Rapport 92.279

ELECTRIC PROFILING BY THE MISC AND SLINGRAM METHODS IN THE PECHENGA AND PASVIK AREAS.

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RAPPORT

Rapport nr. 92.279	ISSN 0800-3416	Gradering: open

Tittel:

Electric Profiling by the MISC and Slingram Methods in the Pechenga and Pasvik Areas.

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Forekomstens navn og koordinater: Skogfoss 35W 6058 76982	Sidetall: 26 Pris: Kr. 50,- Kartbilag: 0

Feltarbeid utført:	Rapportdato:	Prosjektnr.:	Ansvarlig:
1990-1991	01-25-93	61.2600.06	Jan S. Rønning

Sammendrag:

Electrical and Slingram profiling is carried out in the border area between Norway and Russia. The aim of this survey was to map near outcropping conducting structures in the ground, and to see how these two methods worked together on this problem. Magnetic profiling was performed to help in the interpretation.

Two profiles on the norwegian side and two profiles on the russian side of the border were examined. Data from the profiles on the norwegian side are presented in this report. Based on electrical profiling, detailed resistivity cross sections are constructed. Electrical profiling by the MISC method is effective for 2D mapping of rocks in a wide range of electrical resistivity. The Slingram method is less sensitive at low conductivity, but gives complementary informations at moderate and high conductivity.

Emneord:	Geofysikk	Elektrisk måling
Elektromagnetisk måling	magnetometri	Kartlegging
Malmgeologi		Fagrapport

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1 INTRODUCTION

As a part of the soviet-norwegian (now russian-norwegian) program in geology and geophysics a methodical study on electrical and Slingram profiling was carried out in 1990 and 1991. The aim of this study was to map conducting structures in the ground and to see how these two methods worked together where the problem was to map electrical conductors with different conductivity in the ground. To help in interpretation of Slingram data, magnetic profiling was performed.

The study was carried out in the Pechenga Greenstone belt, close to the border between Norway and Russia and along the Lotta river further to the south (see figure 1). Altogether five profiles were examined by electrical profiling. Two profiles on the norwegian side of the border were studied throughout with Slingram, while only interesting parts of the three profiles on the russian side were examined. In addition to the results from methodical studies, the report presents all data from electrical and Slingram profiling at the norwegian side of the border.

The electrical profiling was performed using a configuration called MISC (Method of the Internal Sliding Contact) by the russians (A.A Zhamaletdinov, A.Tokarev and Yu.A. Vinogradov). The norwegians (J.S. Rønning and O. Blokkum) were responsible for the Slingram measurements. In addition Dr. M. Karous from Charles University of Prague participated during measurements in Norway.

2 METHODS

2.1 Method of the Internal Sliding Contact (MISC).

Electric profiling by the internal sliding contact method was performed using colinear dipole-dipole array BAMN. In each observation point an internal measuring electrode M moves (slides) between electrodes A and N, and occupies several fixed positions as shown in Fig. 2A. Due to changing of the AM distance, the vertical sounding of the section is carried out. Subsequently the array is moved to the next point, and the sounding is repeated. Moving along the profile with given steps, the MISC array allows to carry out simultaneous profiling and sounding of the section.

The conditions of a pole-pole array (AB >> AM << MN) are met at a position when the electrode M is close to the current electrode A. When the electrode M approaches the electrode N, the array becomes axial dipole-dipole (AB < AM > MN), or acquires properties of a Wenner - type array with alternating position of electrodes (AB=AM=MN). The sounding depth is determined by effective spacing:

$$r^{eff}=AM+\frac{1}{2}MN(\frac{AM}{AN})^2+\frac{1}{2}AB(\frac{BM}{BN})^2$$

where the distances AM, AN etc. correspond to those in Fig. 3A.

The processing and interpretation of MISC results were conducted in two steps. The first step was made directly in the field. Plots of apparent resistivity were drawn and interpreted qualitatively. The apparent resistivity is calculated by the formula (K is a geometric constant):

$$\rho_a=K\frac{\Delta U}{I} \quad , \quad where\ K=\frac{2\cdot\pi\cdot AM\cdot AN\cdot BM\cdot BN}{MN\cdot(BM\cdot BN-AM\cdot AN)}$$

The starting point refers to the electrode A. The values are plotted on a linear - logarithmic scale, as shown in Fig. 3B. The position of steeply dipping interface boundaries are easily identified by sharp bends of the curves. From the variations in ρ_a depending on spacings, it is not difficult to estimate the relation between the varying apparent electrical resistivity and the position of the appropriate geologic objects, at the surface or at the depth.

The quantitative interpretation was performed on an IBM PC by selection of theoretical solutions of one-dimensional models in an interactive solution or automatically. The values for the model of layered section in the MISC array were calculated by the formula:

$$\rho_a=\frac{\Delta U_{an}^{MN}}{\Delta U_0^{MN}}$$

where ΔU_{an}^{MN} - the anomalous difference in potential between the electrodes MN calculated theoretically for a layered section;

ΔU_0^{MN} - the difference in potential between the electrodes MN calculated for a homogeneous medium (halfspace).

$$\Delta U_{an}^{MN}=\int_{r=AM}^{r=AN} E_{an}^{A}(r)dr-\int_{r=BM}^{r=BN} E_{an}^{B}(r)dr$$

$$where \qquad E_{an}^{i}(r)=\rho_a^{i}(r)E_0^{i}(r) \qquad i=A,B$$

$$\rho_a^i(r)=\rho_1\{1+2\sum_{n=1}^{n=\infty}\frac{q_n\cdot r^3}{[r^2+(n\cdot h_1)^2]^{\frac{3}{2}}}\}$$

q_n - emission factor determined by limiting conditions of n - layered model
ρ_1 - specific resistivity of upper layer
h_1 - thickness of upper layer

$$\Delta U_0^{MN}=\frac{\rho\cdot I}{2\cdot\pi}\cdot\frac{MN\cdot(BM\cdot BN-AM\cdot AN)}{BM\cdot BN\cdot AM\cdot AN}$$

where $\rho = 1$ ohmm; $I = 1$ A.

An example of quantitative interpretation is given in Fig. 3C as printout from the display. The circles at left show an experimental curve, the solid line is a selected theoretical curve. The corresponding geoelectrical section is shown by the column on the right. Routine processing of the field results provided to be more efficient in the automatic selection mode. This was carried out by the algorithm described by Zohdy (1989). In this work the starting model contains the amount of layers equal to the number of spacings (positions of electrode M), the layer depths are equal to the effective spacings and specific resistivity for each layer are equated to the measured apparent resistivity at the corresponding spacings. Varying the depth first, and subsequently the layers resistivity, the programme automatically selects the most appropriate one-dimensional model and assesses the discordance percentage against the experimental curve.

Large discordances generally appear in cases when the medium does not correspond to the one-dimensional model; it is typically manifested by the curve slopes steeper than 45°. In such cases it was necessary to fit the values successively: at large spacings first, and then at lower ones up to the extent of agreement between the theoretical and experimental curves with a precision not worse than 10 percent. The results of processing MISC data by this method is illustrated in Fig. 4, 5 and 6 as geoelectrical sections.

Technique and equipment.

The MISC electric profiling was performed using the low-frequency russian equipment (Geologorazvedka, ANC-3). A portable generator provided the 4.86 Hz frequency current in the earth in the form of square bipolar pulses. Stabilized current can have one of 5 fixed values: 1, 3, 10, 30 or 100 mA, depending on the resistance of the groundings AB from 60 kOhm and less.

Threshold sensitivity of the ANC-3 microvoltmeter is 3 μV, the input resistance being not lower than 2-3 MOhm.

The relations and dimensions of power supplying and receiving lines in the MISC array were selected on basis of the expected maximum thickness of till, and dimensions of the objects that are to be found in the inferred conditions of horizontal heterogeneity of the geoelectrical section. In the Pechenga area, where the section is characterized by an alternation of contrast conductive and non-conductive interlayers, and where the till thickness does not exceed a few tens of meters, the most efficient parameters of the MISC array prove to be as follows:

BA= 100 m, AN= 350 m, AM= 6, 12, 20, 32, 50, 75, 100 m.

This array was serviced by a team of 3 persons due to the fact that the electrode N is grounded by means of an unisolated wire with a length (l) of 50 m. Contact resistance R of this electrode was calculated by the equation R = ρ/l (Ohm). The grounding conditions of the receiving line was controlled by means of comparing the signal ΔU^{MN} with two polarities of MN. The obtained discordance of ±ΔU testifies to a high input resistance or to the presence of some leakage.

An error related to the linear character of N grounding is given by:

$$\delta = \frac{m_1 - m_2}{m_1 + m_2} \cdot 200\%$$

where

$$m_1 = (AN - 0.5 \cdot l) \cdot (MN + 0.5 \cdot l)$$

$$m_2 = (AN + 0.5 \cdot l) \cdot (MN - 0.5 \cdot l)$$

This error in the above array does not exceed 6 percent, the average being 2-3 percent.

To avoid large errors in the measurements, a possibility to work with an AN =100 m was employed. In this case there is an additional opportunity for horizontal sounding-profiling at the expense of a general decrease in the depth penetration of the MISC array under the transition from AN =350 m to AN =100 m. Geometric coefficients for a MISC array of the described design are given below in the table.

	AM spacing , m	Geometric coefficient,m AN =100 m	 AN =350 m
1	6	41	40
2	12	90.5	85
3	20	171	153
4	32	336	273
5	50	754	495
6	75	2400	900
7	100	--	1440

During the reported measurements the spacing between each sounding station was 100 metres.

2.2 Slingram profiling.

Slingram measurements were performed using Scintrex SE-88 Genie (Scintrex 1983). This instrument is a horizontal loop EM system where the measurements are based on simultaneous transmission of two preselected, well separated frequencies. A proportional DC voltage is obtained for each signal, averaged over a selectable time period. The ratio between voltages from a high (signal) and low (reference) frequency is calculated and displayed in percent. For methodical studies, the reference frequency was 112.5 Hz while the signal frequencies were 337.5 Hz, 1012.5 Hz and 3037.5 Hz. Measurements along PAS-1 and PAS-2 profiles were performed using 112.5 Hz as reference frequency and only 3037.5 Hz as signal frequency. The distance between transmitter and receiver was 50 metres, and the distance between stations was 25 metres.

The profiling by the Slingram method was aimed at making a comparison with the results of the MISC electric profiling, and estimating the areas where both methods can be applied to complement each other.

2.3 Magnetic profiling

Magnetic profiling was performed using Geometrics portable proton magnetometer model G-836 (Geometrics 1977) which has a resolution of 10 nT. Station spacing was 25 metres.

3 RESULTS AND DISCUSSION

Figure 1 illustrates the location of jointly studied profiles. Detailed location of the profiles on the norwegian side is given in figure 2. All profiles were examined by the MISC method. The Slingram method was used throughout the profiles PAS-1 and PAS-2 and some segments of the Rayakoski, Shuoni-Kuets and Lotta profiles. The results of electric profiling along profiles PAS-1, PAS-2, Rayakoski and Shuoni-Kuets are given in figure 7,8,9 and 10 together with the data from magnetic survey. Results from Slingram profiling along profile PAS-1 and PAS-2 are presented in figure 11 and 12.

The advantages of electric profiling by the Slingram and MISC methods are demonstrated by three examples in Fig 4, 5 and 6. These figures provide evidence that the Slingram method is the best to distinctly identify the highly conductive objects. Besides, this method makes it possible to carry out more detailed investigation of deep structures and to distinguish between each thin conductive interlayers.

The resolution of the Slingram method decreases abruptly over the middle and low conductivity zones. The resistance changes in the range of 200-300 ohmm and over, are actually not registered by the Slingram method. This conclusion is in good agreement with theoretical conceptions, since the Slingram method, as well as all methods based on induction, is designed for distinguishing the highly conductive objects. The main condition for anomaly fields to be registered by the Slingram method is described by the following (r is coil separation):

$$K \cdot r > 1$$

$$K = \sqrt{\frac{2 \cdot \pi \cdot \mu_0 f}{\rho}} \qquad (\textit{wavenumber})$$

$$\mu = 4 \cdot \pi \cdot 10^{-7} \quad [ohm \cdot s/m] \qquad (\textit{magnetic permeability})$$

$$f = \textit{frequency} \quad [Hz]$$

There is no difficulty in calculating that the condition is not fulfilled when r=50 m, ρ = 200 ohmm and f = 3 kHz. Due to the above properties, the Slingram method recordings are less affected by interferences of low conductive geological objects. The method mainly deals with "pure" anomalies: its aim being identification of ore objects or high conductive fractures zones.

The MISC method is primarily intended for mapping. Due to combination of two functions, sounding and profiling, the MISC method allows us to distinguish anomalies related to upper unconsolidated sediments (soil) from anomalies caused by the changes in the resistivity at depth in the bedrock. A combination of qualitative and quantitative interpretation of MISC results provides $\rho(h)$ sections (ρ as a function of the depth h) and plots for specific electrical resistivity ρ of the bedrock. Examples of such sections are given in figure 4, 5 and 6, and for profiles PAS-1 and PAS-2 as a hole in figure 13 and figure 14.

The common analysis of profiling data gave information about the structure and electrical properties of the soil and about the resistivity distribution in bedrock down to the depth of 20 - 25 m. The total length of the profiles are about 40 km. The moraine thickness changes from 0 up to 10 - 15 m. Moraine can be divided in three types;

- wet moraine (resistivity 100 - 1000 Ohmm)
- dry moraine (resistivity 1000 - 10000 Ohmm)
- super dry moraine (resistivity 10000 - 40000 Ohmm)

The resistivity of the bedrock changes in 6 decades - from 0.1 up to 10^5 ohmm. The lowest resistivity (0.1 - 100 ohmm) is characteristic for graphite and sulphide bearing rocks. They are distributed widely in the southern part of Pechenga structure among the rocks of Poroyarvinsky (Porjitash) fault zone. The obvious existence of the electron conductive (graphite and sulphide bearing) rocks in the northern part of Pechenga structure is noticed only at the 4.3 km location along the Nickel - Prizechny road on the Shuoni - Kuets profile. The nature of the conductor is connected with the prolongation of the fourth sedimentary layer of Pechenga that is known as nickel perspective productive belt. Further to the west, on the profile Rayakoski, the layer is not present near the today surface according to geological mapping and MISC profiling. Electron conducting layers are especially widely distributed on profile Pas-2. Their total thickness reaches up to 1.5 km (25 % of the profile). At profile Pas-1 the thickness of conductors are at least halfened. The existence of the conductors, belonging to the northern part of Pechenga, is not well pointed out here. These are mapped using EM-fields from the "Khibiny" source (Zhamaletdinov & al. 1993).

For geological mapping, it is important to study also the moderate conductors in bedrock. The moderate conductivity (100 - 1000 Ohmm) is characteristic for schists, mylonite zones, tuff, schisted diabases etc. The Lottinsky fault zone on the Shuoni - Kuets profile is characterazed by a drop in resistivity from 20000 to 5000 Ohmm (location 7.4 km). Typically resistivities for amfibolites, diabases and granites in the area are 3000 to 20000 Ohmm.

Slingram is the method of "pure" anomalies. It is sensitive only for zones with resistivity less than 200 ohmm, it can be used to study inner structures of very high electron conductive structures.

4 CONCLUSIONS

1. Electrical profiling by the MISC method is effective for mapping rocks in a wide range of electrical resistivity (5 decades or more). Due to combination of profiling and sounding, the method define anomalies of the subsurface both in overburden (moraine) and at depth (bedrock). MISC profiling gives possibility to make both qualitative and quantitative interpretation.

2. The Slingram method is less sensitive at low conductivity, but gives complementary informations at "pure" anomalies. Qualitative interpretation of of Slingram data gives possibility to obtain more detailed information on inner structures on wide high conductive belts and zones.

3. MISC profiling is made at four profiles in the western flank of the Pechenga belt. These are supplemented with Slingram measurements. Detailed resistivity cross sections with geological descriptions are constructed along these four profiles.

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Zhamaletdinov, A.A., Tokarev, A.D., Vinogradov, Yu.A., Asming, V.E., Otchkur, A.A., Lile, O.B. and Rønning, J.S. 1993: Deep Geoelectrical Studies in the Finnmark and the Pechenga Area by Means of the "Khibiny" Source. Submitted for publication in *Physics of the Earth and Planetary Interiors.*

Zohdy, A.A.R. 1989: A new method for the automatic interpretation of Schlumberger and Wenner Sounding Curves. *Geophysics, Vol. 54. no. 2*, p. 245-253.

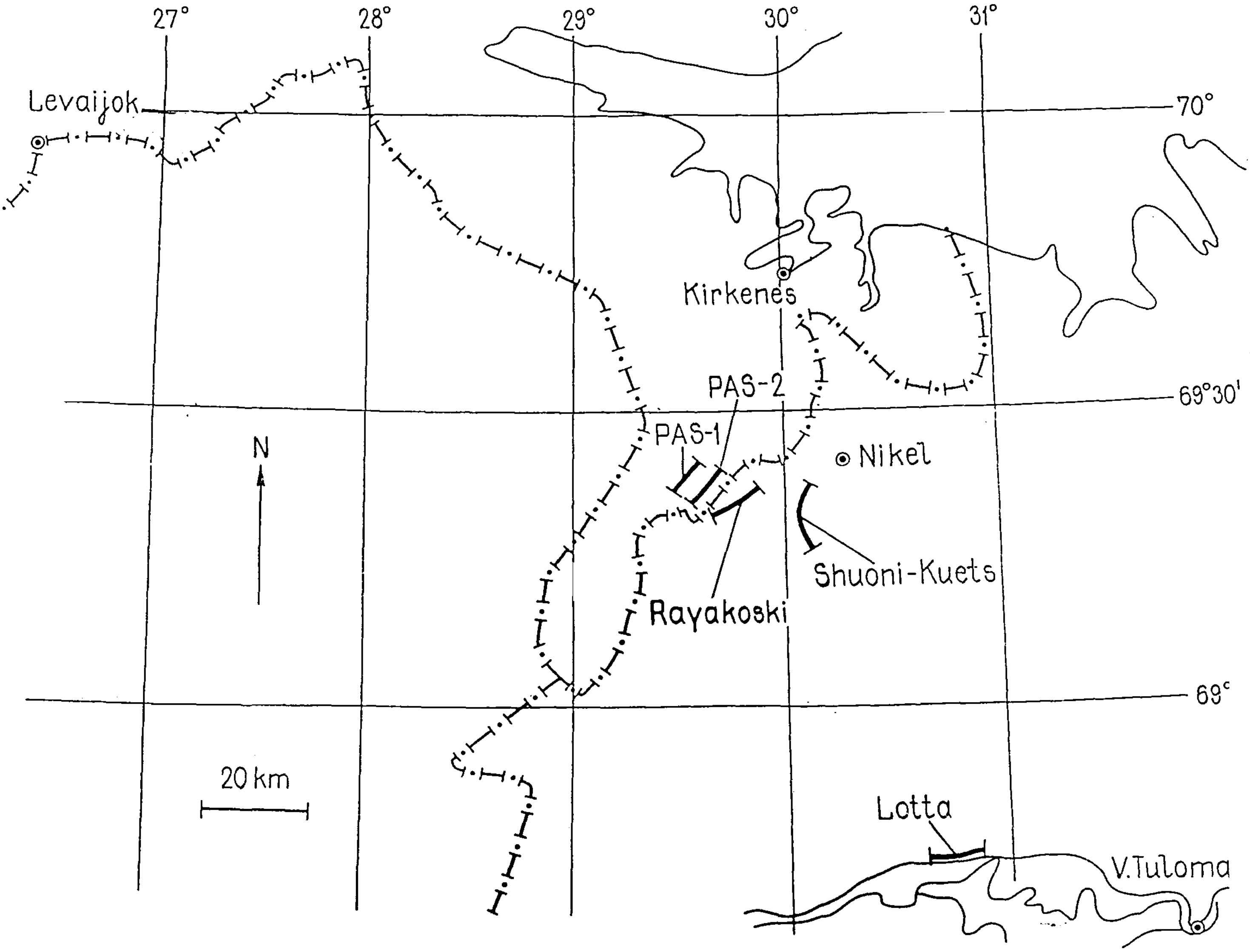


Figure 1: Location map, scale 1:1.2 million.

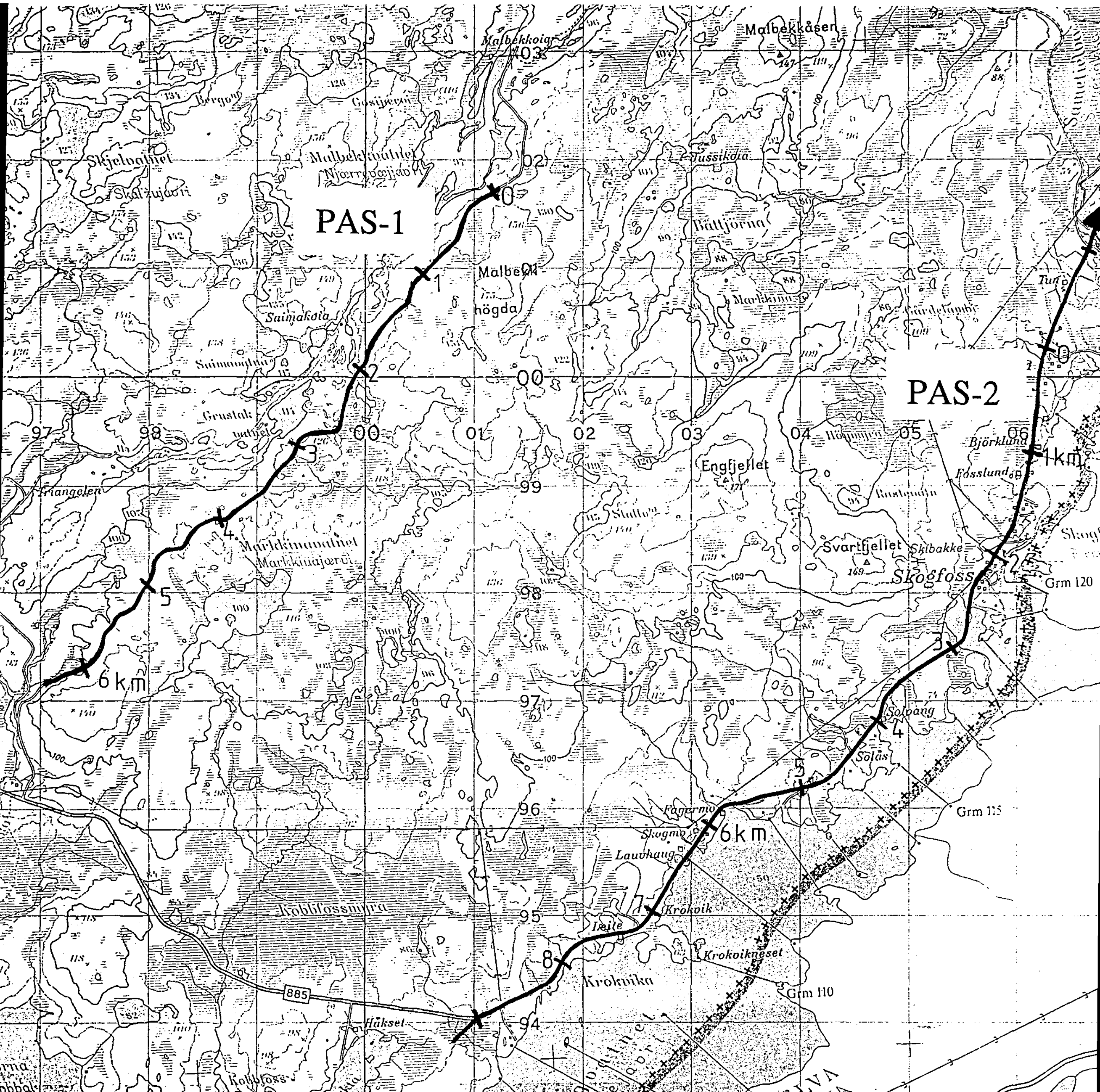
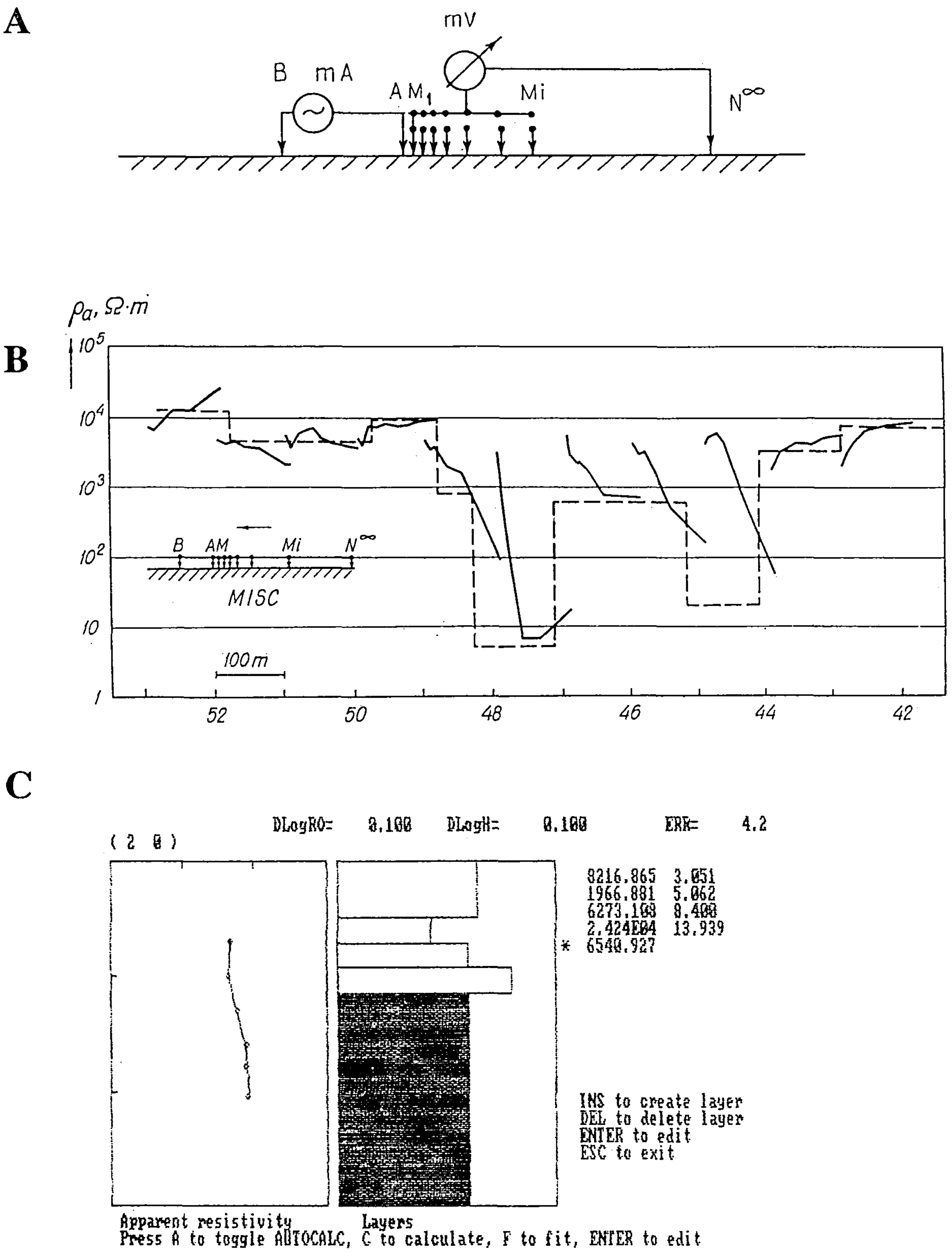


Figure 2: Location map norwegian side, M 1:50 000.



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( 2  0 )
                                                     8216.865  3.051
                                                     1966.881  5.062
                                                     6273.100  8.400
                                                     2.424E04  13.939
                                                   * 6540.927

                                                    INS to create layer
                                                    DEL to delete layer
                                                    ENTER to edit
                                                    ESC to exit
 Apparent resistivity       Layers
 Press A to toggle AUTOCALC, C to calculate, F to fit, ENTER to edit
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Figure 3: MISC profiling, A) Electrode array, B) Qualitative interpretation and C) Quantitative interpretation

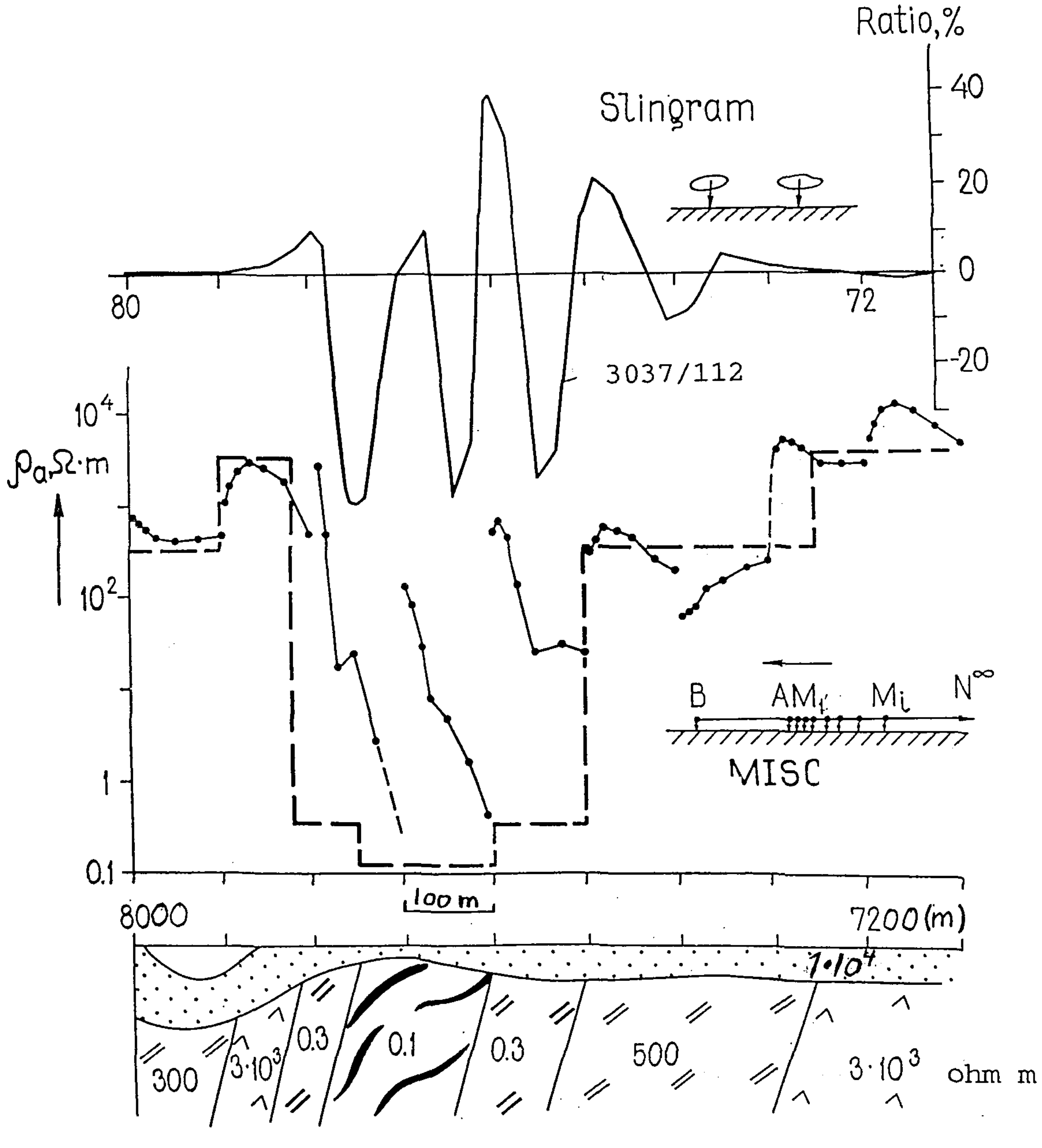

Figure 4: Example of MISC and Slingram profiling over a highly conductive structure.

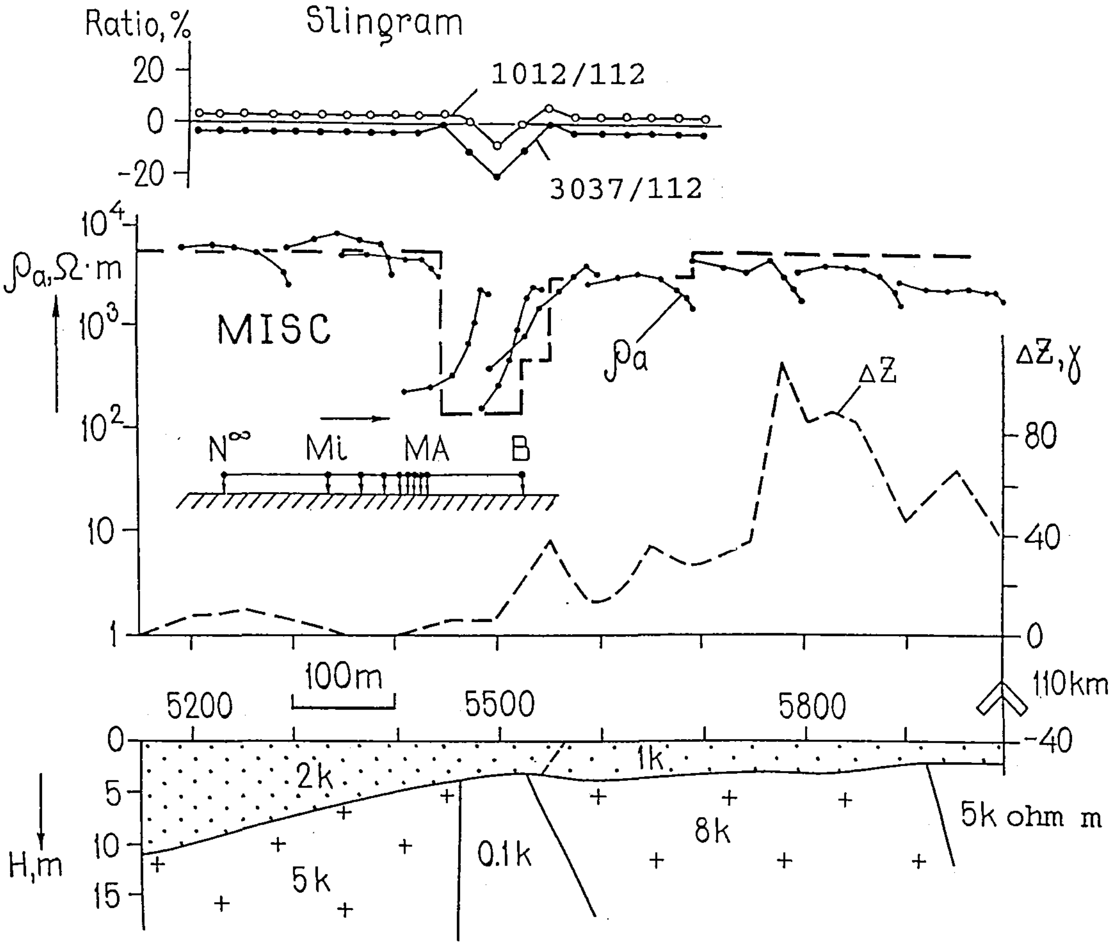

Figure 5: Example of MISC and Slingram profiling over a moderately conductive structure.

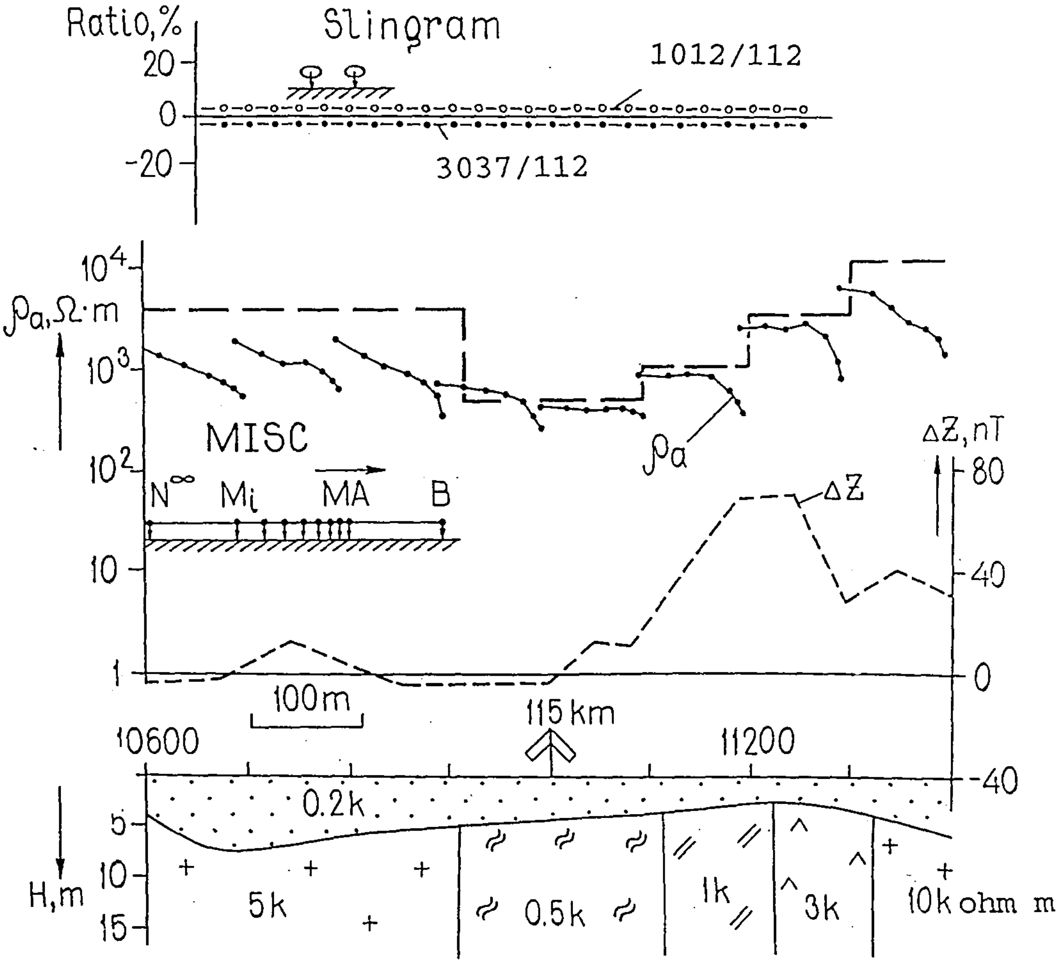

Figure 6: Example of MISC and Slingram profiling over a low conductive structure.

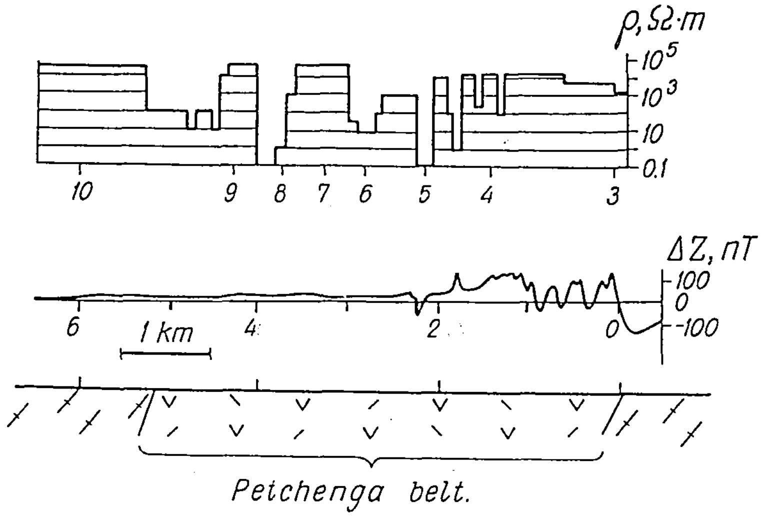

Figure 7: The result of MISC and magnetic profiling along the PAS-1 profile.

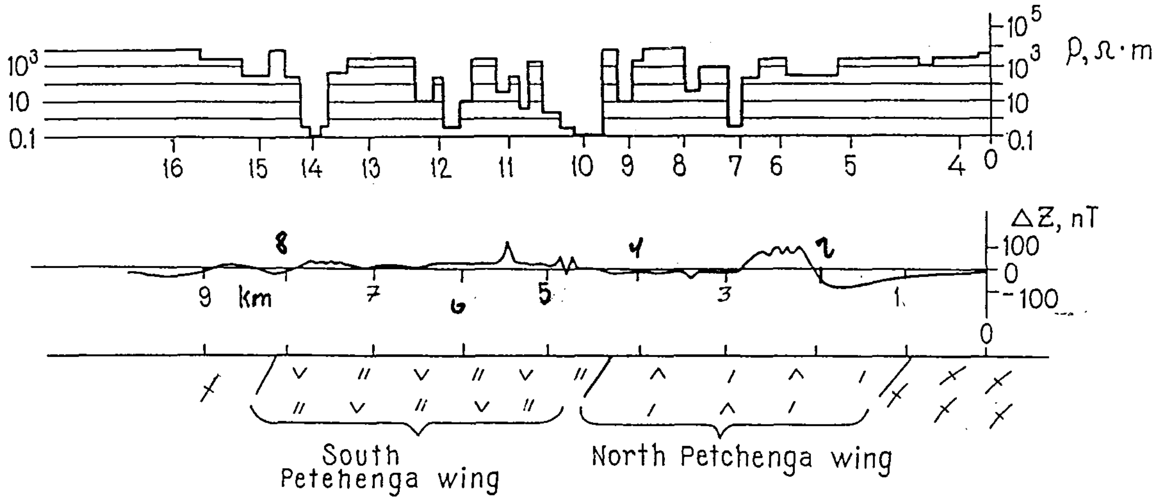

Figure 8: The result of MISC and magnetic profiling along the PAS-2 profile.

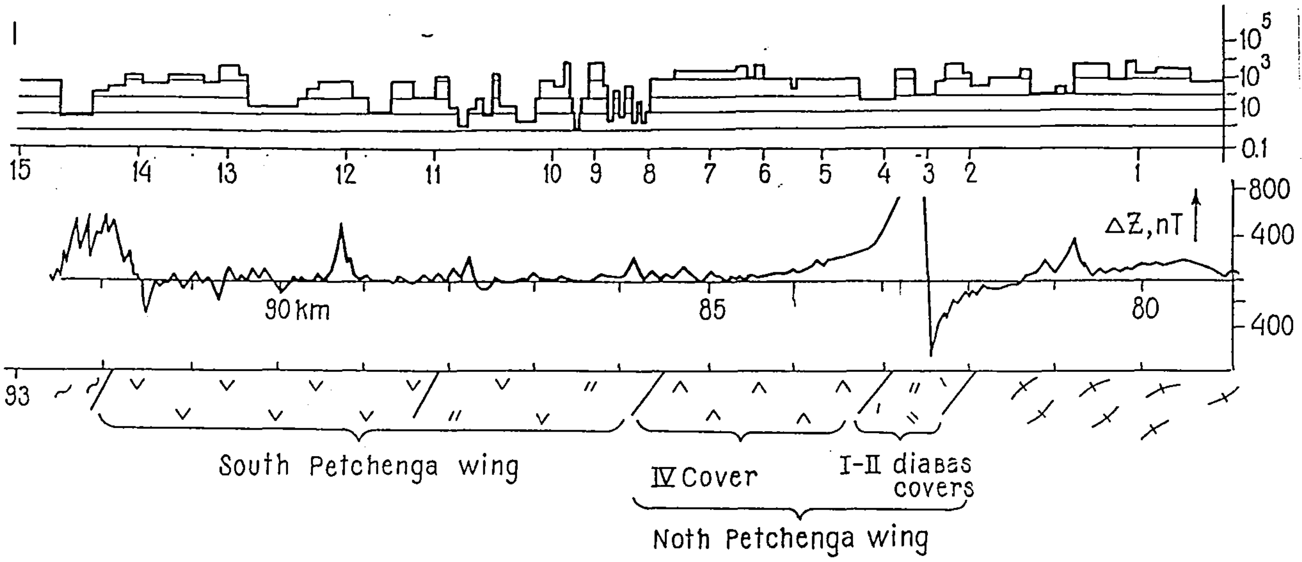

Figure 9: The result of MISC and magnetic profiling along the Rayakoski profile.

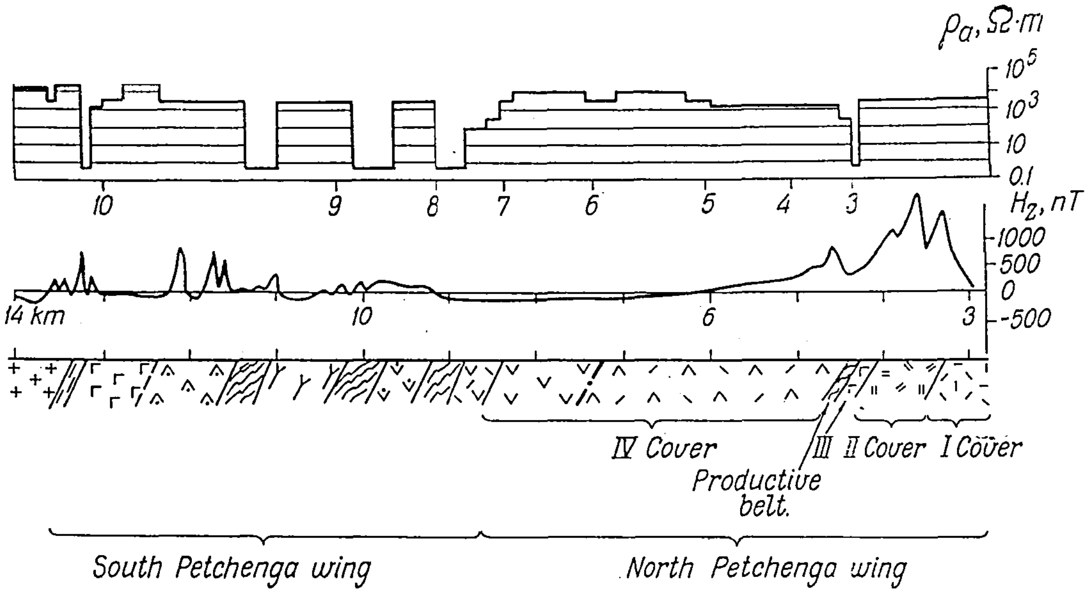

Figure 10: The result of MISC and magnetic profiling along the Shuoni-Kuets profile.

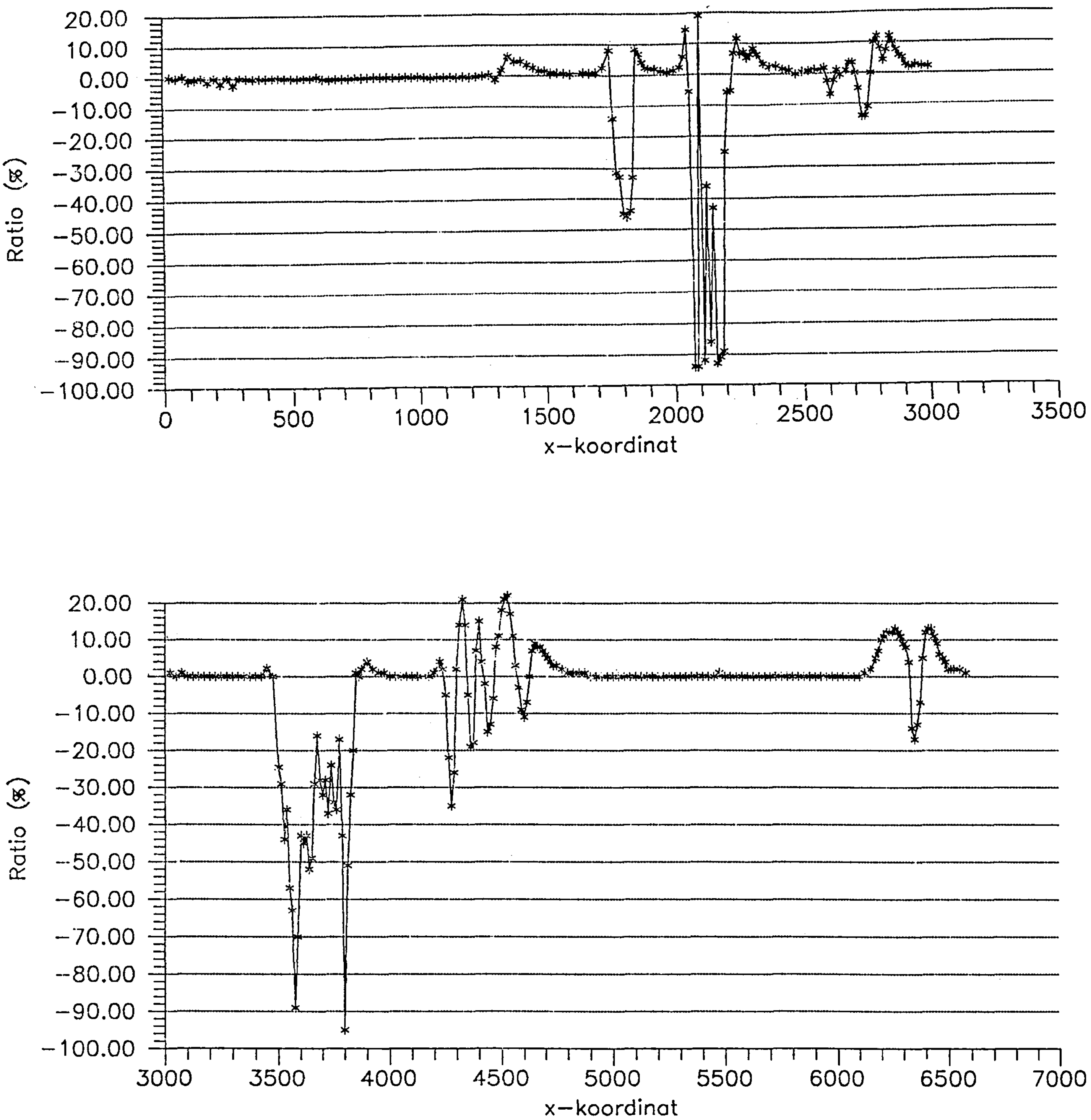

Figure 11: Results of Slingram profiling along the PAS-1 profile.

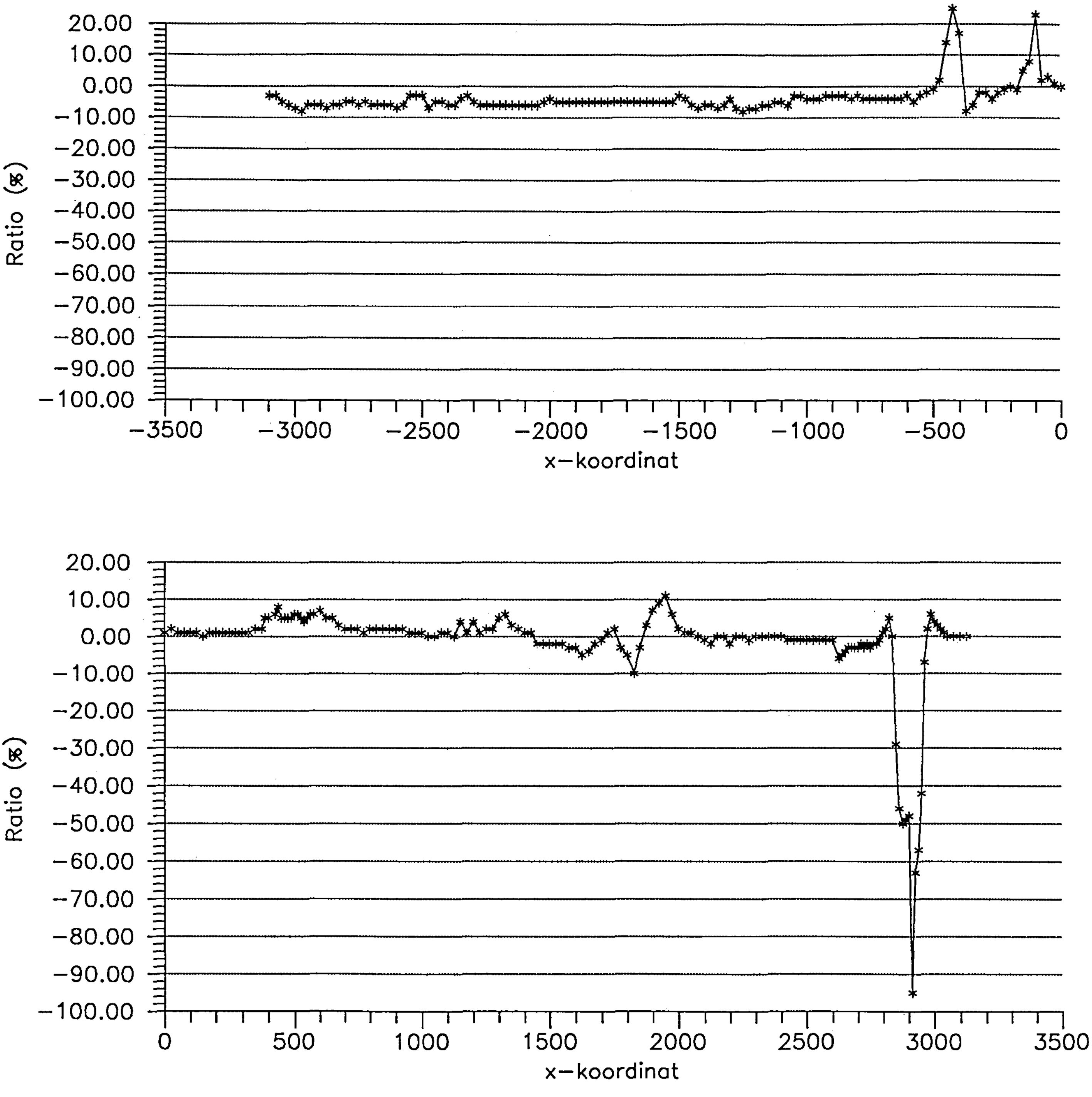

Figure 12: Results of Slingram profiling along the PAS-2 profile.

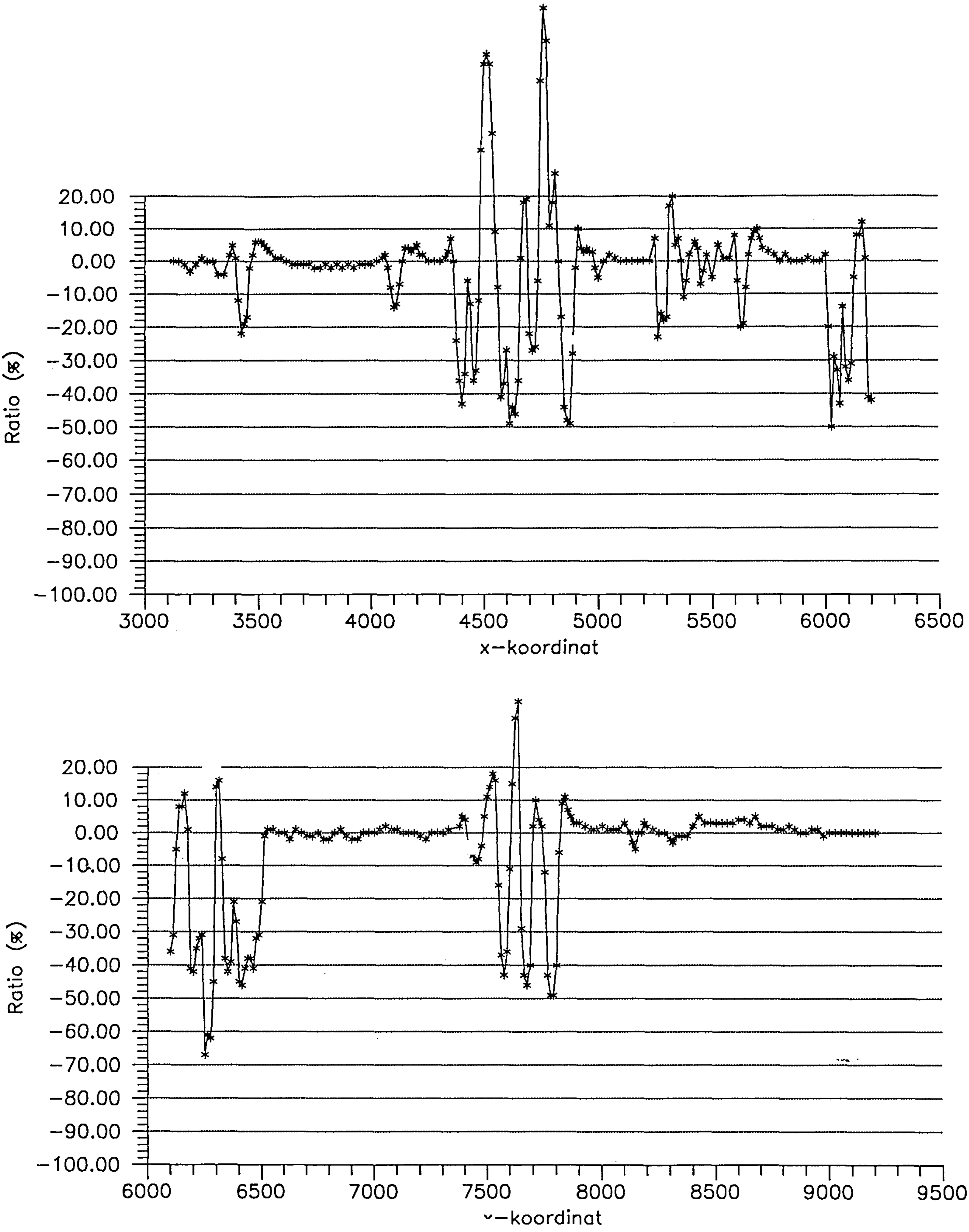

Figure 12 (continued): Results of Slingram profiling along the PAS-2 profile.

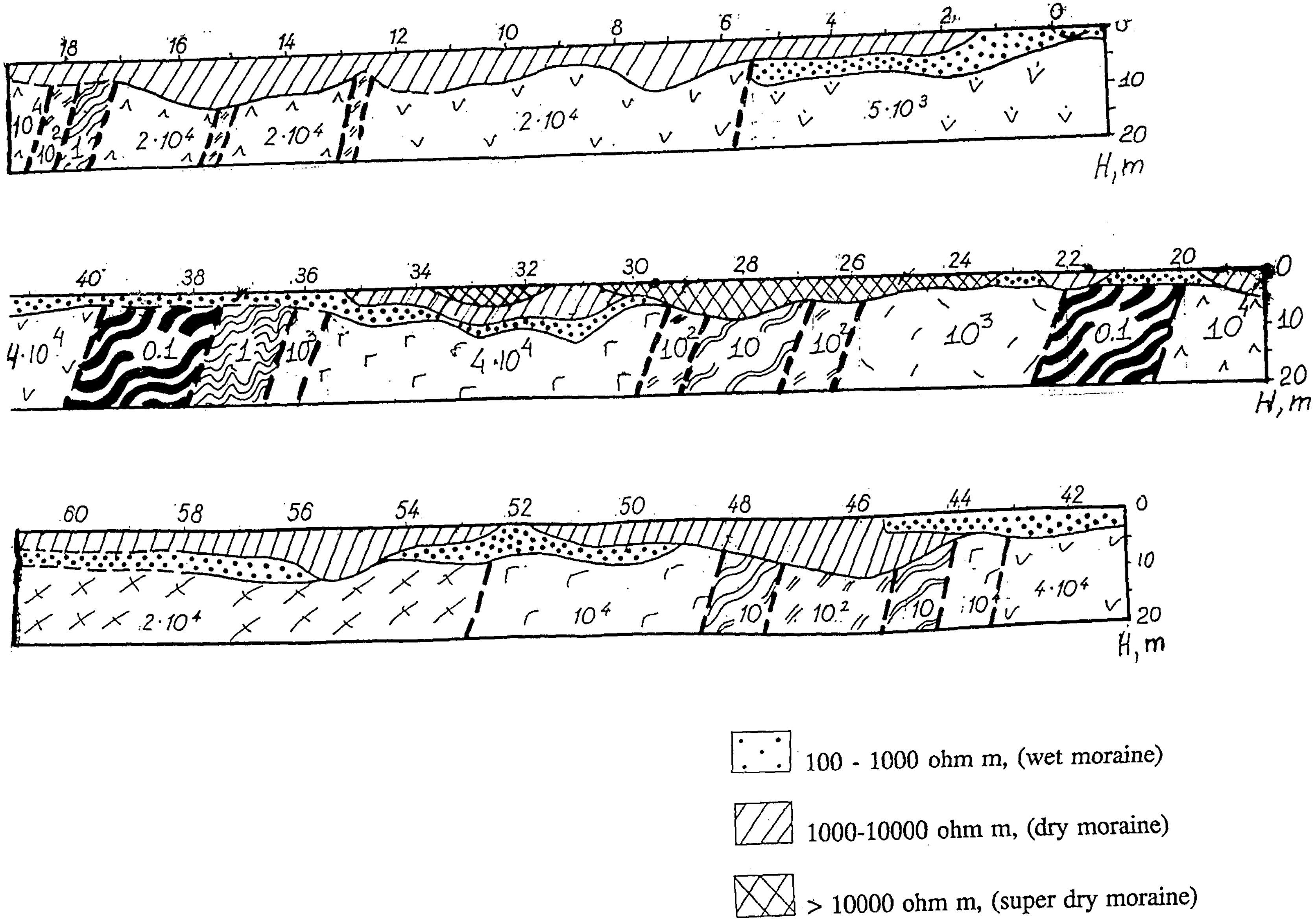

Figure 13: Interpreted resistivity cross-section along the profile Pas-1.

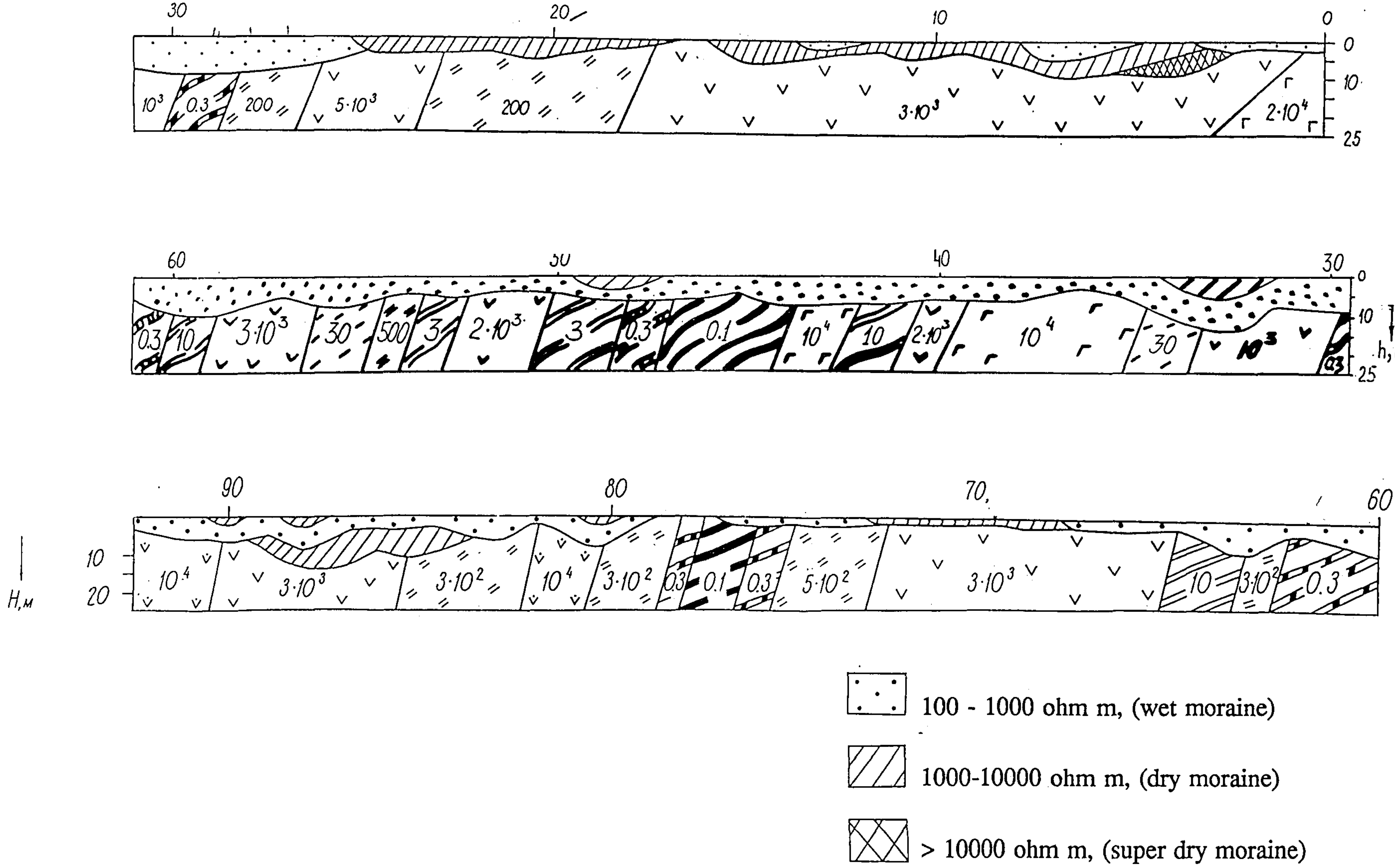

Figure 14: Interpreted resistivity cross-section along the profile Pas-2.