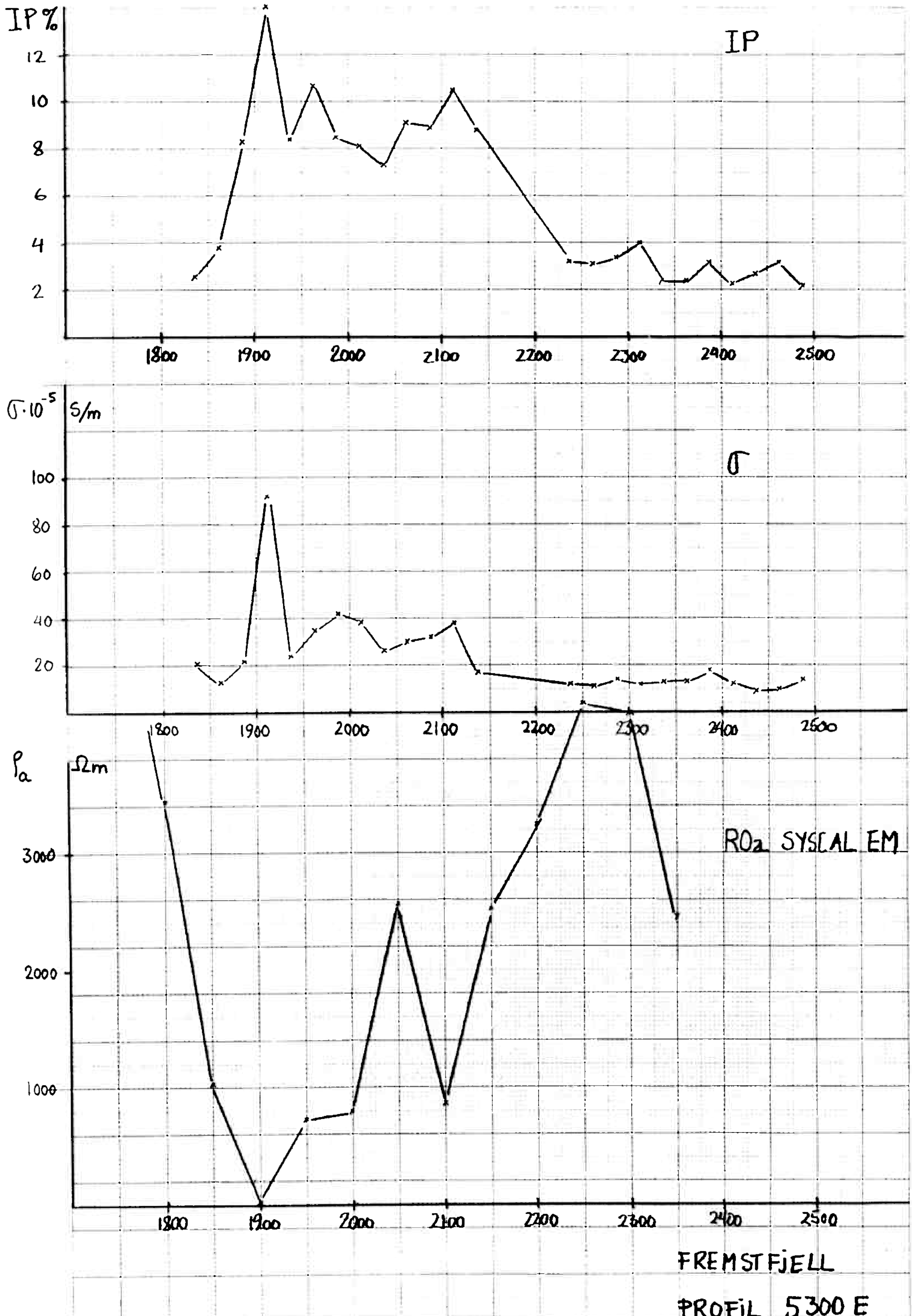
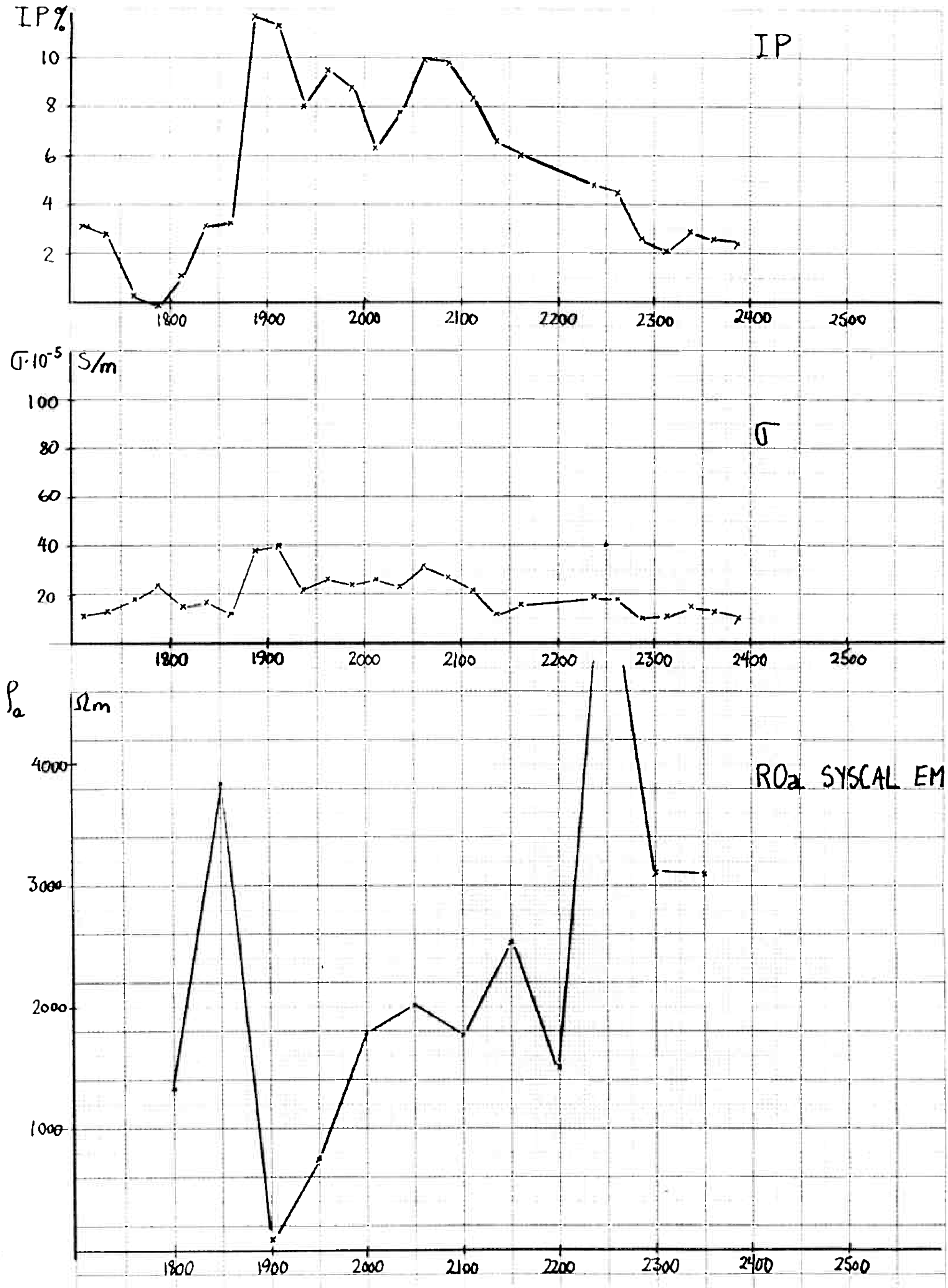

IP%
12
10
8
6
4
2
IP
1800
1900
2000
2100
2200
2300
2400
2500
σ·10⁻⁵ S/m
100
80
60
40
20
σ
1800
1900
2000
2100
2200
2300
2400
2500
ρa Ωm
3000
2000
1000
ROa SYSCAL EM
1800
1900
2000
2100
2200
2300
2400
2500
FREMSTFJELL
PROFIL 5300 E

Fig.5.43



FREMSTFJELL

PROFIL 5400 E

Fig.5.44

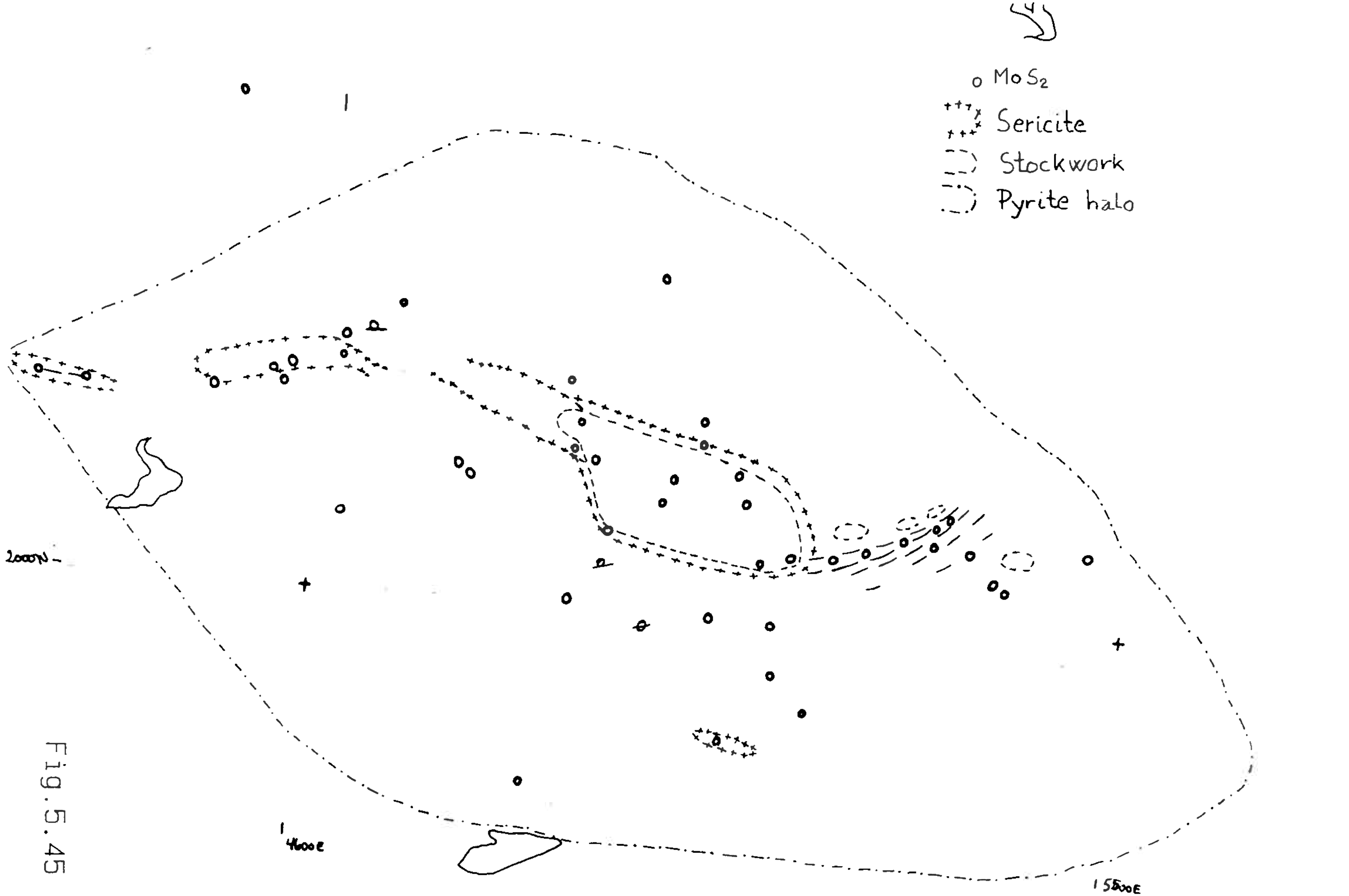


Fig.5.45

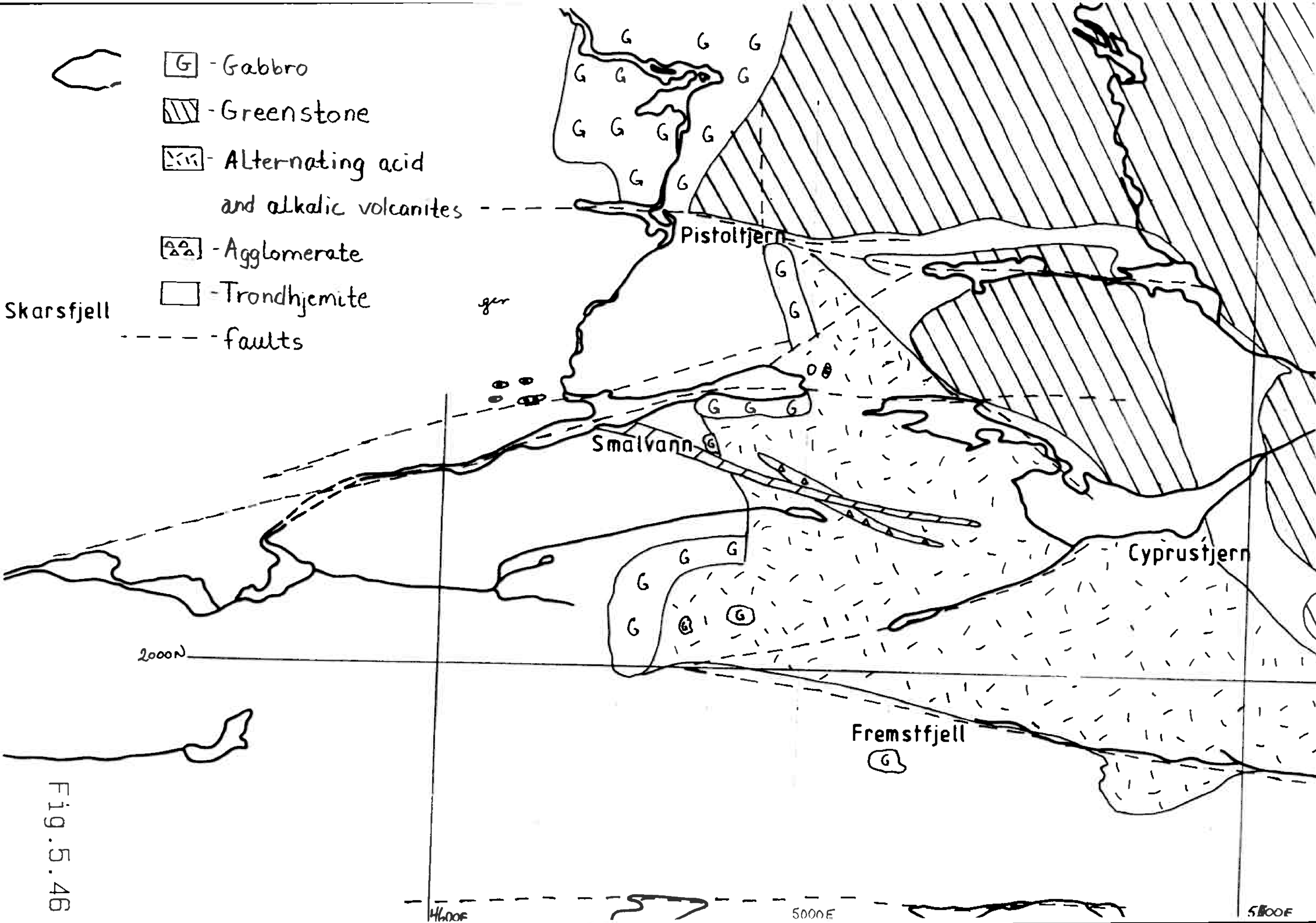
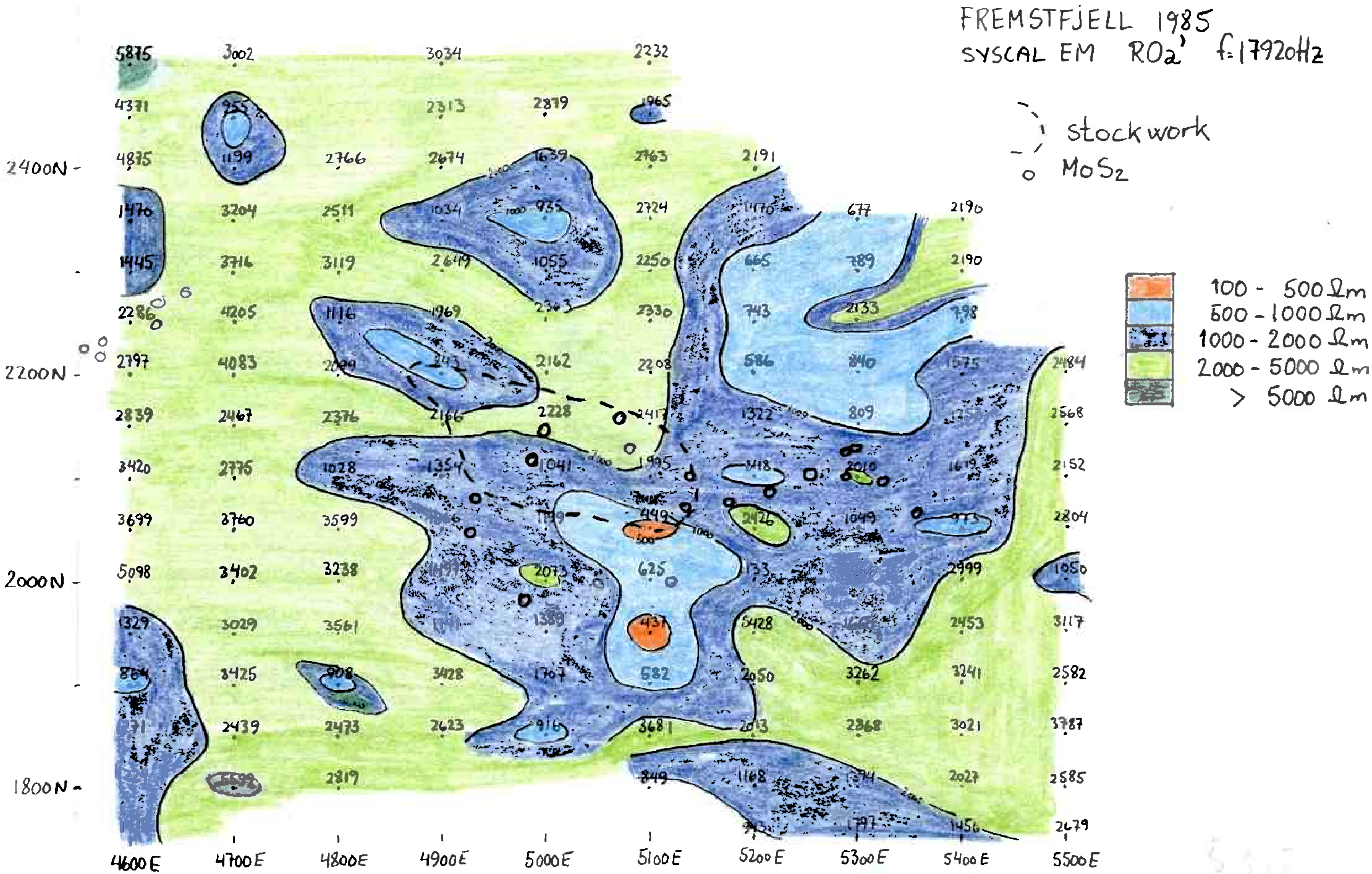

G - Gabbro
- Greenstone
- Alternating acid and alkalic volcanites
- Agglomerate
- Trondhjemite
- - - - - faults
Skarsfjell
Pistoltjern
Smalvann
Cyprustjern
Fremstfjell
2000N
4600E
5000E

Fig.5.46



FREMSTFJELL 1985
SYSCAL EM RO2' f=17920Hz
stockwork
MoS2
100 - 500 Ωm
500 - 1000 Ωm
1000 - 2000 Ωm
2000 - 5000 Ωm
> 5000 Ωm
2400N
2200N
2000N
1800N
4600E
4700E
4800E
4900E
5000E
5100E
5200E
5300E
5400E
5500E

Fig. 5.47

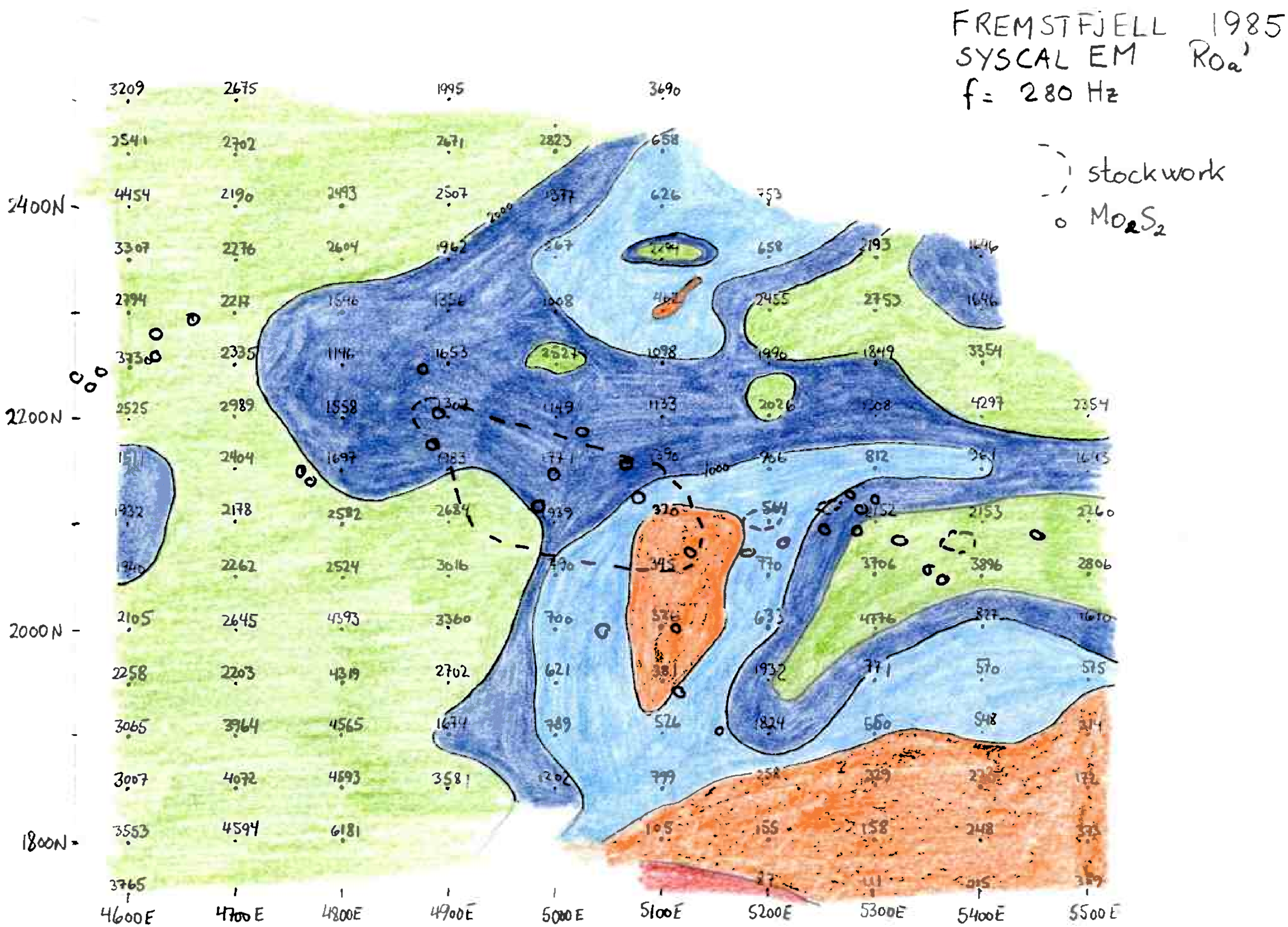

FREMSTFJELL 1985
SYSCAL EM Roa'
f= 280 Hz
stockwork
Mo_2S_2
2400N
2200N
2000N
1800N
4600E
4700E
4800E
4900E
5000E
5100E
5200E
5300E
5400E
5500E

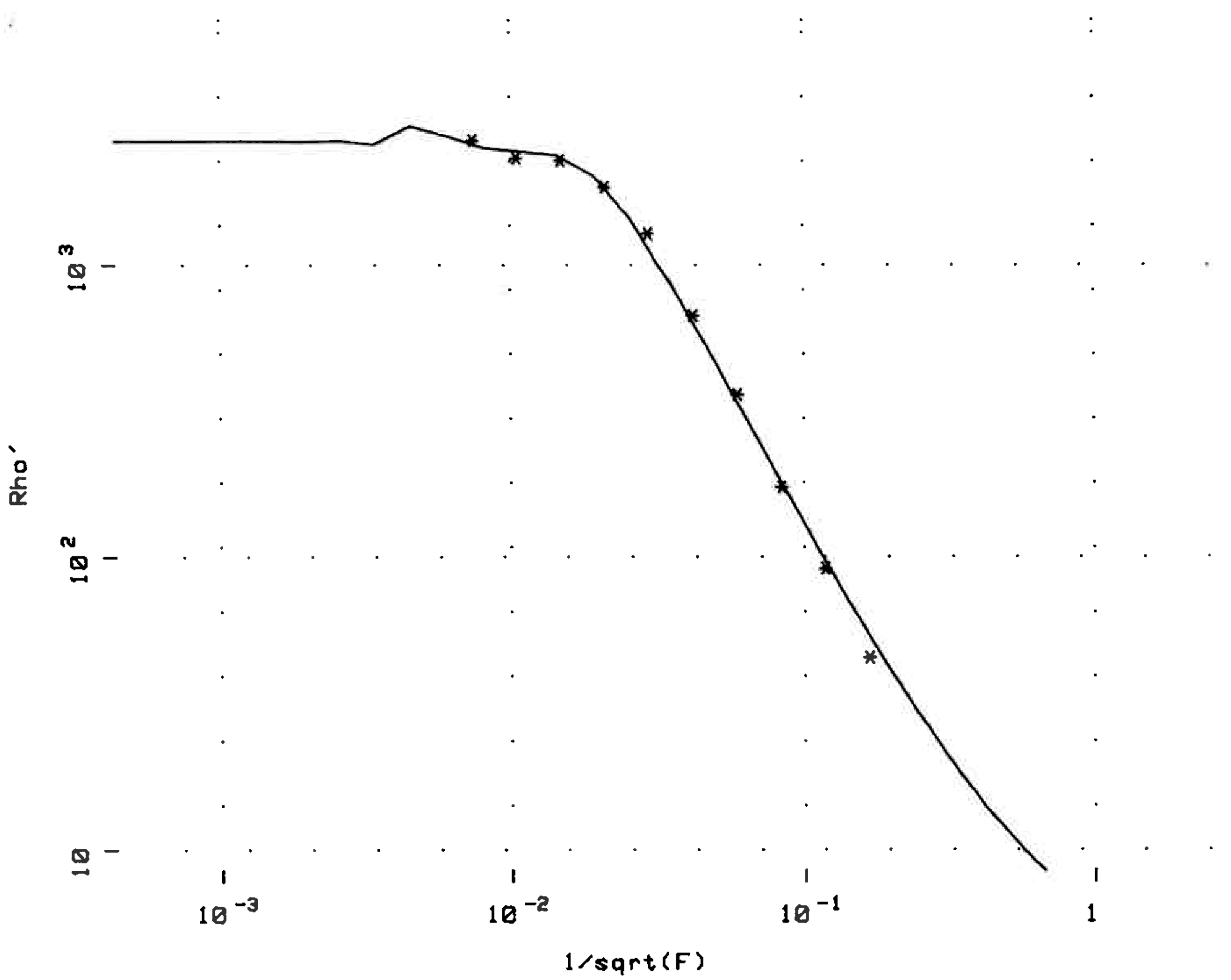
Fig. 5.48

NORGES TEKNISKE HØGSKOLE

FREMSTFJELL 1985 5500E

Resistivity (ohm.m)	Depth (m)
oo	
1----------------------	0.000
2700.000	
2----------------------	229.642
10.000	
3----------------------	230.621
2000.000	
4----------------------	340.550
1.000	

1750N



* BRGM/GPH * MELOSI *

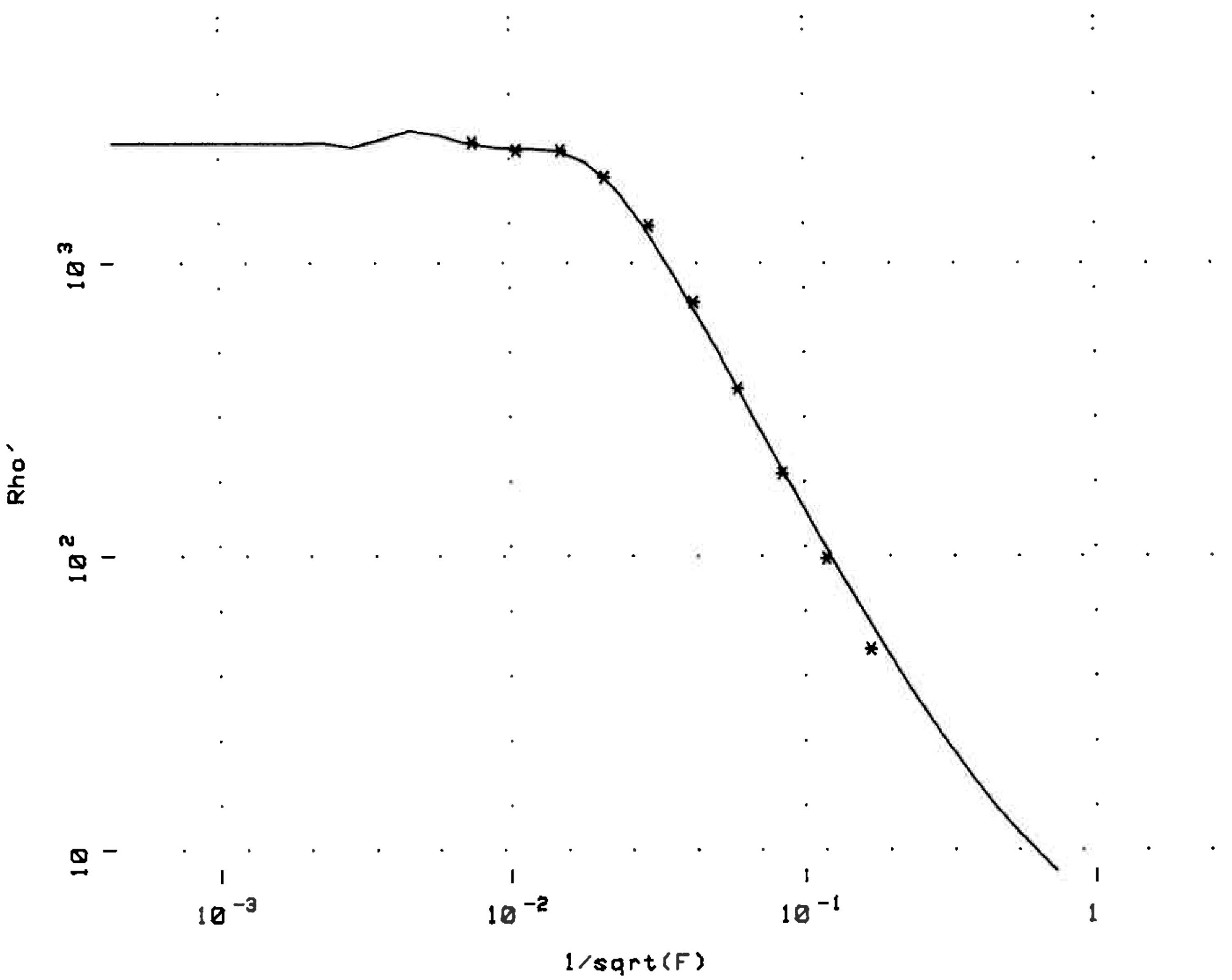
Fig.5.49

NORGES TEKNISKE HØGSKOLE

FREMSTFJELL 1985 5500E

	Resistivity (ohm.m)	Depth (m)
	oo	
1		0.000
	2800.000	
2		240.000
	10.000	
3		241.000
	2000.000	
4		350.000
	1.000	

1800N



* BRGM/GPH * MELOSI *

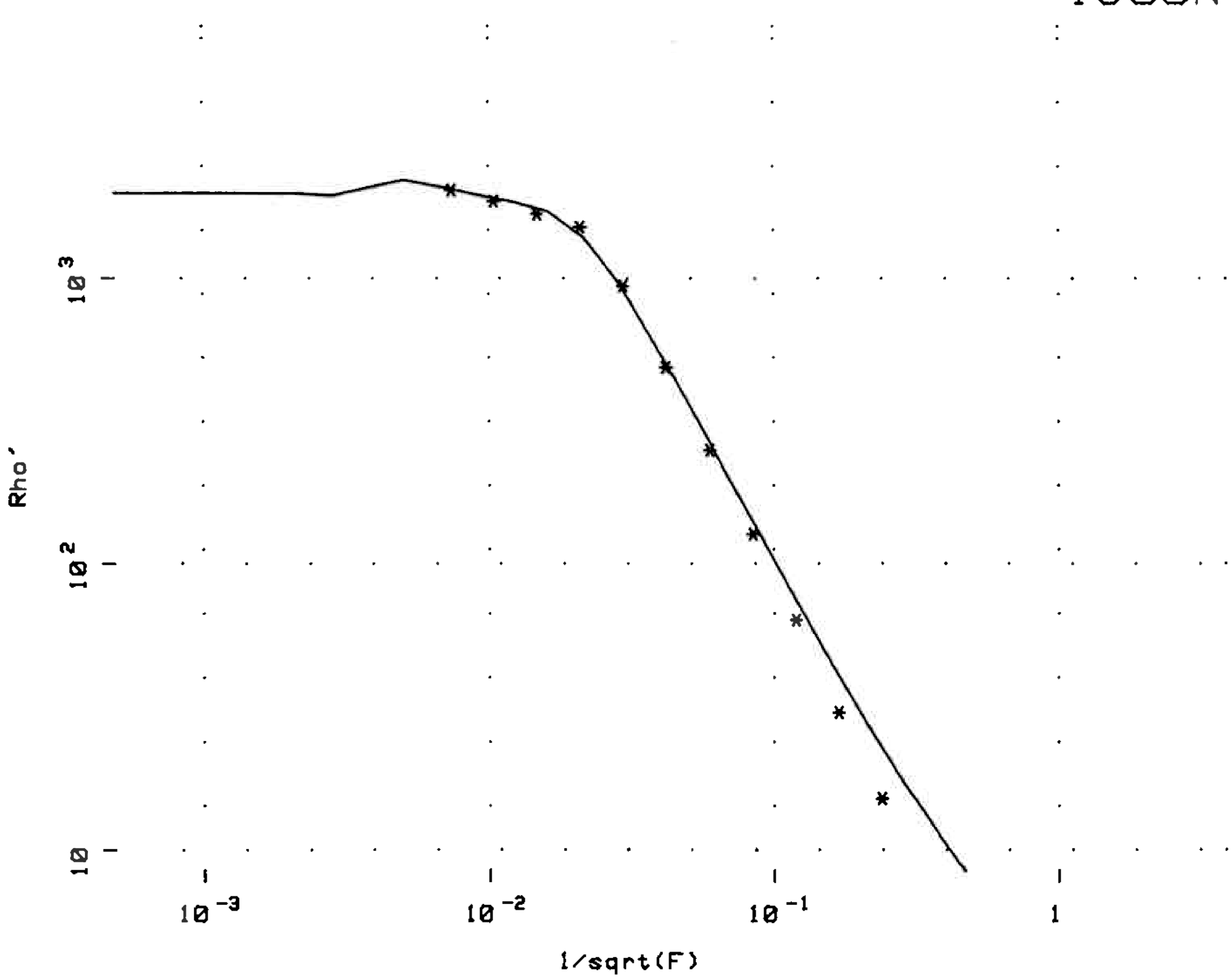
Fig.5.50

NORGES TEKNISKE HØGSKOLE

FREMSTFJELL 1985   5400E

Resistivity (ohm.m)	Depth (m)
oo	
1---------------------	0.000
2000.000	
2---------------------	220.000
10.000	
3---------------------	222.000
2000.000	
4---------------------	300.000
.500	

1800N



* BRGM/GPH * MELOSI *

Fig.5.51

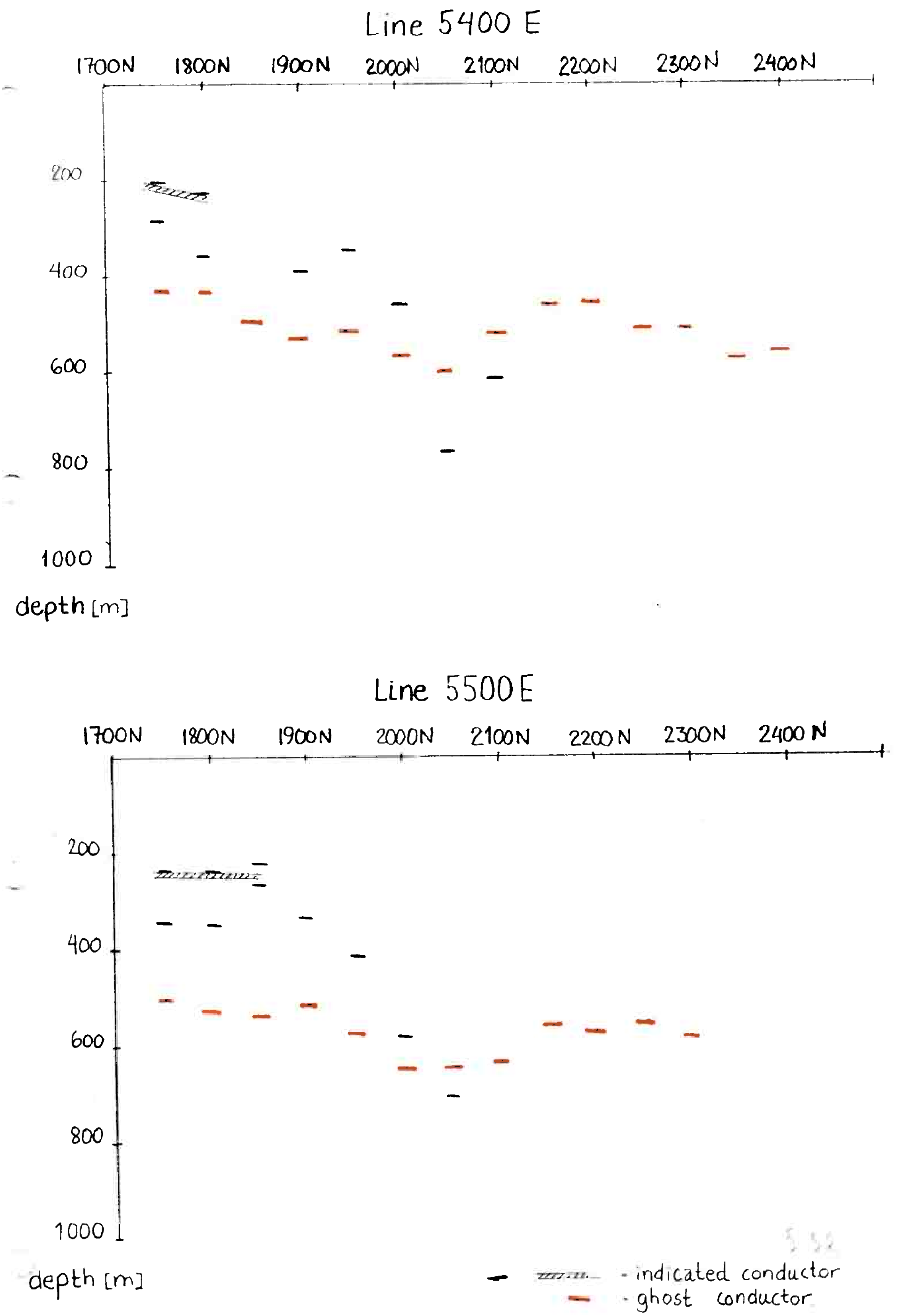

Line 5400 E
1700N
1800N
1900N
2000N
2100N
2200N
2300N
2400N
200
400
600
800
1000
depth [m]
Line 5500 E
1700N
1800N
1900N
2000N
2100N
2200N
2300N
2400N
200
400
600
800
1000
depth [m]
- indicated conductor
- ghost conductor

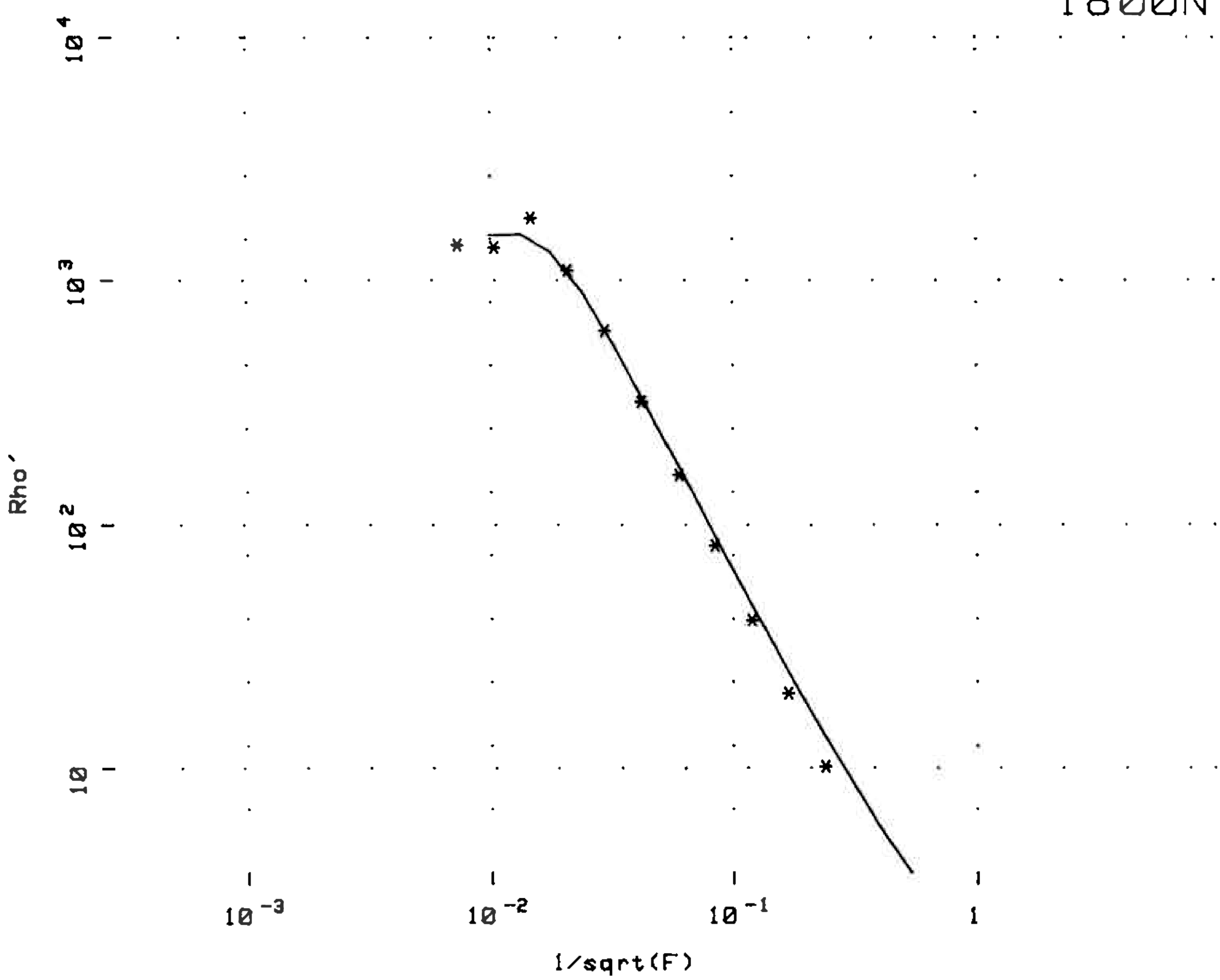
Fig.5.52

NORGES TEKNISKE HØGSKOLE

FREMSTFJELL 1985 5300 E

Resistivity (ohm.m)	Depth (m)
oo	
1----------------------	0.000
1300.000	
2----------------------	245.884
.171	

1800N



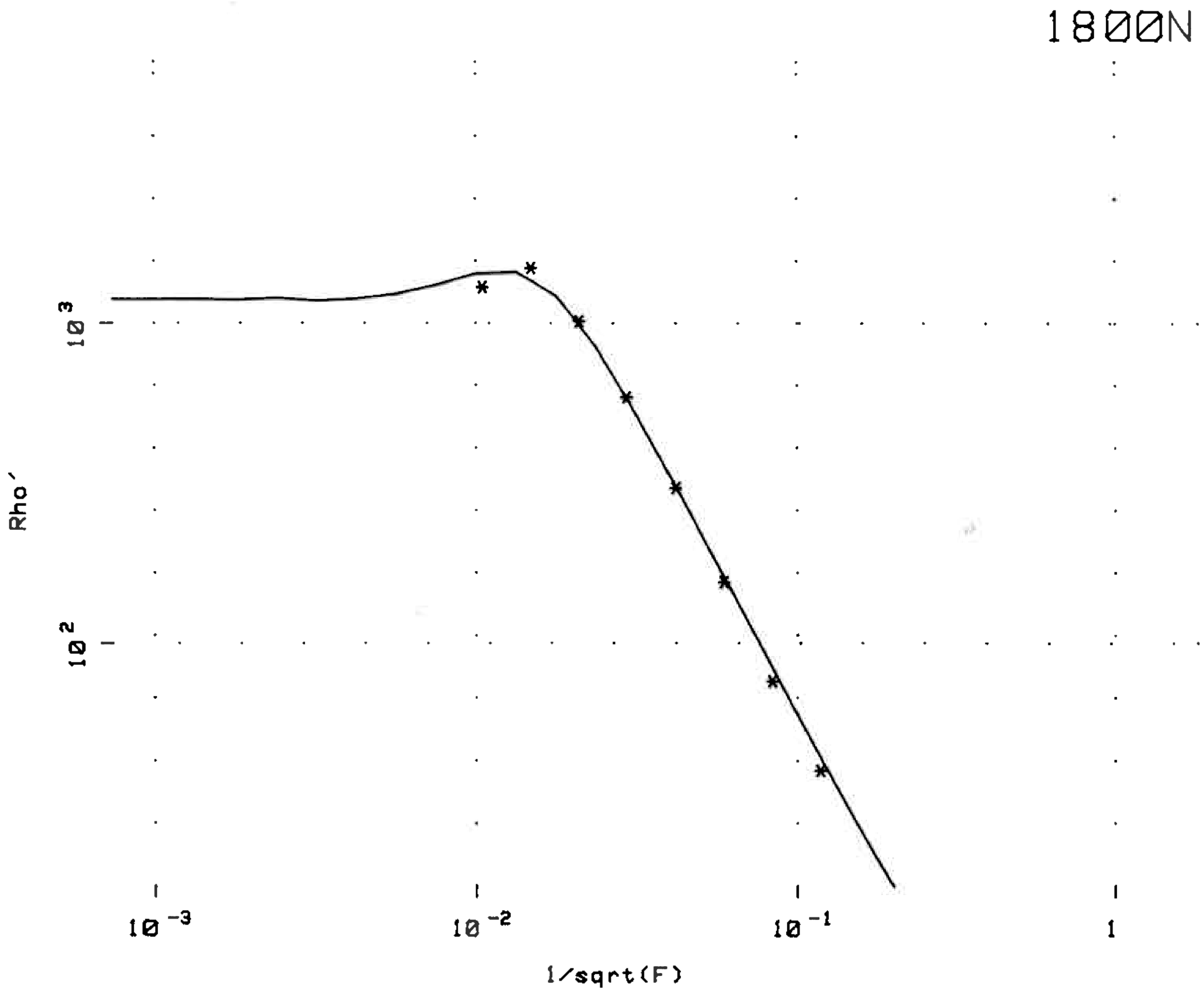
* BRGM/GPH * MELOSI *

Fig.5.53

NORGES TEKNISKE HØGSKOLE

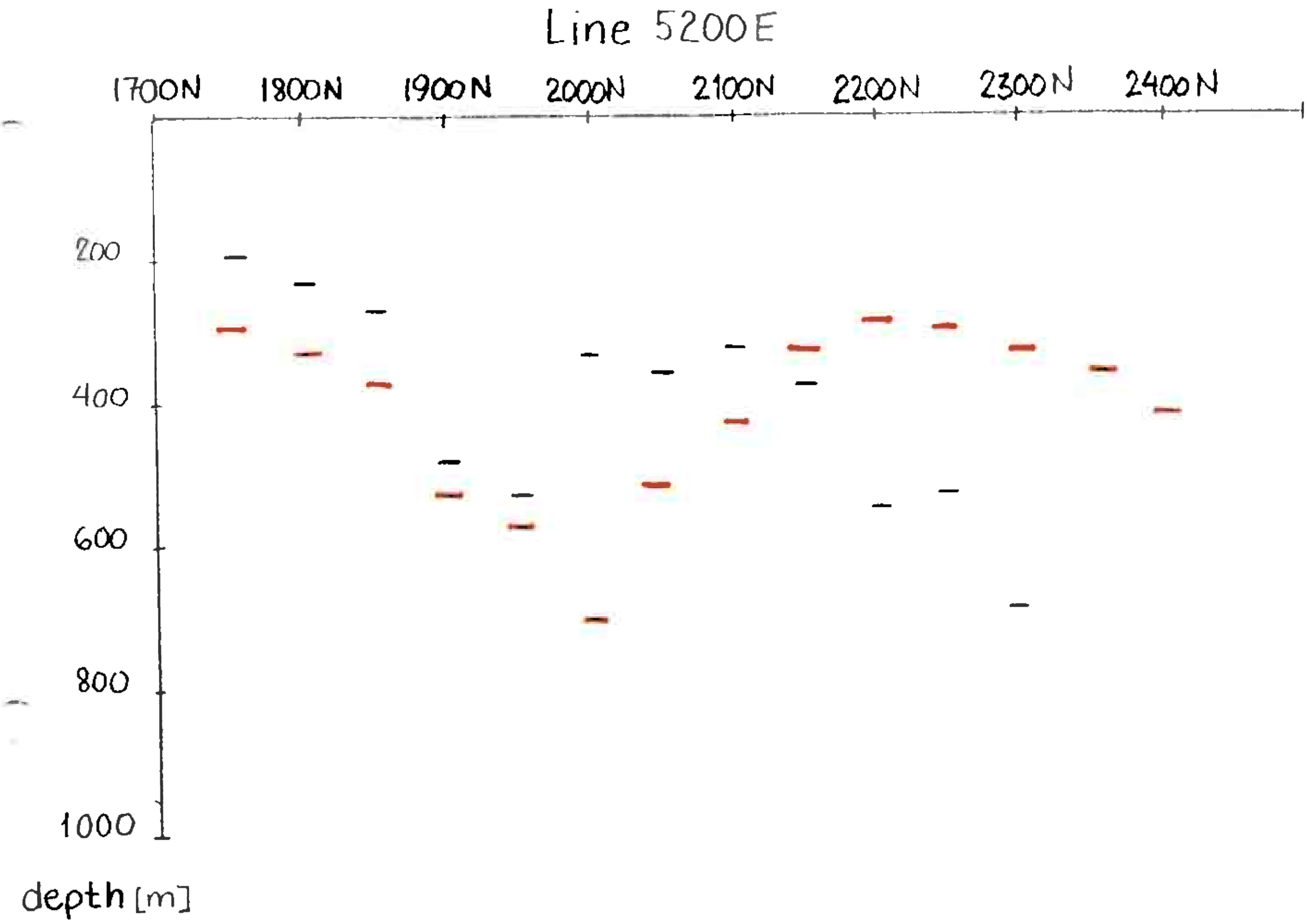
FREMSTFJELL 1985 5200E

Resistivity (ohm.m)	Depth (m)
oo	
1---------------------	0.000
1200.000	
2---------------------	228.928
.214	

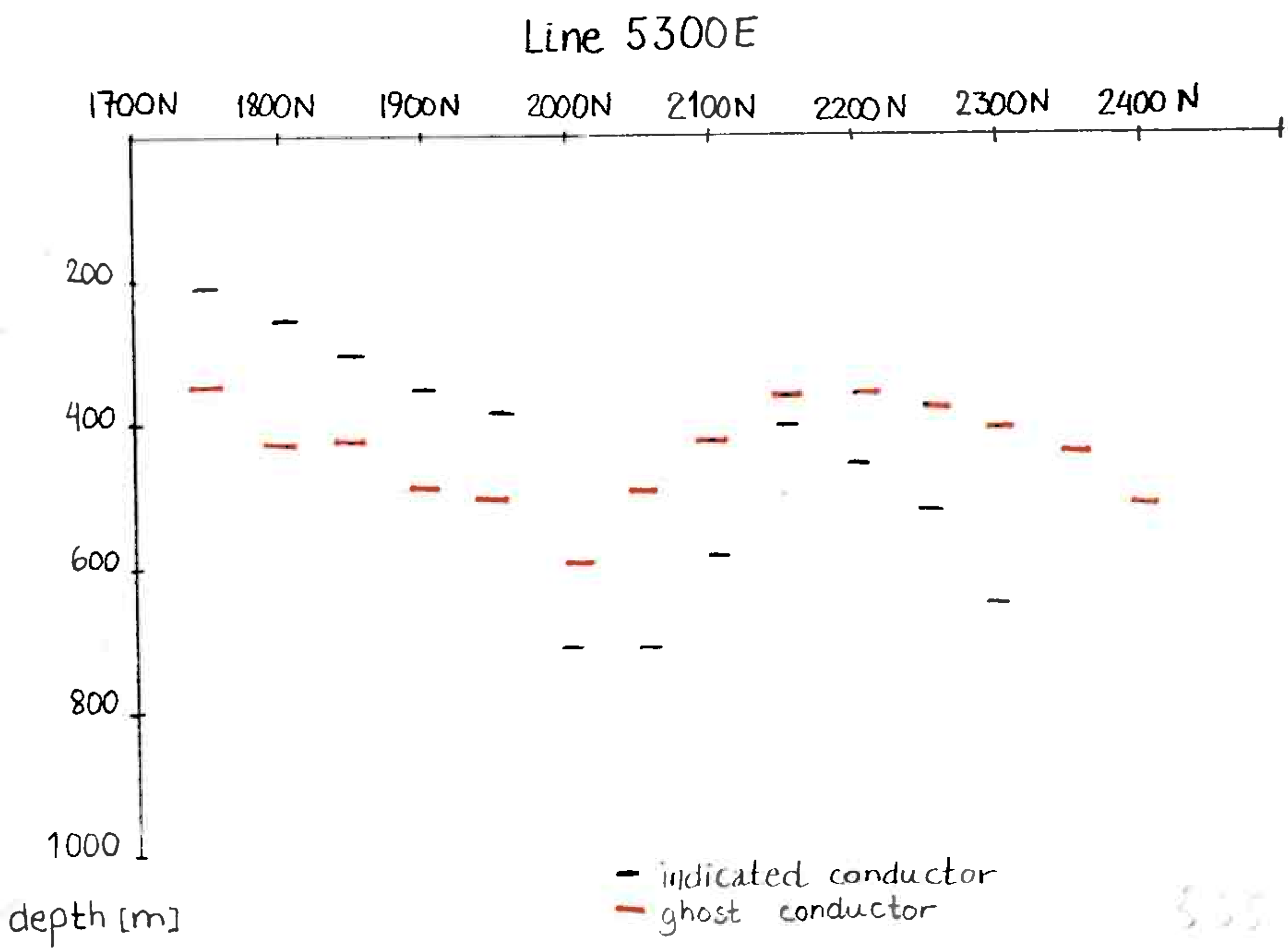


* BRGM/GPH * MELOSI *

Fig.5.54



Line 5200E
1700N
1800N
1900N
2000N
2100N
2200N
2300N
2400N
200
400
600
800
1000
depth [m]



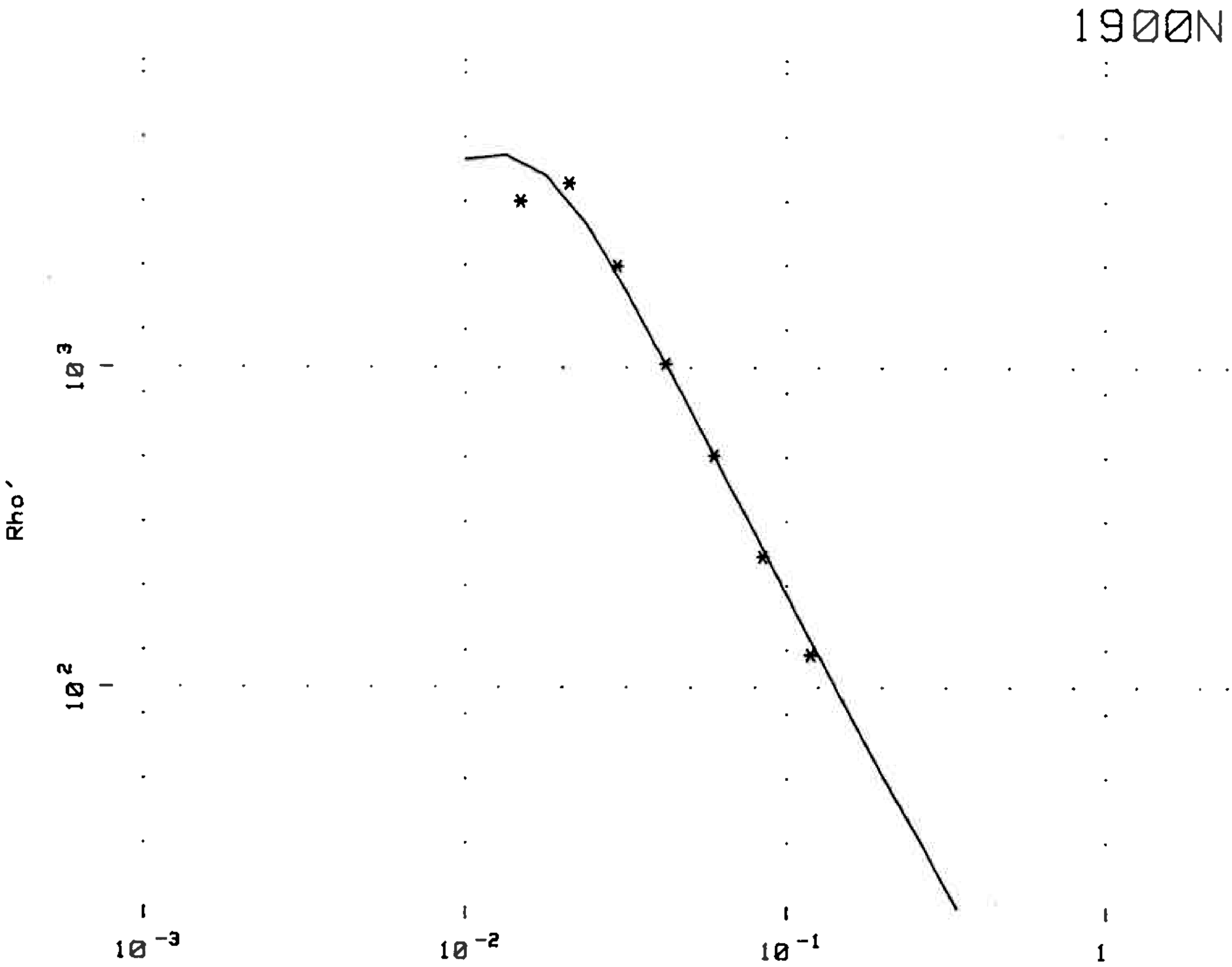
Line 5300E
1700N
1800N
1900N
2000N
2100N
2200N
2300N
2400N
200
400
600
800
1000
depth [m]
indicated conductor
ghost conductor

Fig.5.55

NORGES TEKNISKE HØGSKOLE

FREMSTFJELL 1985 5100E

	Resistivity (ohm.m)	Depth (m)
	oo	
1		0.000
	3700.000	
2		385.879
	.185	



* BRGM/GPH * MELOSI *

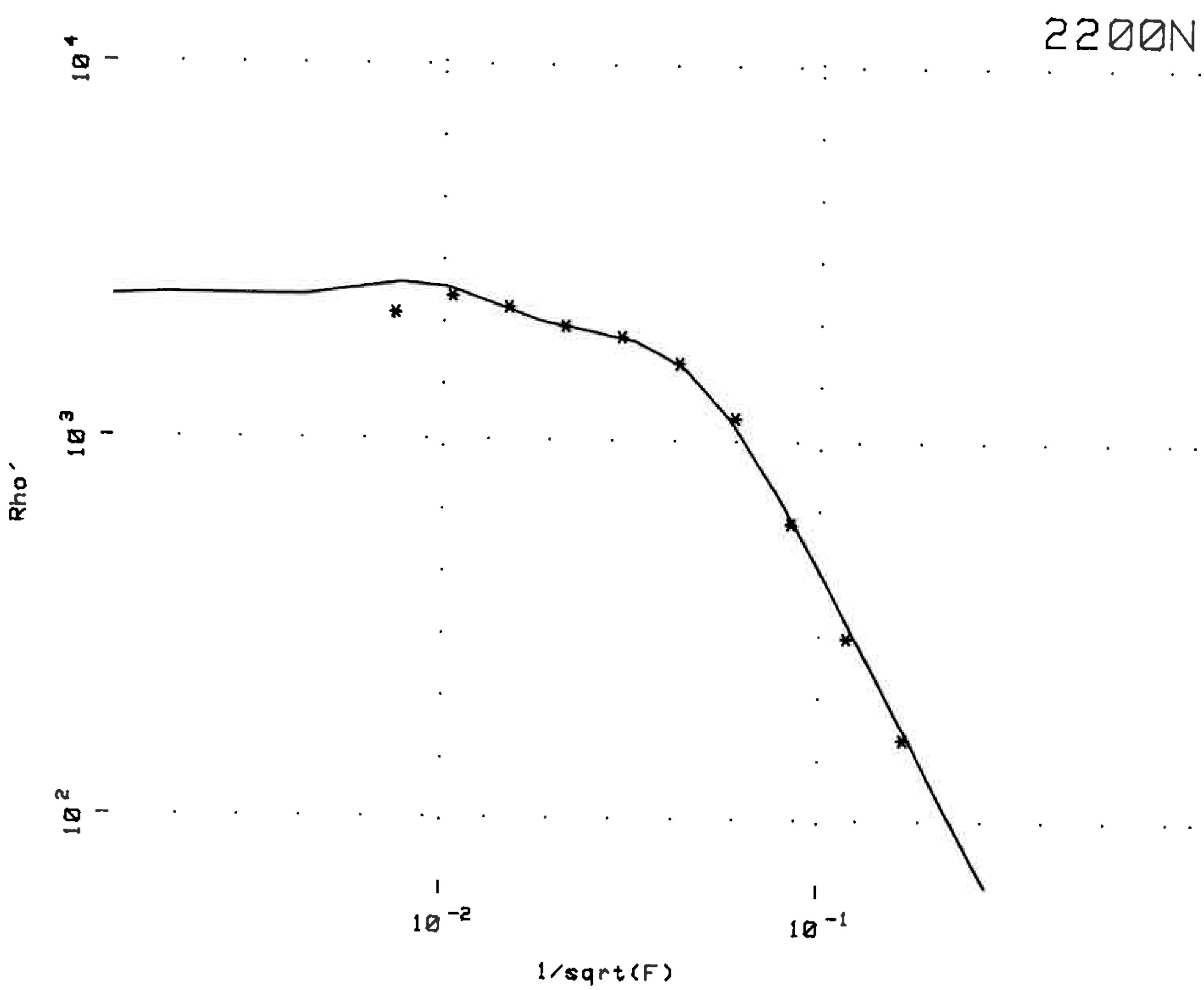
Fig.5.56

NORGES TEKNISKE HØGSKOLE

FREMSTFJELL 1985 5000E

Resistivity (ohm.m)	Depth (m)
oo	
1---------------------	0.000
2400.000	
2---------------------	275.000
5.000	
3---------------------	276.300
2000.000	
4---------------------	470.000
.100	

$\sigma t = 0.26$



3AGM/GPH * MELOSI *

Fig.5.57

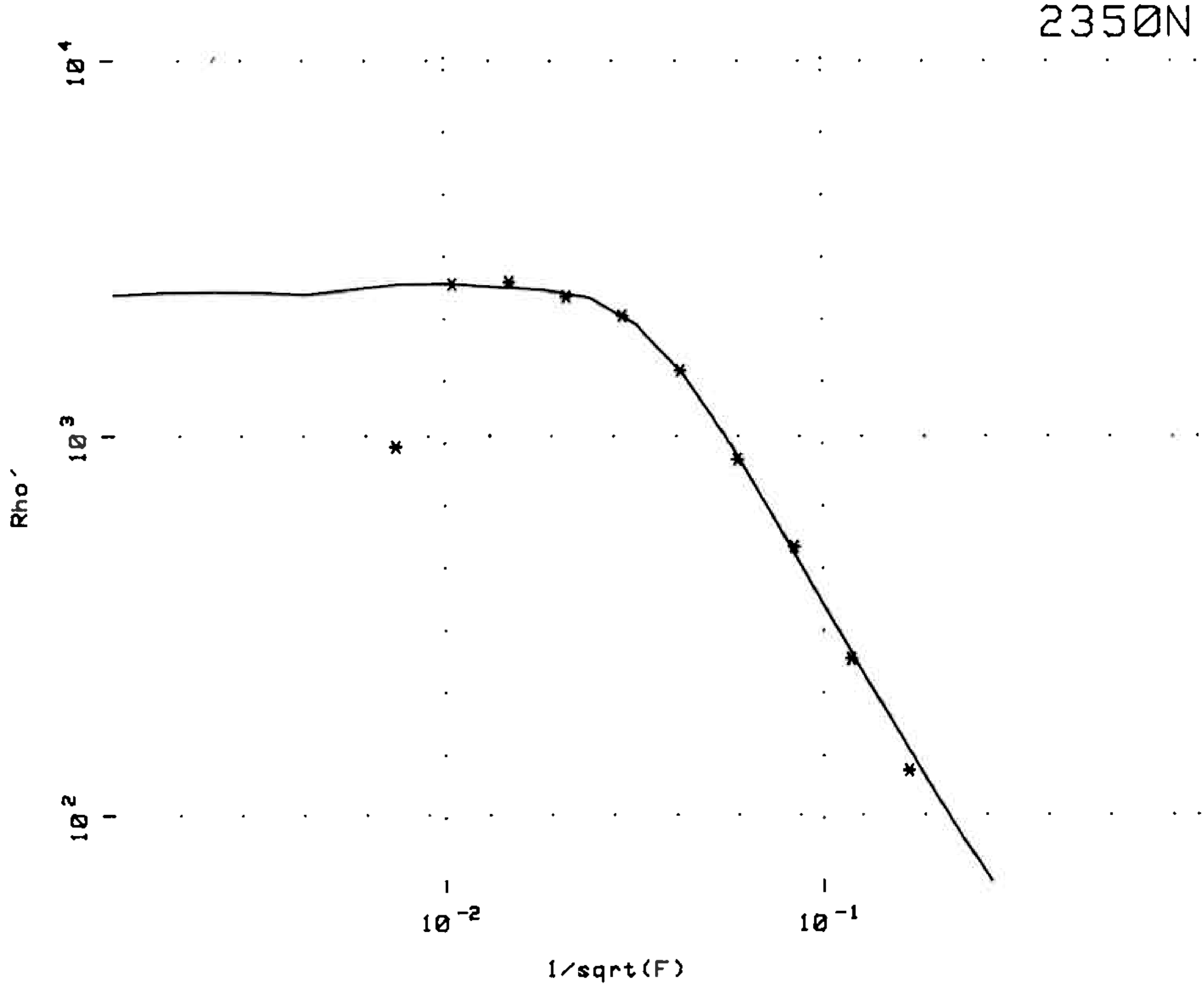
NORGES TEKNISKE HØGSKOLE

FREMSTFJELL 1985 5000E

Resistivity (ohm.m)	Depth (m)
oo	
1---------------------	0.000
2400.000	
2---------------------	300.000
5.000	
3---------------------	301.000
2000.000	
4---------------------	415.000
1.000	

σt = 0.20

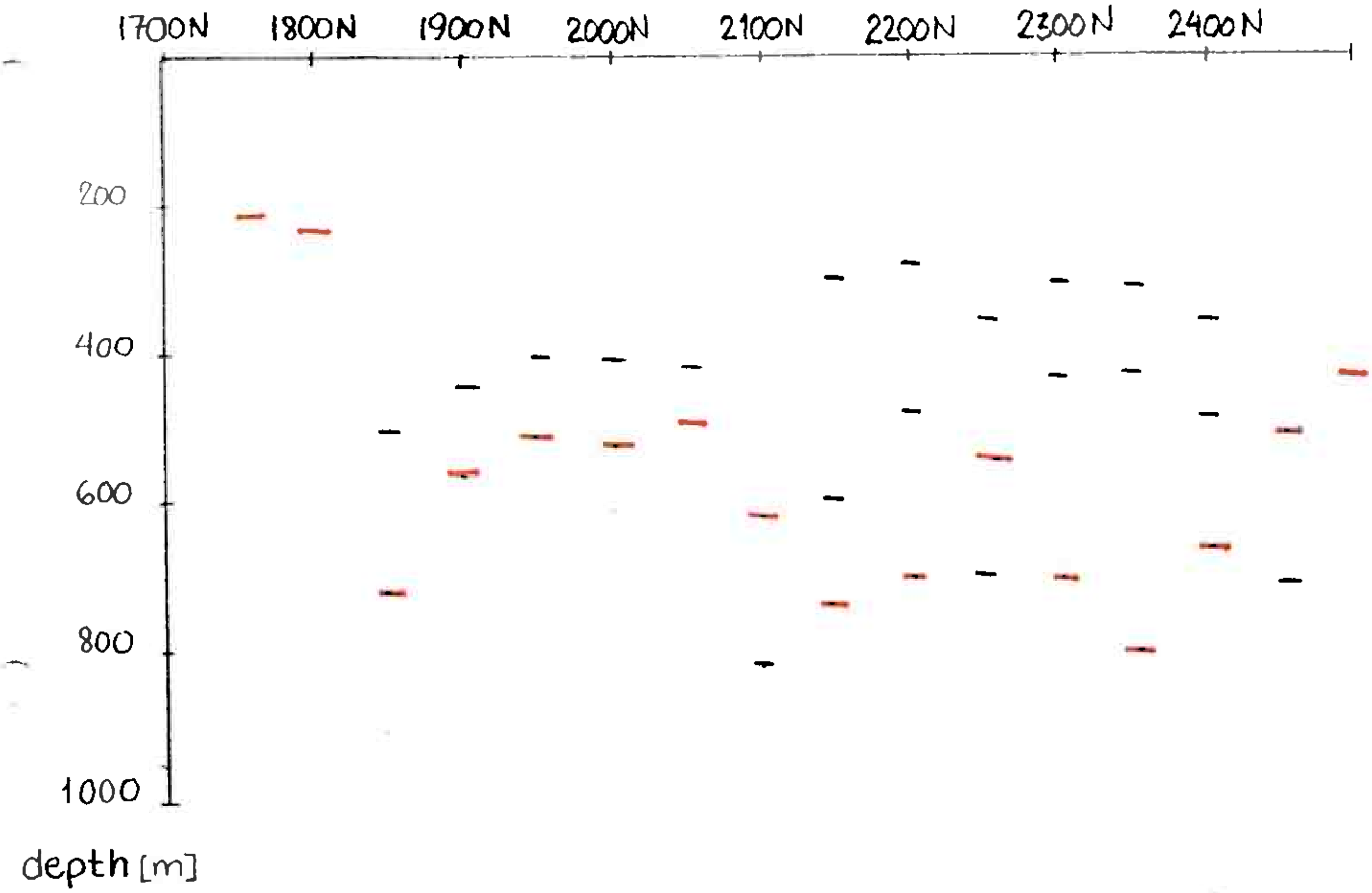
2350N



* BRGM/GPH * MELOSI *

Fig.5.58

Line 5000 E



Line 5100E

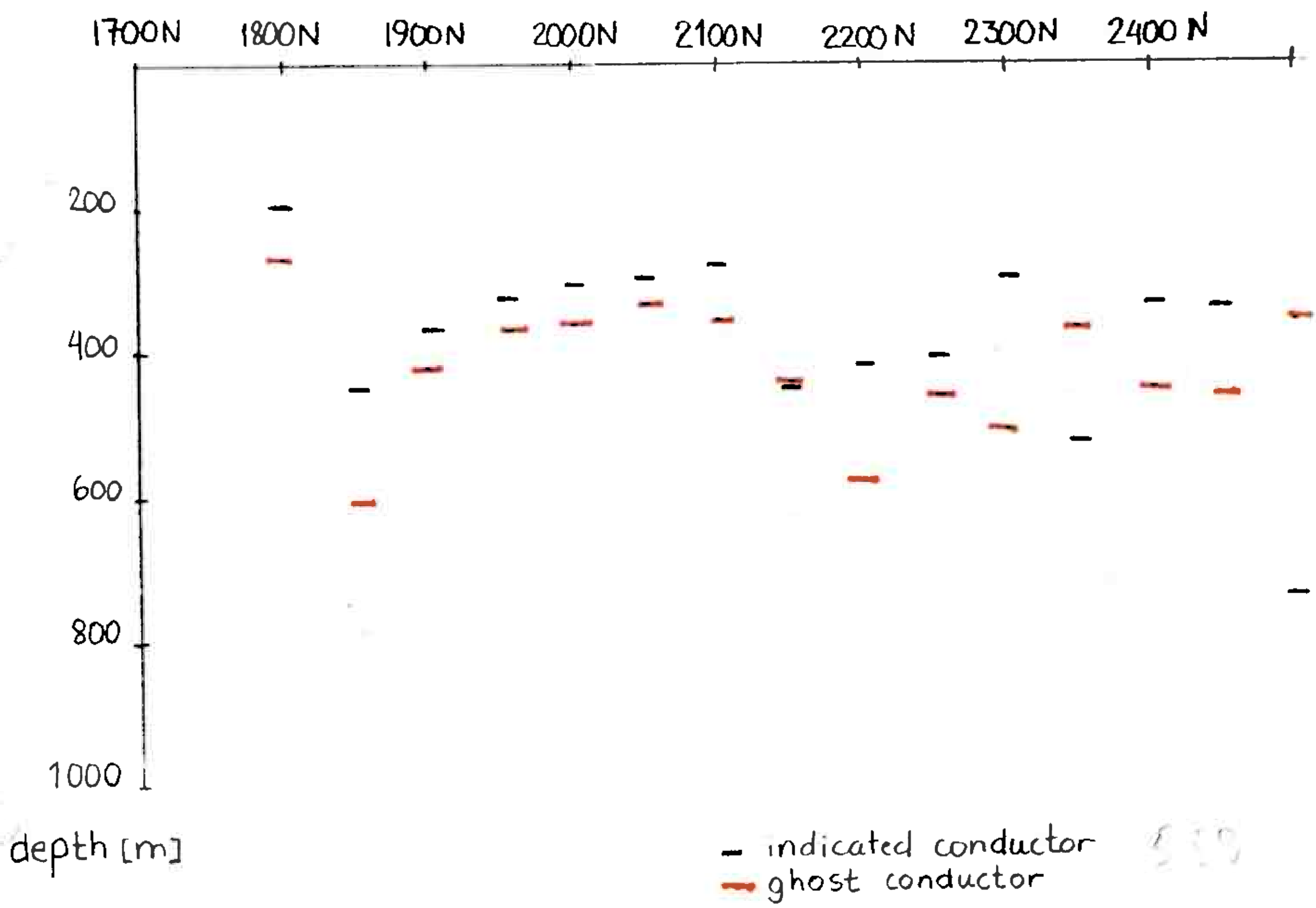
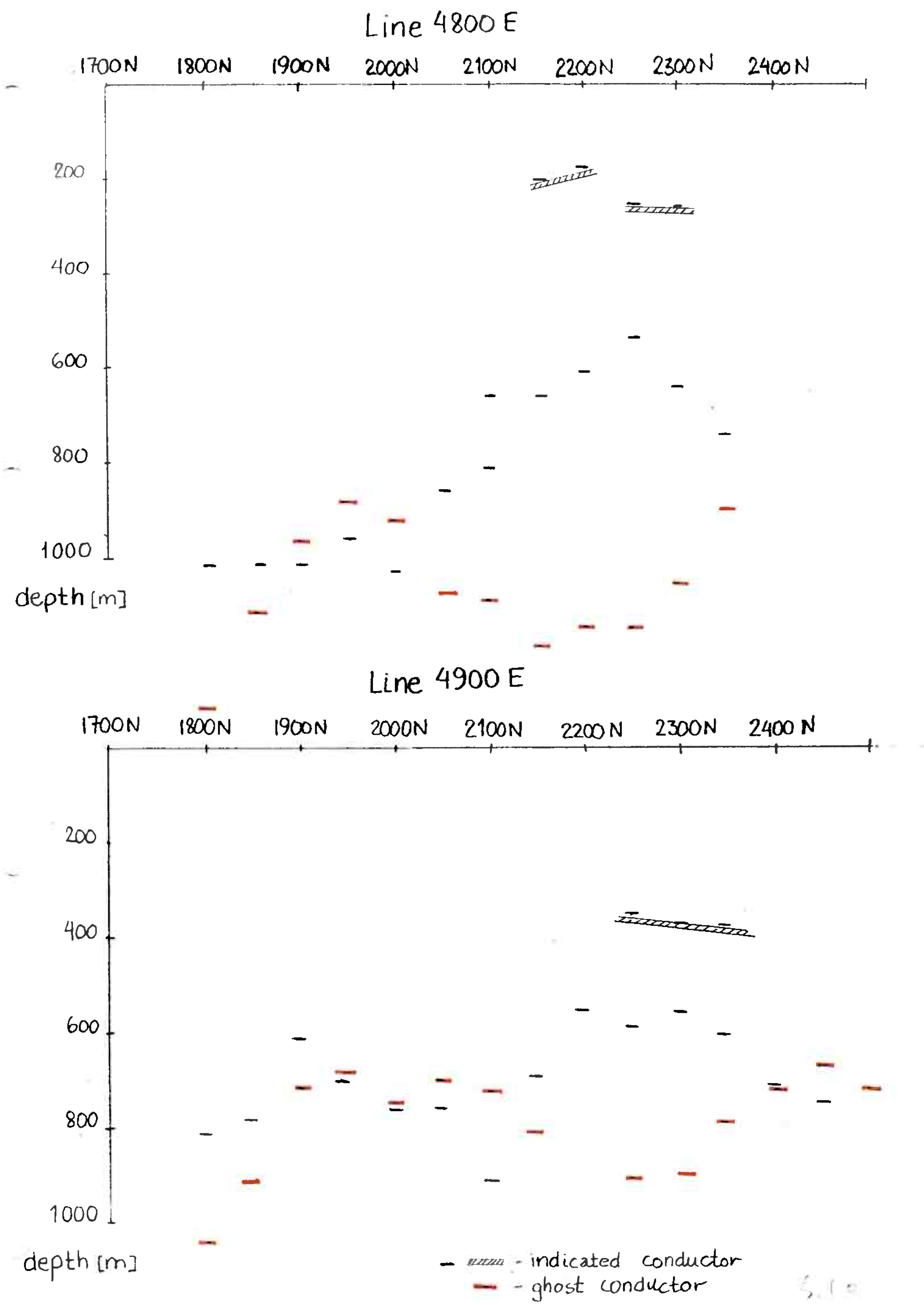


Fig.5.59



Line 4800 E
1700N
1800N
1900N
2000N
2100N
2200N
2300N
2400N
200
400
600
800
1000
depth [m]
Line 4900 E
1700N
1800N
1900N
2000N
2100N
2200N
2300N
2400N
200
400
600
800
1000
depth [m]
- indicated conductor
- ghost conductor

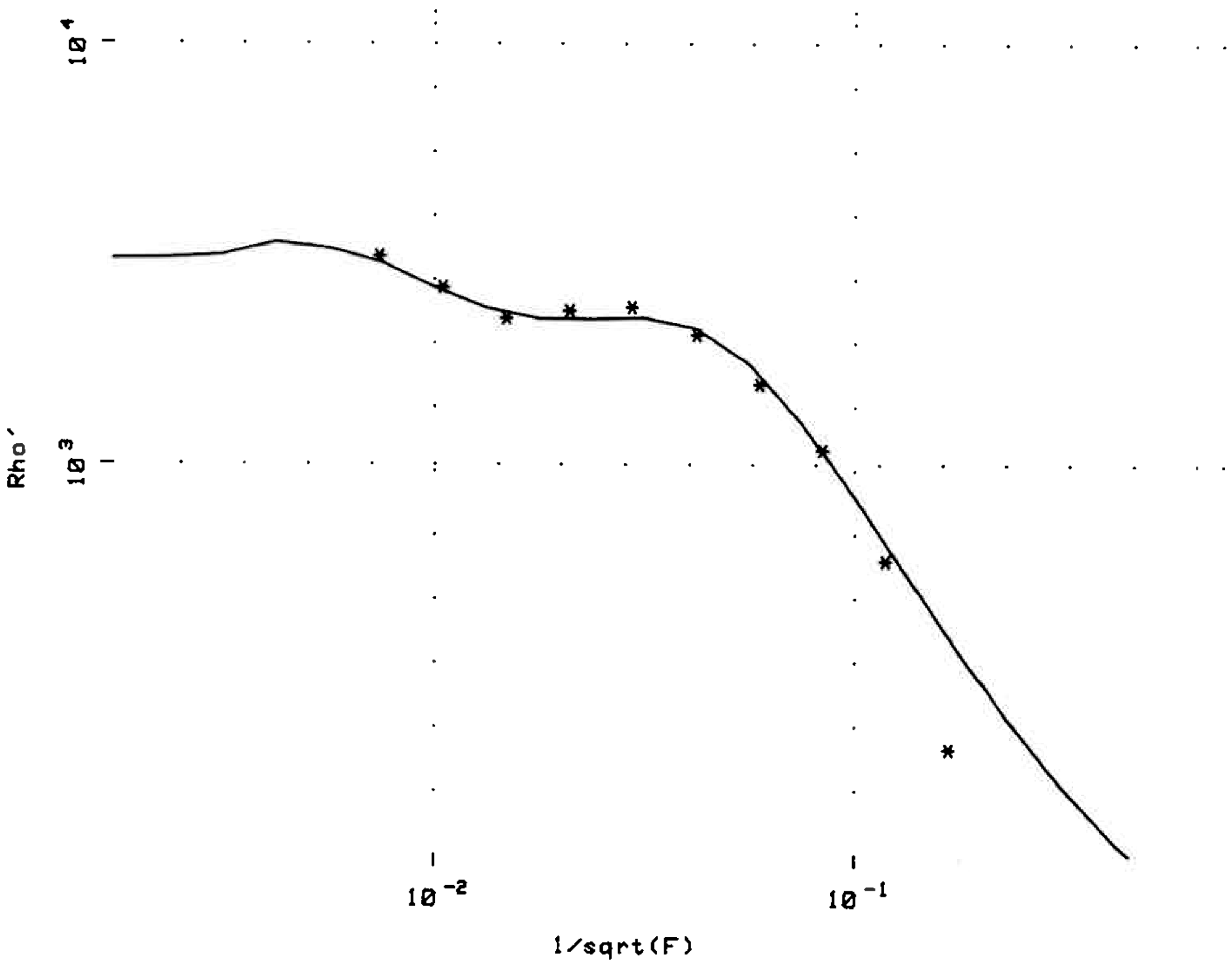
Fig.5.60

NORGES TEKNISKE HØGSKOLE

FREMSTFJELL 1985 4800E

	Resistivity (ohm.m)	Depth (m)
	oo	
1		0.000
	3100.000	
2		250.000
	5.000	
3		250.800
	3000.000	
4		825.000
	5.000	

2300N



* BRGM/GPH * MELOSI *

Fig.5.61