31. ON THE APPLICATION OF GEOPHYSICS IN THE INDIRECT EXPLORATION FOR COPPER SULPHIDE ORES IN FINLAND

M. Ketola
Outokumpu Oy, Exploration, Finland.

Ketola, M., On the application of geophysics in the indirect exploration for copper sulphide ores in Finland; in Geophysics and Geochemistry in the Search for Metallic Ores; Peter J. Hood, editor; Geological Survey of Canada, Economic Geology Report 31, p. 665-684, 1979.

Abstract

Exploration for sulphide ores in Finland is becoming increasingly difficult. Most of the easily detectable economic sulphide ores, whose location is indicated either by outcropping mineralization or by measurable geophysical anomalies, have probably been discovered. Hence measurements conducted by conventional geophysical methods are less and less able to pinpoint an anomaly caused by an ore deposit. For the time being, however, the survey data collected by various geophysical results can often be utilized in indirect exploration, in which they serve as a supplement to the geological information available on the survey area. This paper presents some examples to illustrate the principle of combining various geophysical methods and adapting them to the exploration for sulphide ores in Finland.

Résumé

L'exploration des minerais sulfurés en Finlande devient de plus en plus difficile. La plupart des gîtes sulfurés "facilement repérables", ayant une valeur économique, et dont la position est indiquée soit par des affleurements minéralisés, soit par des anomalies géophysiques mesurables, ont probablement déjà été découverts. Ceci explique que les mesures découlant des méthodes géophysiques conventionnelles permettent de plus en plus rarement de localiser des anomalies dues à la présence d'un gisement métallifère. Mais pour l'instant les résultats de divers levés géophysiques, qui apportent un appoint d'information géologique, permettent souvent une exploration indirecte dans la région étudiée. Dans le présent rapport quelques exemples illustrent la méthode, qui consiste à combiner diverses méthodes géophysiques, et à les adapter à l'exploration des minerais sulfurés en Finlande.

INTRODUCTION

In Finland, where the bedrock is intensely metamorphosed and is almost completely of Precambrian age, sulphide ore prospecting concentrates mainly on areas with all but ubiquitous graphite-bearing schists. These rocks, which in Finland are usually called black schists or phyllites, contain variable amounts of pyrrhotite and pyrite. Because the thickness of the overburden is mostly less than 30 m and its resistivity, except in coastal areas, is high, varying according to Puranen (1959) from 50 to 30 000 Ωm, black schists are normally delineated by means of electrical methods. If the black schists contain appreciable amounts of pyrrhotite, as they often do, they can also be detected by magnetic measurements.

Prospecting for sulphide ores in black schist areas is however becoming increasingly more difficult. Most of the easily detectable economic sulphide deposits (i.e. ores) which can be localized either by means of a mineralized exposure or a conspicuous geophysical anomaly, have probably already been found.

It is typical of black schist areas that the number of anomalies resulting from magnetic and electrical surveys is far too high to make it economically feasible to check them all by diamond drilling. Seldom can a geologist establish the cause of an anomaly on an exposure. Pyrrhotite-bearing graphite schists and associated mineralization have usually been eroded more deeply by glacial ice than the surrounding country rock and thus they are mostly covered by overburden.

A fair number of methods are available for classifying geophysical anomalies and selecting explorationally-interesting anomalies in black schist areas, e.g. the simultaneous use of a combination of geophysical and geochemical methods. The contact polarization curve method developed in the Soviet Union and which uses the anodic and cathodic electrochemical reactions produced at the contact of mineralization with country rock, enables anomalies caused by graphite to be discerned from those caused by base metal mineralization. The method has been discussed in several publications, e.g. those by Ryss (1973), Parasnis (1974) and the U.S. Exchange Delegation in Mining Geophysics (1976).

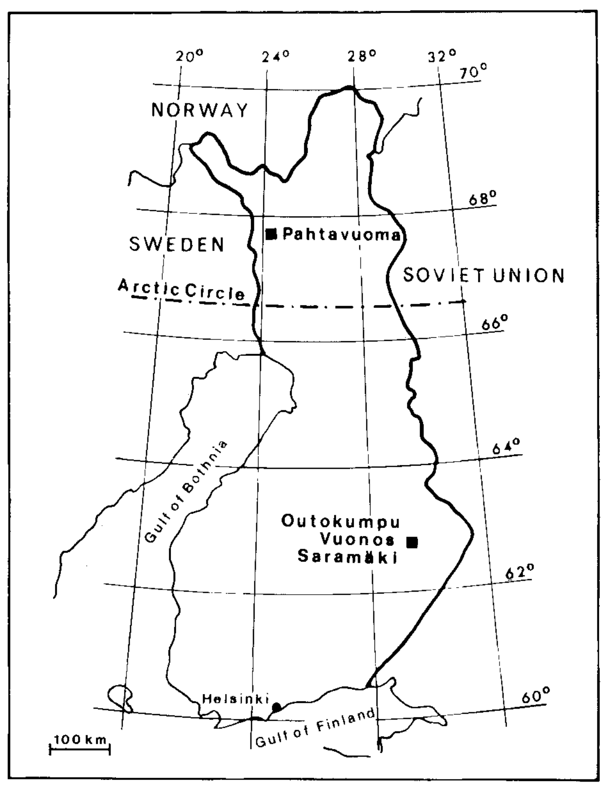


Figure 31.1. *Location of copper orebodies in Finland.*

Because it is difficult to discriminate between geophysical anomalies caused by economic sulphide mineralization and anomalies caused by black schists and other rocks, geophysical data are also utilized in so-called indirect exploration, in other words, in supplementing geological information. In the black schist areas of Finland, geophysical surveys are mainly conducted by magnetic, electromagnetic and gravity methods. The IP method is used only in special cases, owing to the intense electromagnetic anomalies caused by the black schist zones. Copper ores that occur in the black schist areas pose a very difficult exploration problem. This paper deals with geophysical results and their use in indirectly exploring for copper ores within black schist areas.

The copper deposits of Vuonos and Saramäki in the Outokumpu area in eastern Finland and the Pahtavuoma deposit, associated with the greenstone area of Kittilä, in northern Finland, have been selected as examples. The average copper content at Vuonos is about 2.5 per cent, at Saramäki 0.7 per cent and at Pahtavuoma 1.0 per cent. A map of Finland showing the location of the deposits discussed is presented in Figure 31.1.

The ores of Vuonos and Saramäki are of the Outokumpu-type, which means that they are compact copper ores with some cobalt. The ores occur in a geological formation that is surrounded by mica gneiss and is characterized by serpentinites, dolomites, skarns, quartz rocks and black schists. By means of aerogeophysical maps, this rock complex known as the Outokumpu association, can be traced for more than 240 km.

The Outokumpu deposit, averaging 3.80 per cent Cu and 0.20 per cent Co, was discovered in 1910. The orebody lies in a depression in association with serpentinite-quartzite formations. The total length of the ore deposit is 4 km. The width fluctuates from 200 to 400 m in the central part of the deposit but tapers off to the southwest at a depth of 150 m. At the extreme northeastern end, the orebody outcrops. The ore varies in thickness from a few metres to 40 m, the average being about 10 m. At the northeastern end the deposit dips 30° to 60° SE but is almost subhorizontal in the southwestern end. Some of the publications in which the geology of the Outokumpu and Vuonos ores is discussed, are those by Vähätalo (1953), Isokangas (1975) and Gaál, Koistinen and Mattila (1975). The latter paper includes a slingram (horizontal loop EM) map of the Outokumpu zone covering an area of 150 km^2.

THE GEOPHYSICS OF THE ORE DEPOSITS

The Vuonos orebody, eastern Finland

The Vuonos orebody, located about 4 km northeast of Outokumpu, was found in 1965. Preliminary drilling demonstrated that the Vuonos area, underlain by thick serpentinite-quartzite formations, was analogous to the Outokumpu area. Lithogeochemical investigations of drill cores, analyzed for sulphide copper, nickel and cobalt, showed that the copper content and the nickel-to-cobalt ratio in the serpentinites at Vuonos were anomalous compared with the serpentinites in the areas free from cobalt mineralization. Häkli (1963) has shown that in areas where serpentinites are not associated with copper-cobalt mineralization their nickel-to-cobalt ratio is similar to that in ultramafic rocks and varies from 20:1 to 25:1. Follow-up drilling led to the discovery of the Vuonos ore, whose average Ni-to-Co ratio is 2:3.

The geological and lithogeochemical investigations of the Outokumpu area have been reported by Huhma and Huhma (1970).

The Vuonos orebody is about 3.5 km long and 50 to 200 m wide. The average thickness is 5 to 6 m but it may attain as much as 20 m. The ore tapers out gradually towards both ends. The southwestern end is at a depth of about 60 m and the northeastern at a depth of about 200 m. Hence the orebody is blind.

The magnetic, slingram and gravity maps of the Vuonos area are presented in Figure 31.2 and show that the subhorizontal copper ore is not detectable by those methods. Figure 31.3 shows the geophysical results along profile y = 194.25 directly across the Vuonos orebody. The petrophysical data is plotted in profile form along the holes drilled in the profile. Resistivity values were obtained by in situ measurements by the single-point method, the smallest measured resistance being 1 Ω. The susceptibility and density determinations were done in the laboratory on drill core samples about 10 cm long, at intervals of 1 m for the whole length of the hole. Considering the geological and petrophysical information, the density of the conducting chrysotile serpentinite overlying the ore is low and the susceptibility higher than that of the surrounding rock types. The negative slingram anomalies are due to the black schists that, in conjunction with serpentinite, also cause magnetic anomalies. The susceptibility of the skarn is low, but the density is higher than that of other rock types, and so these rocks give rise to the positive gravity anomaly measured on the profile. Due to its horizontal position and great depth, the high density conducting orebody cannot be localized by means of geophysical methods because the anomalies produced by the country rocks camouflage the weaker anomaly produced by the ore.

The Saramäki orebody, eastern Finland

The Saramäki copper ore of Outokumpu-type is located in a formation that consists of skarns, serpentinites, quartzites and black schists surrounded by mica gneiss. The ore, which was found by drilling, outcrops. Nontheless it is not possible to localize it on the basis of the geophysical results depicted in Figure 31.4. The geology and resistivity results plotted along the drillholes show that the whole formation is a good conductor. The negative slingram anomalies are mainly caused by the black schists. The susceptibility values suggest that the formation is heterogeneously magnetized and that its upper part produces the strong magnetic anomaly. The gravity anomaly is generated by the whole formation, the density value of which differs clearly from that of the surrounding mica gneiss.

The Pahtavuoma orebody, northern Finland

The four ore lenses, found after the discovery of some copper-bearing outcrops at Pahtavuoma, are situated in a phyllite schist zone in the southern part of the Kittilä greenstone formation. The phyllite zone strikes from east to west. The phyllites are graphite-bearing and cause the strong slingram and VLF-EM anomalies shown in Figure 31.5. The VLF-EM map suggests that the phyllites are notably more continuous along the strike than does the slingram map, on which the anomalies are discontinuous from east to west. This is probably due to the higher frequency and better depth penetration of the VLF-EM method. The outcrops of the two ore lenses (A ore, the largest, and Uila ore) are depicted on the geophysical maps in Figure 31.5. It is clear from the magnetic and gravity maps that the phyllite zones and ore lenses cannot be located by geophysical techniques. One reason is that the pyrrhotite content of the phyllites is very low. In Figure 31.6, the geophysical and petrophysical data of the profile y = 11.9 from Figure 31.5 are presented together with the geological information. The magnetic curve drawn in the upper part of the figure is almost nonanomalous, and the

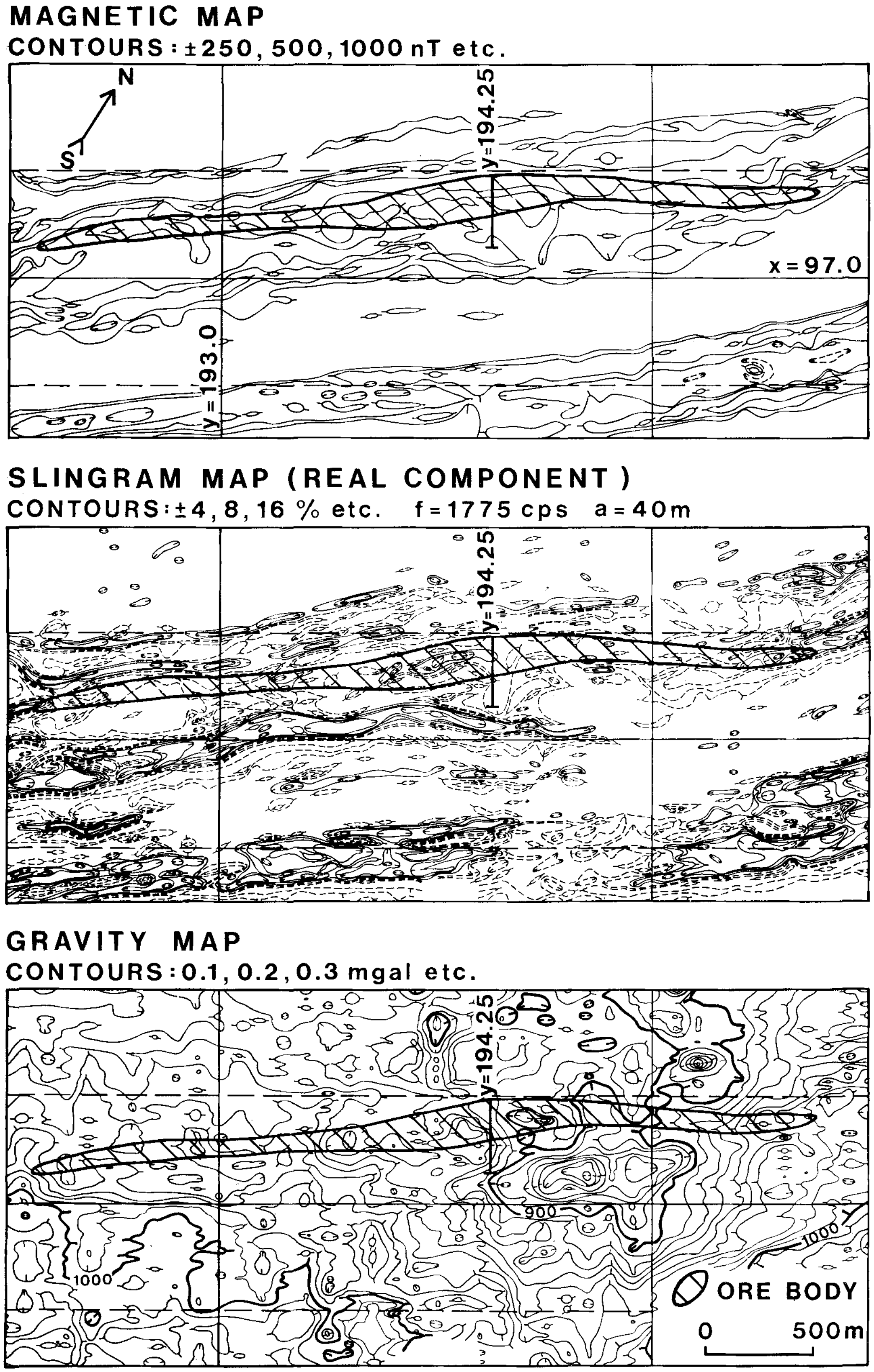


Figure 31.2. *Geophysical maps of the Vuonos area.*

Contents

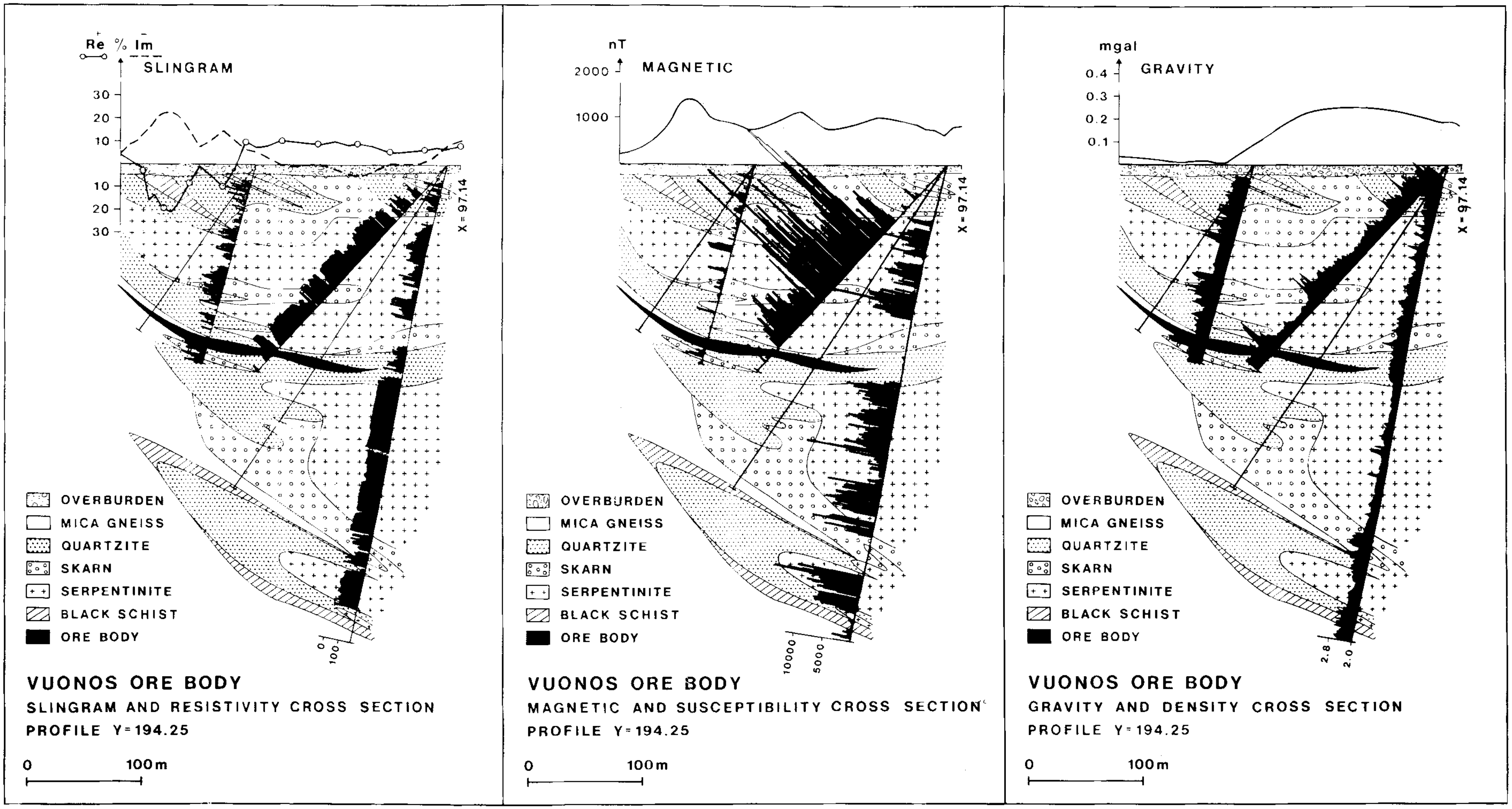
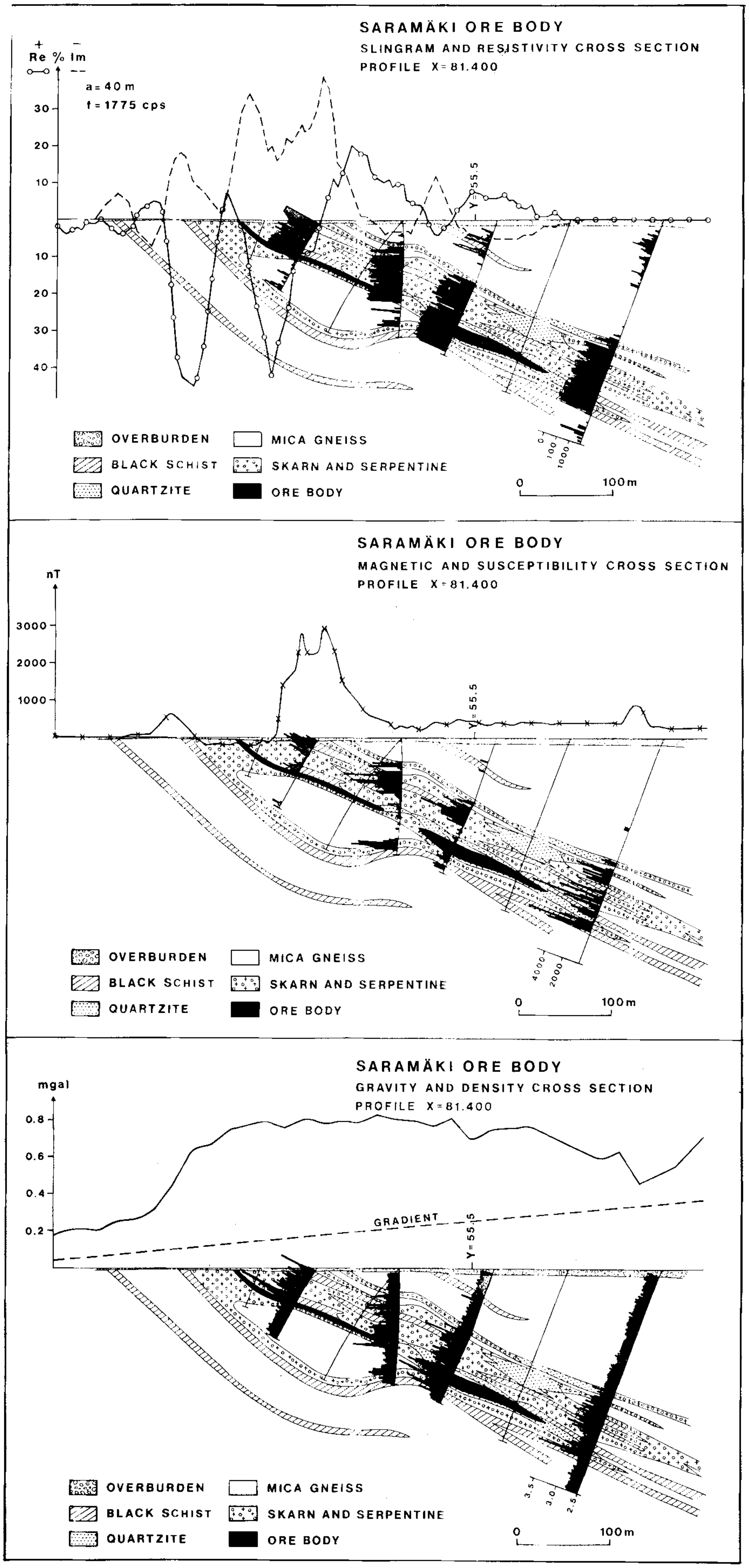


Figure 31.3. *Geophysical and petrophysical data from profile y = 194.25 in the Vuonos area. The values on the drillhole profiles are respectively in Ω, x 10^{-5} SI and gm/cc.*

Contents



susceptibility determinations made on drill cores gave values that were too low to warrant their inclusion in Figure 31.6. The resistivity measurements conducted in drillholes demonstrate that the slingram anomalies are caused by phyllites and that the ore cannot be detected electromagnetically. In the lower part of Figure 31.6, next to the drillholes, the average density values for different rock types have been drawn. The density of phyllites is lower than that of greenstones. Although the alternation of phyllites and greenstones is not clearly seen from the gravity curve due to the steep gradient, these rocks can be localized on the residual anomaly map.

Kokkola and Korkalo (1976) have described the till- and stream-sediment investigations in the Pahtavuoma area. Soil surveys, whose purpose was to classify geophysical anomalies, turned out to be difficult to interpret owing to the existence of five till beds and layers deposited by ice that moved successively in different directions and because the shape of a geochemical anomaly in till depends on the direction of glacial transport.

GEOPHYSICAL METHODS IN GEOLOGICAL MAPPING

Because it has not been possible by means of geophysical methods to localize directly the copper ores at Vuonos, Saramäki and Pahtavuoma, survey data have and will continue to be used for indirect exploration in these areas.

The following chapter gives some examples of the use of airborne, ground and drillhole methods in the indirect exploration for sulphide ores.

Airborne geophysical surveys

The first phase of exploration of extensive areas entails airborne magnetic and electromagnetic (AEM) surveys. These are presently being conducted at a low flight altitude and with a dense line spacing, because the general aerogeophysical maps made by the Geological Survey of Finland from a flight altitude of 150 m already cover the whole country. The aim of the low-altitude airborne geophysical surveys is to obtain a picture of the magnetized and conductive rock types of the area under investigation in as great a detail as possible. Because the thickness of the overburden in Finland averages only 8 m, rigid airborne electromagnetic systems are eminently suitable for mapping the magnetic and conductive rock types in black schist areas that suboutcrop under the overburden.

Figure 31.7 shows an aeromagnetic and AEM map of the Miihkali area about 10 km north of Saramäki surveyed from an altitude of 40 m with a 125 m linespacing. The AEM

Figure 31.4.

Geophysical and petrophysical data from profile x = 81.4 over the Saramäki orebody.

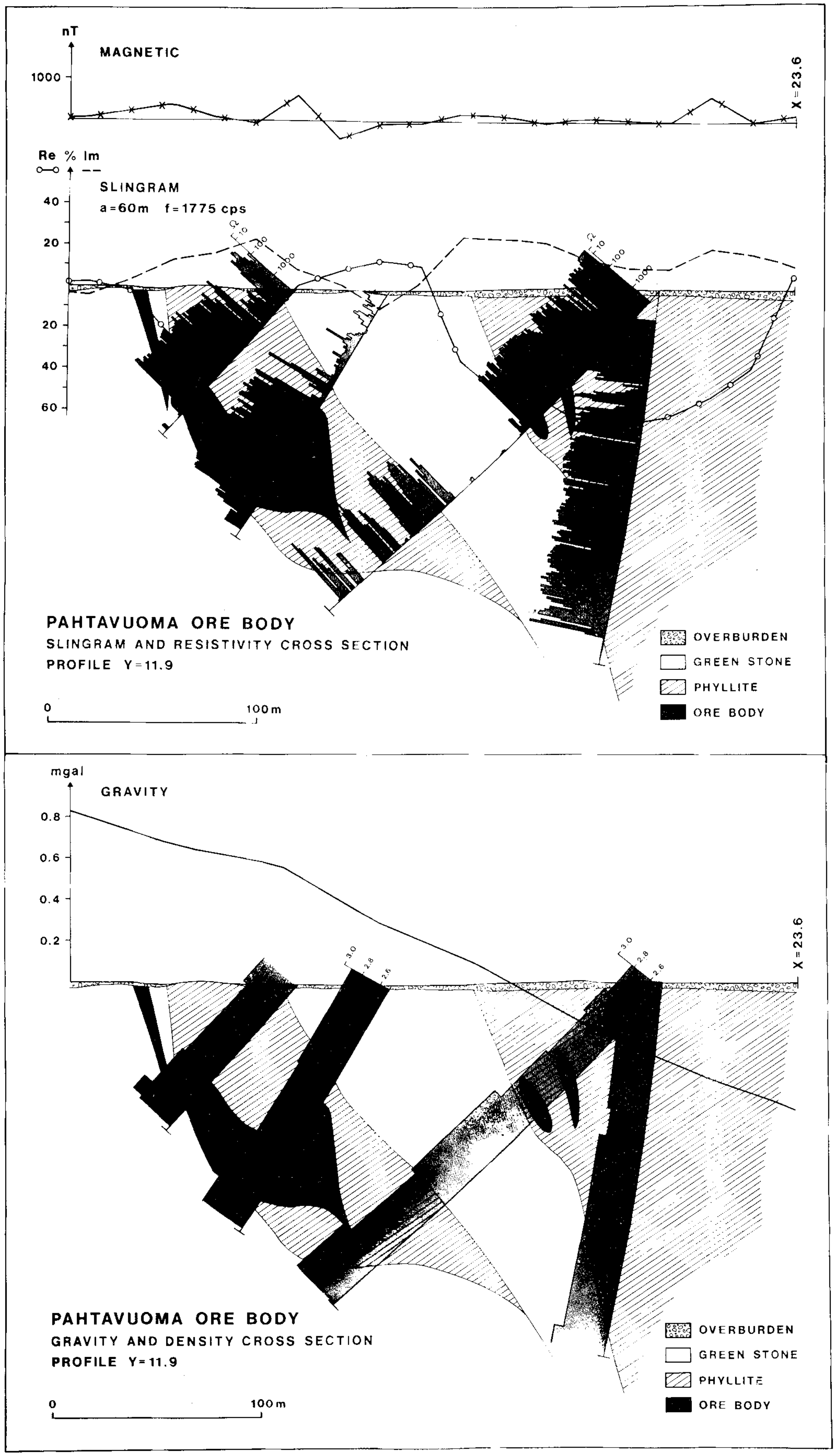


Figure 31.6. *Geophysical and petrophysical data from profile y = 11.9 in the Pahtavuoma area.*

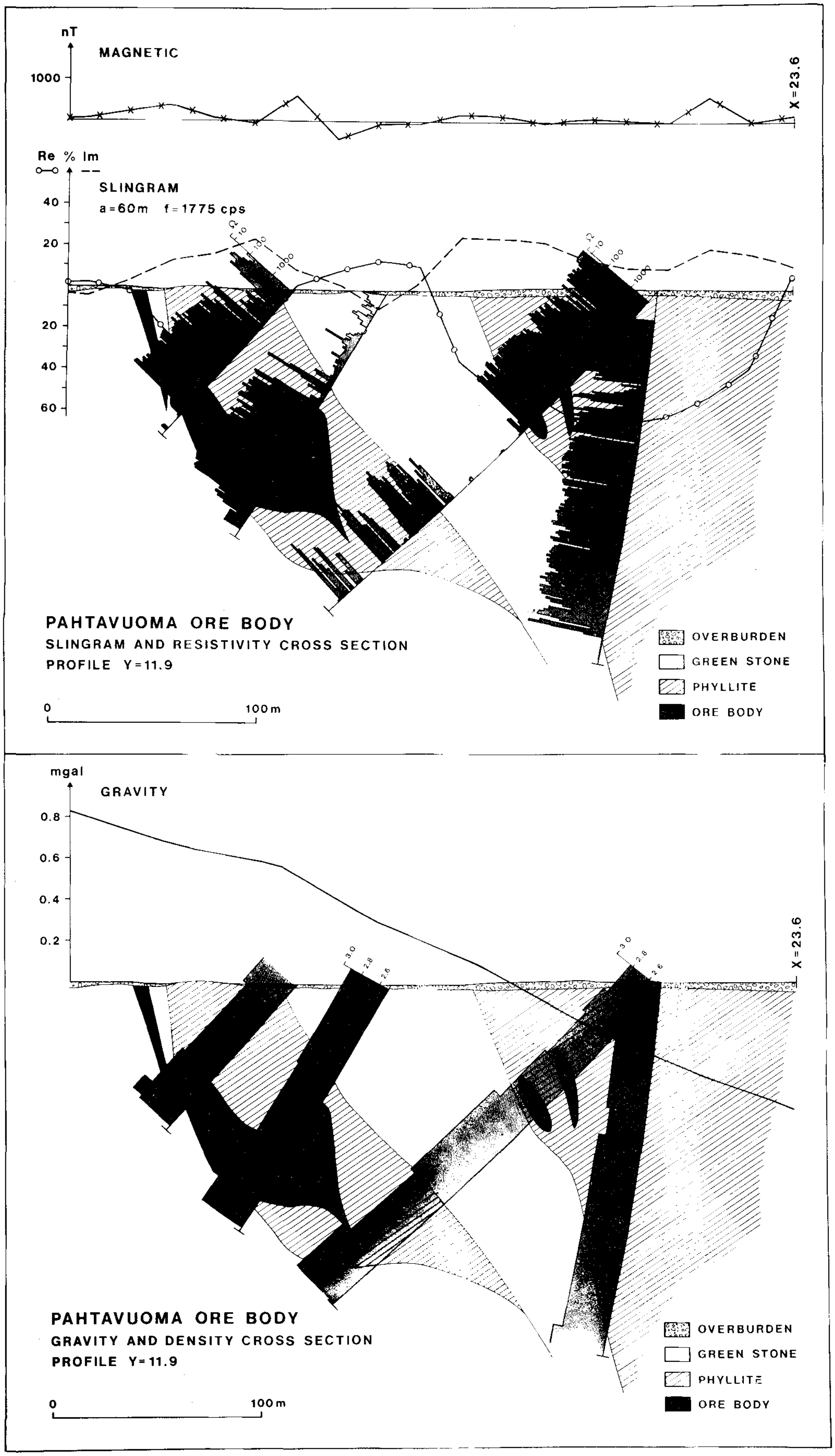


Figure 31.6. *Geophysical and petrophysical data from profile y = 11.9 in the Pahtavuoma area.*

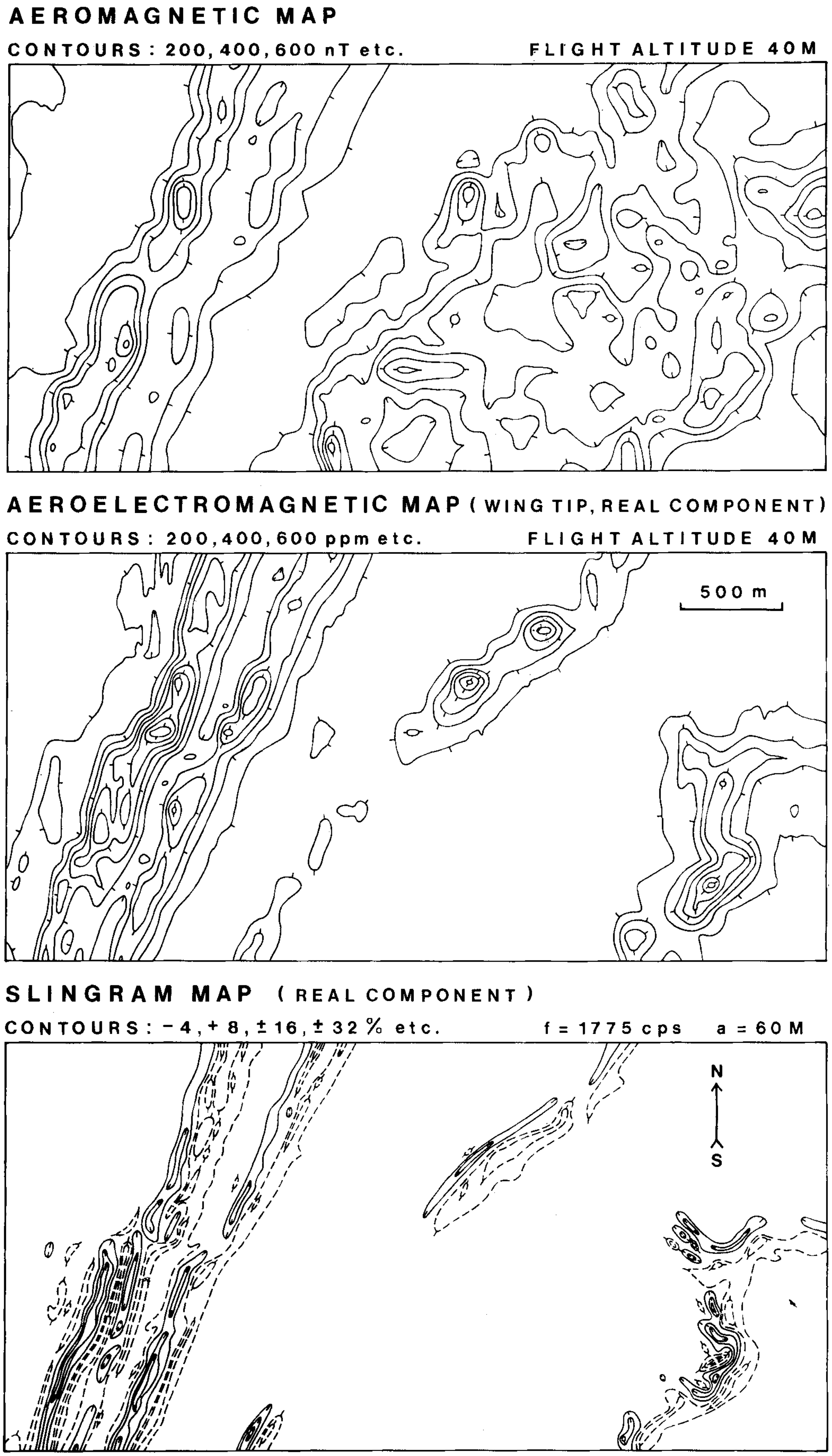


Figure 31.7. *Comparison between airborne and ground geophysical data from the Miihakali area.*

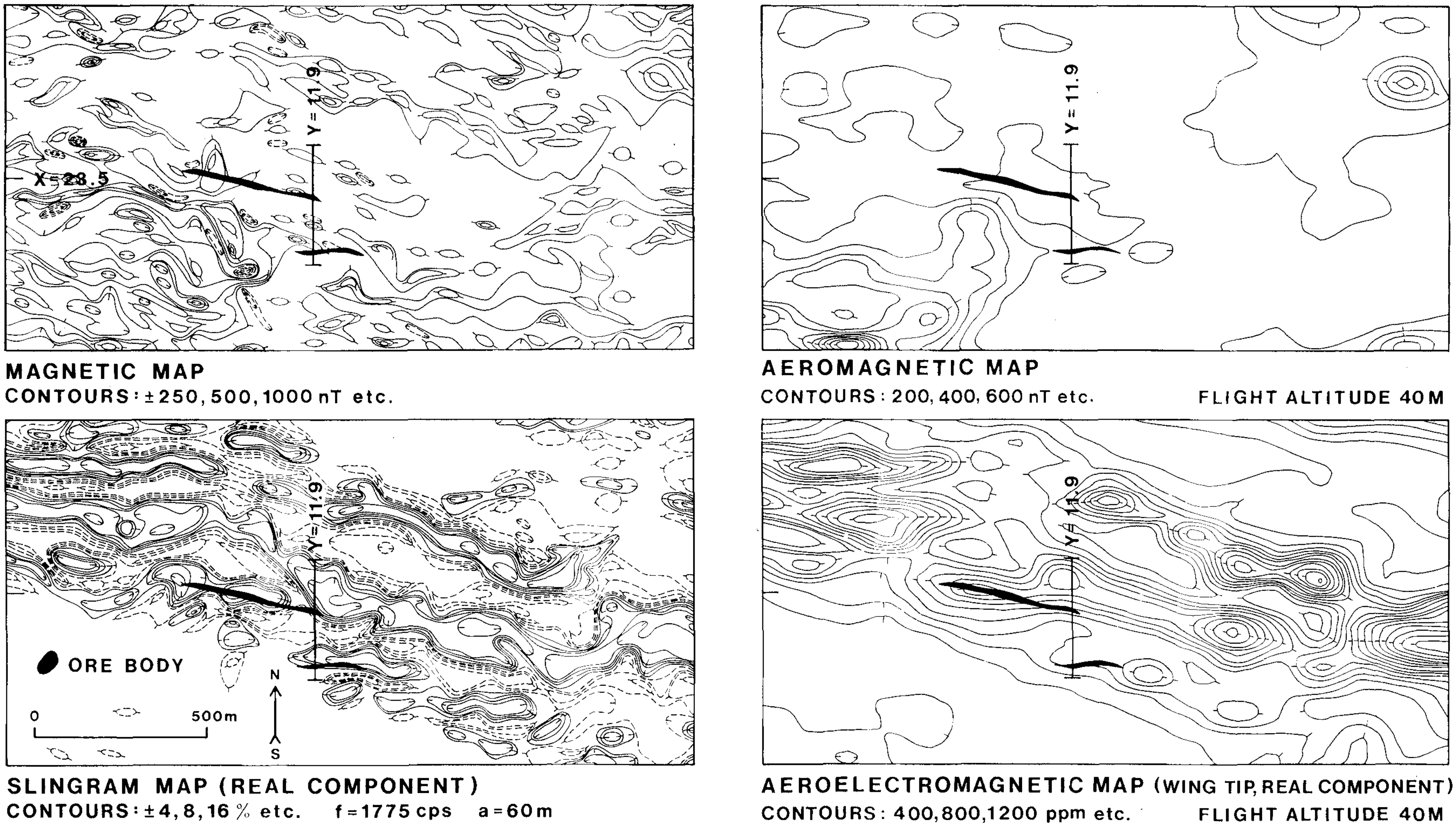


Figure 31.8. *Comparison between airborne and ground geophysical data from the Pahtavuoma area.*

measurements were obtained using the Coplanar-coil wing-tip system. For the sake of comparison, the slingram real component map of the area investigated by airborne surveys is also shown in Figure 31.7. The correlation between the AEM and ground EM results is excellent bearing in mind the inevitable broadening of the AEM anomalies with height. Experience has shown that if the flight lines are perpendicular to the strike of the conducting zones and the flight-line positioning is sufficiently accurate, the Coplanar-coil wing-tip AEM system gives results that closely correspond to those of the slingram method. If the direction of the flight lines coincides with the strike of the conducting zones, AEM measurements do not produce results as good as those obtained by ground EM surveys, because the latter allow a ready change of measurement direction to meet the requirements of the strike of the geological formations.

The airborne and ground geophysical surveys of the Pahtavuoma area are displayed and compared in Figure 31.8. The east-west striking, phyllite belt is indicated by the real component map of the AEM survey. The anomalies of the AEM map display a good correlation with slingram anomalies. The profiles in Figure 31.9 confirm the good correlation between the wing-tip and slingram results above the phyllite formation that enclose the orebodies in the Pahtavuoma area. The Pahtavuoma case indicates that AEM surveys provide detailed geological information in areas where the magnetite and pyrrhotite contents of the bedrock are so small that only weak anomalies occur. Thus the AEM technique may be used as a geological mapping tool in such areas.

Ground geophysical surveys

The detailed results of low-altitude airborne magnetic and electromagnetic surveys have reduced the need for ground measurements, so these have been concentrated on those areas favourable for the occurrence of ores. In order to augment geological information as much as possible these areas are investigated using several ground geophysical methods. The most commonly used are magnetic, slingram and gravity measurements carried out with a 20 m station spacing and 50-100 m line separation. The geophysical results of aeromagnetic and AEM measurements are sometimes supplemented by a gravity survey conducted over the whole flight area with a grid density of 0.5 to 1 km.

Copper-cobalt ores of Outokumpu type are associated with serpentinite-skarn-quartz rock formations, and so geophysical measurements can be used to localize these explorationally important rock types. Figure 31.10 presents the geophysical results from a profile in the Miihkali area. Several holes have been drilled on this profile to check the anomalies. The petrophysical information from some of the holes drilled in the profile is plotted in the lower part of Figure 31.10. A broad chrysotile serpentinite formation with low resistivity (r in ohms), low density (ρ in gm/cc) and high susceptibility (k x 10^{-5} SI) and which is represented by intersection 4 in hole D 6 can be localized by the positive magnetic and slingram anomalies and the well developed negative gravity anomaly. The positive gravity anomaly in the middle of the profile is caused by a skarn formation, whose average density (ρ), according to intersection 3, is 2.95 gm/cc. Pyrrhotite-bearing black schists produce strong magnetic and slingram anomalies.

Figure 31.11 shows the magnetic, gravity and slingram maps of the Usinjärvi area. A rounded anomaly is visible in the middle of the area. The negative gravity anomaly and the positive slingram anomaly suggest that the magnetized formation is conductive and that its density is low. It is a chrysotile serpentinite body in the northern part of which there are black schists that cause negative slingram anomalies.

In the localization of ultrabasic formations, especially when prospecting for nickel ores, systematic gravity surveying has turned out to be of much practical importance. Presented in Figure 31.12 A and B are the results of magnetic, slingram and gravity measurements performed in two different black schist areas. In both areas the black schists cause strong slingram anomalies. Figure 31.12 B shows a gravity anomaly caused by a peridotite body, in the northeastern end of which there is nickel mineralization that also causes a weak magnetic and slingram anomaly. A strong positive anomaly is depicted on the gravity map in Figure 31.12 A. This anomaly is produced by a peridotite body that cannot be discovered by means of a magnetic survey as the magnetic results indicate.

Experimental reflection seismic measurements have been conducted in the Outokumpu area to trace the deep-seated continuation of the geological formations. The measurements and interpretation were the work of a team from the Institute of Seismology in Helsinki University under the leadership of Dr. E. Penttilä. Figure 31.13 is a simplified reflection seismic cross-section obtained across the

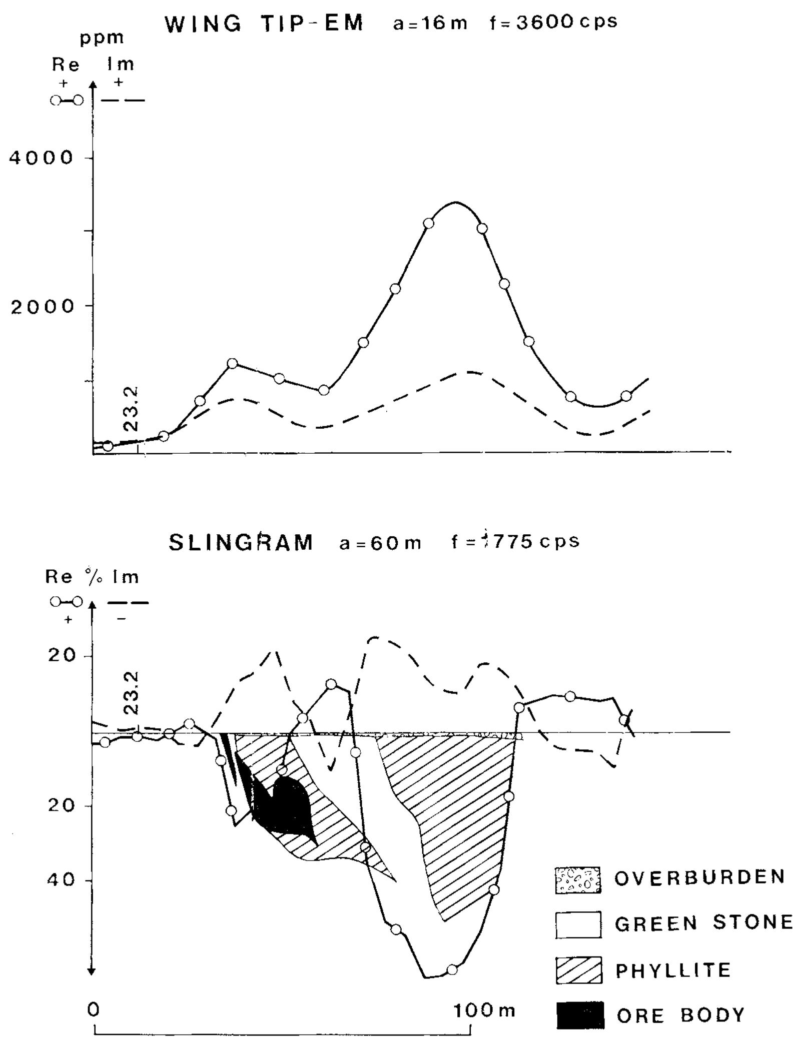


Figure 31.9. *Comparison between airborne and ground electromagnetic data from profile x = 11.9 in Pahtavuoma area.*

Outokumpu area. The location of the Outokumpu-association and the most clearly reflecting horizons have been marked in Figure 31.13 on the basis of the reflector distances. The reflections, of unknown origin, suggest that the Outokumpu formation might continue albeit thinly, down to a depth of about 1.5 km. The dip of the continuations begin to slope more gently at the greater depth. Thus the seismic technique can be of value in delineating the extension of important ore-associated formations at depth.

Figure 31.14 displays the magnetotelluric survey results in the Saramäki area where the continuation of the ore-associated formation was followed down to depth. As a result of this survey the conductive formation can partly be located. Anomalous area A indicates the upper part of the conductive formation. The anomalous area B correlates with the proven deeper parts of the formation and indicates further continuation to depth. The results do not indicate the presence of the ore-associated formation at depths between 300-400 m. The magnetotelluric surveys were carried out with French equipment fabricated by Societé ECA, acquired by the University of Oulu. The output of the apparatus was the apparent resistivity at nine frequencies from 8 to 3700 Hz. In the interpretation of the magnetotelluric results, an interactive computer program was adapted, which used a layered earth model and hyperparabola minimization process presented by Lakanen (1975).

The localization and establishment of deep-seated continuations of geological formations is important when planning deep and expensive drillholes for finding new ore deposits. It is obvious from the foregoing examples that the use of reflection seismic and magnetotelluric investigations is of considerable benefit in indirect exploration.

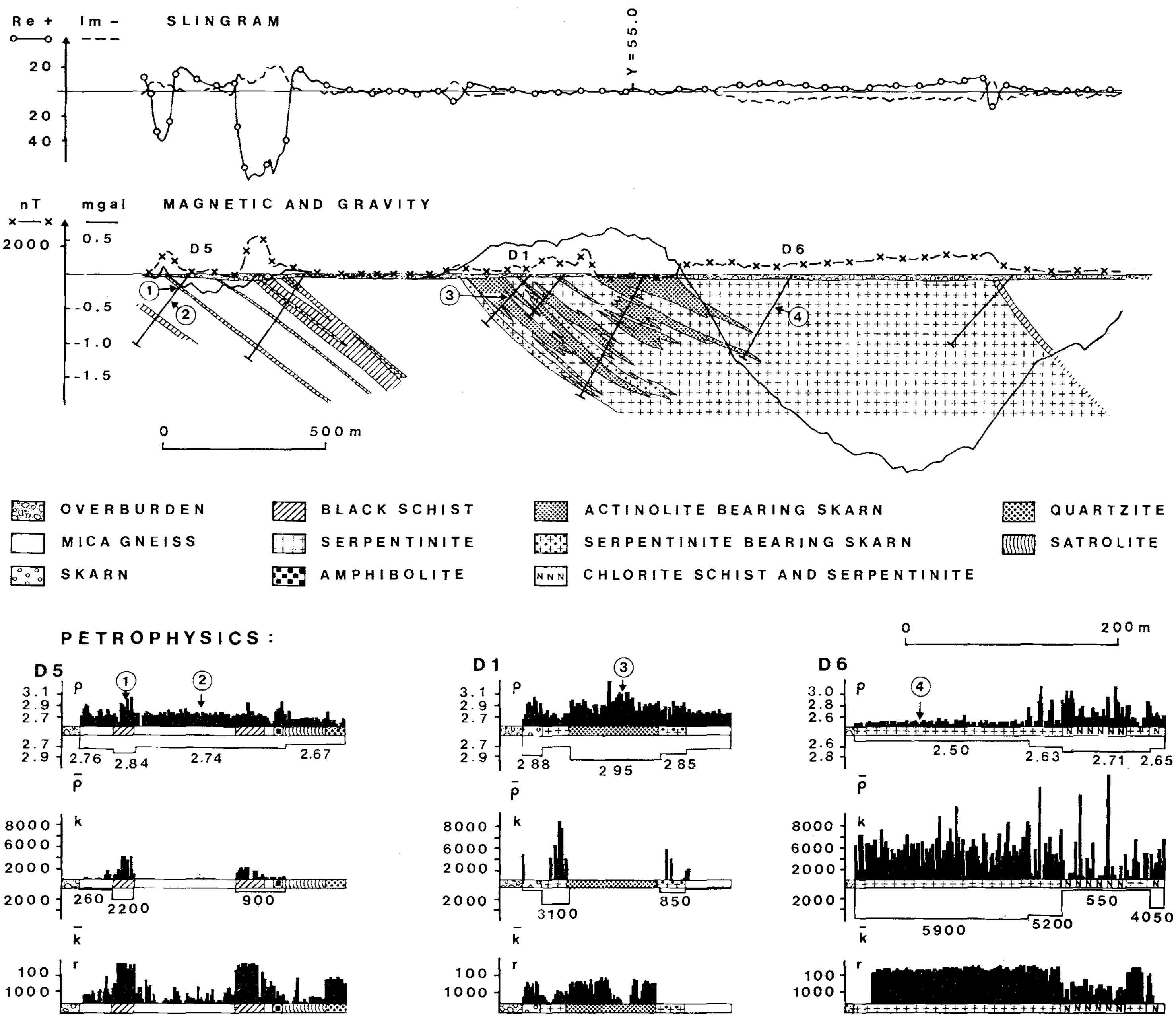


Figure 31.10. *Geophysical and petrophysical data from profile x = 91.0 in the Miihkali area.*

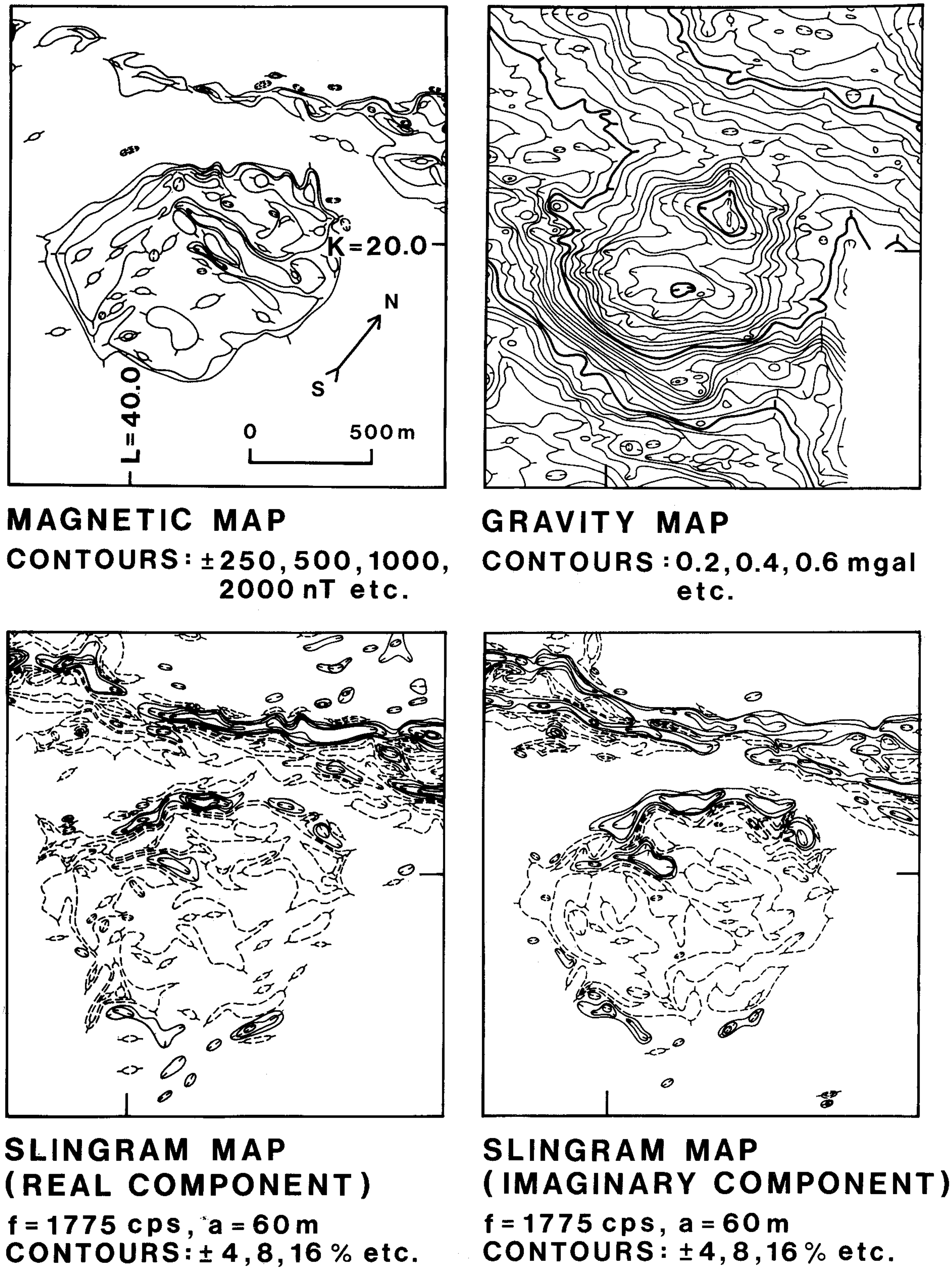


Figure 31.11. *Geophysical results from the Usinjärvi area.*

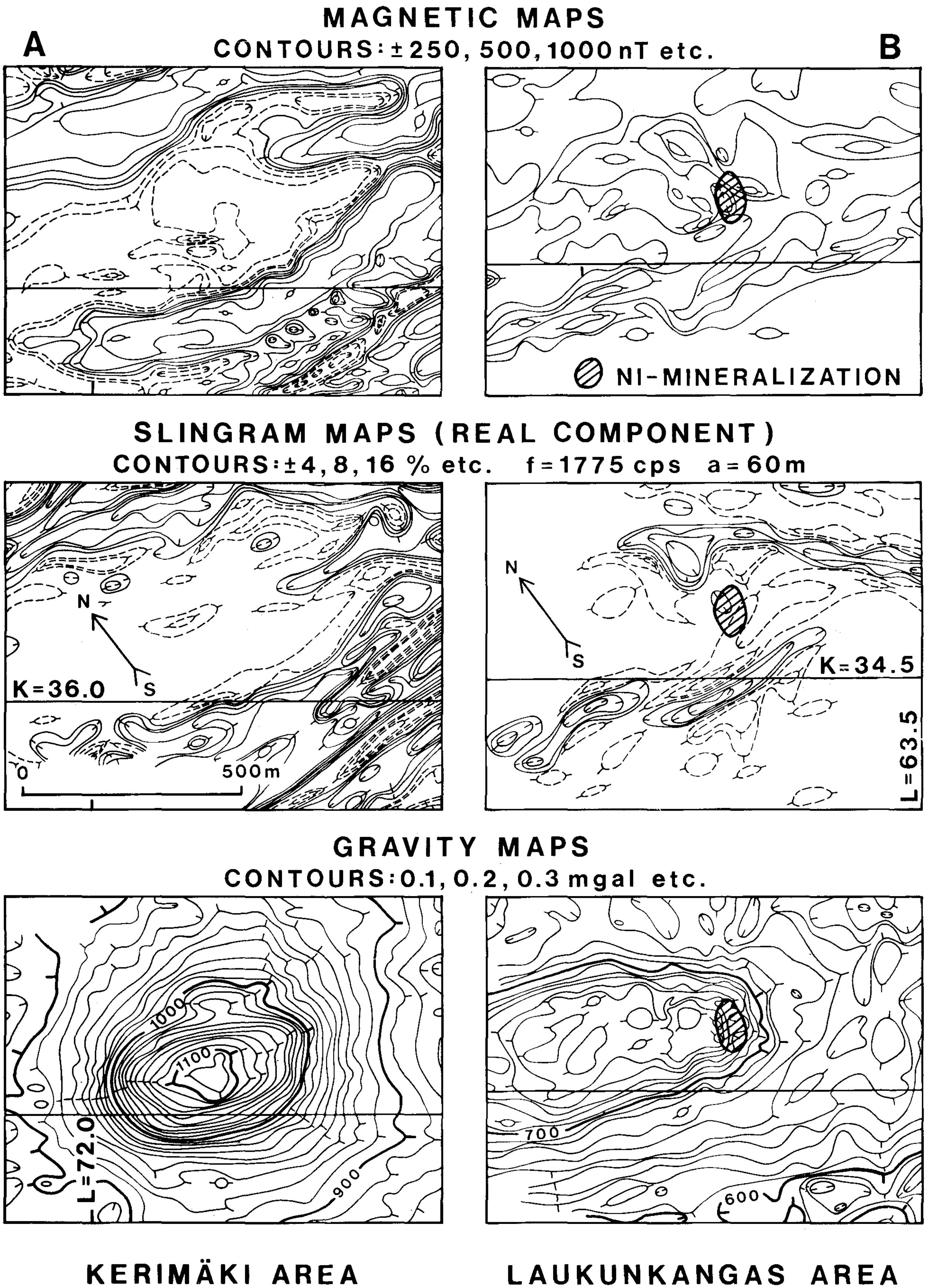


Figure 31.12. Geophysical results from the Kerimäki and Laukunkangas areas.

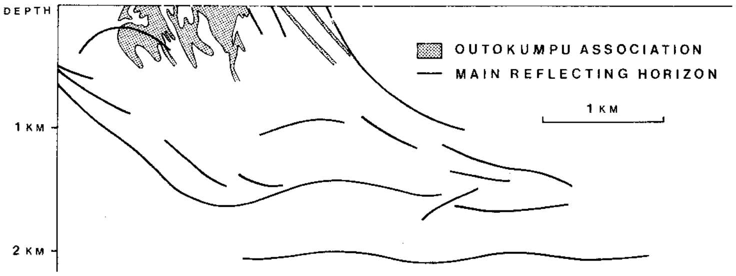


Figure 31.13. Reflection seismic cross-section through the Outokumpu area.

Borehole surveys

The inner structure of formations rich in black schists cannot usually be investigated by electrical ground methods. The conductive subsurface schists shield the underlying rocks, even though the depth penetration of the geophysical methods adopted would otherwise be sufficient. In some black schist areas it is possible to use electrical drillhole logging to investigate geological formations.

Figure 31.15 shows profile y = 12.0 from the Pahtavuoma area, where resistivity and charged-potential (mise-à-la-masse) measurements were obtained in the holes drilled into the orebody. The resistivity measurements demonstrate that there is a clear conductivity contrast between phyllites and greenstones. Although it was not possible to solve directly the connection between the ore intersections by means of charged-potential measurements, they nevertheless present an indirect means, because the host rock of the ore is a highly conductive phyllite.

The results of the charged-potential measurements, drawn in the form of the isoanomaly cross-section, reveal that ore intersections 1 and 2 are not located in the same phyllite formation, there being a marked increase in potential between the intersections. The holes drilled from the adit marked in Figure 31.15 confirm that a narrow weakly-conducting greenstone zone is sandwiched in phyllites.

The upper part of Figure 31.16 shows a slingram profile measured over the Outokumpu formation together with the holes drilled into it. The resistivity results are marked at the drillholes as are the intersections in which the conducting black schists and serpentinites occur in association with skarns. The geological picture given of the formation by drilling is not well established. To clarify the geological information charged-potential measurements were conducted using a number of grounding systems. The results from two of the grounding systems are depicted in Figure 31.16, and demonstrate that the formation is composed of various units. The results of grounding system 1 indicate that the formation surrounded by mica schist is a syncline. The results also demonstrate that there is a good conductivity connection between the intersections of the rock types favourable for the occurrence of ore in the southeastern part of the formation. The results of grounding system 2 are from another part of the formation, where the black schist-serpentinite intersections are at the same potential.

Ketola (1972) has published the results of the charged potential measurements conducted in the Saramäki (earlier called Miihkali) area. The ore formation was also investigated by means of SP measurements obtained on the surface and in drillholes. It can be seen from Figure 31.17 that the formation produces a clear negative SP anomaly, the intensity of which is – 200 mV at the surface. There is only a weak response in the SP anomaly curve above the black schists, which cause negative slingram anomalies.

The surface and drillhole SP data were processed by the method described by Logn and Bølviken (1974). The field anomalies were divided into two parts, a time-dependent anomaly of a separate conductor in the formation ECP (electronic current potential) and an anomaly caused by the whole formation ICP (ionic current potential). Shown in the lower part of Figure 31.17 is the cross-section, compiled on the basis of the ICP data, which demonstrates that the anomaly caused by the formation is reversed along the dip from negative to positive. The positive anomaly may be extensive, as was demonstrated by Semjonov (1975) using some practical examples. Hence, it is not always possible to localize accurately the lower end of the formation.

INTERPRETATION OF THE GEOPHYSICAL ANOMALIES AND THEIR GEOCHEMICAL CLASSIFICATION

Before the start of drilling or geochemical sampling the geophysical data are interpreted in order to evaluate the dimensions, positions and petrophysical properties of anomalous formations. Ketola, Ahokas, Liimatainen and Kaski (1975) and Ketola, Liimatainen and Ahokas (1976) have investigated the feasibility of two- and three-dimensional interpretation methods and petrophysical determinations.

Depicted in Figure 31.18 are the two-dimensional interpretations of a magnetic and gravity anomaly curves measured over the Saramäki orebody. The geophysical and petrophysical data of this profile have been discussed above. The result of the first magnetic interpretation with effective susceptibility values (k), remanence omitted, is seen in the upper part of Figure 31.18. In the other magnetic interpretation, which suggests a more gentle dip and smaller susceptibilities (k_r) for anomalous formations, the remanence has been taken into account. In the interpretation, the average ratio of remanent to induced magnetization was 10:1 and the inclination and declination of the remanence were 45° and 90°, respectively (compared to 75° and 7° respectively for the earth's magnetic field) measured on some oriented samples drilled from black schist exposures. Susceptibility determinations on drill cores demonstrate that the remanence-corrected interpretation gives the better susceptibility and dip estimates to the magnetized upper part of the formation depicted in Figure 31.4. The gravity anomaly is caused by the skarn rocks, which in the light of interpretation and drilling data are located mainly between the magnetized parts of the formation, but partly also within them. Thus the magnetic and gravity data cannot be combined in the interpretation although the dip of the adjacent formations must be compatible i.e. 30°.

The results from profile x = 81.4 given by the magnetic, slingram and gravity interpretations were put to good use when planning geochemical humus sampling with the purpose of classifying geophysical anomalies. Beneath the magnetic and gravity profiles in the upper part of Figure 31.19 there is a petrophysical cross-section constructed by means of the two-dimensional interpretation results on the basis of which the sites of humus samples were selected. The petrophysical interpretation reveals the magnetized, conducting and anomalously high density sections. The copper contents of humus, showing an anomaly above the copper mineralization is presented together with slingram and geological data in the lower part of Figure 31.19. A strong but rather narrow humus anomaly indicates that geochemical sampling, the aim of which in this case was to check the magnetic and conducting sections, should be done with a short enough sample spacing. When planning sampling it is also worth employing the results of geophysical interpretation.

According to Wennervirta (1973), the Saramäki copper mineralization also manifests itself as an intense geochemical till anomaly. The samples were taken by percussion or pneumatic drilling from the depth of maximum penetration immediately above the surface of the bedrock.

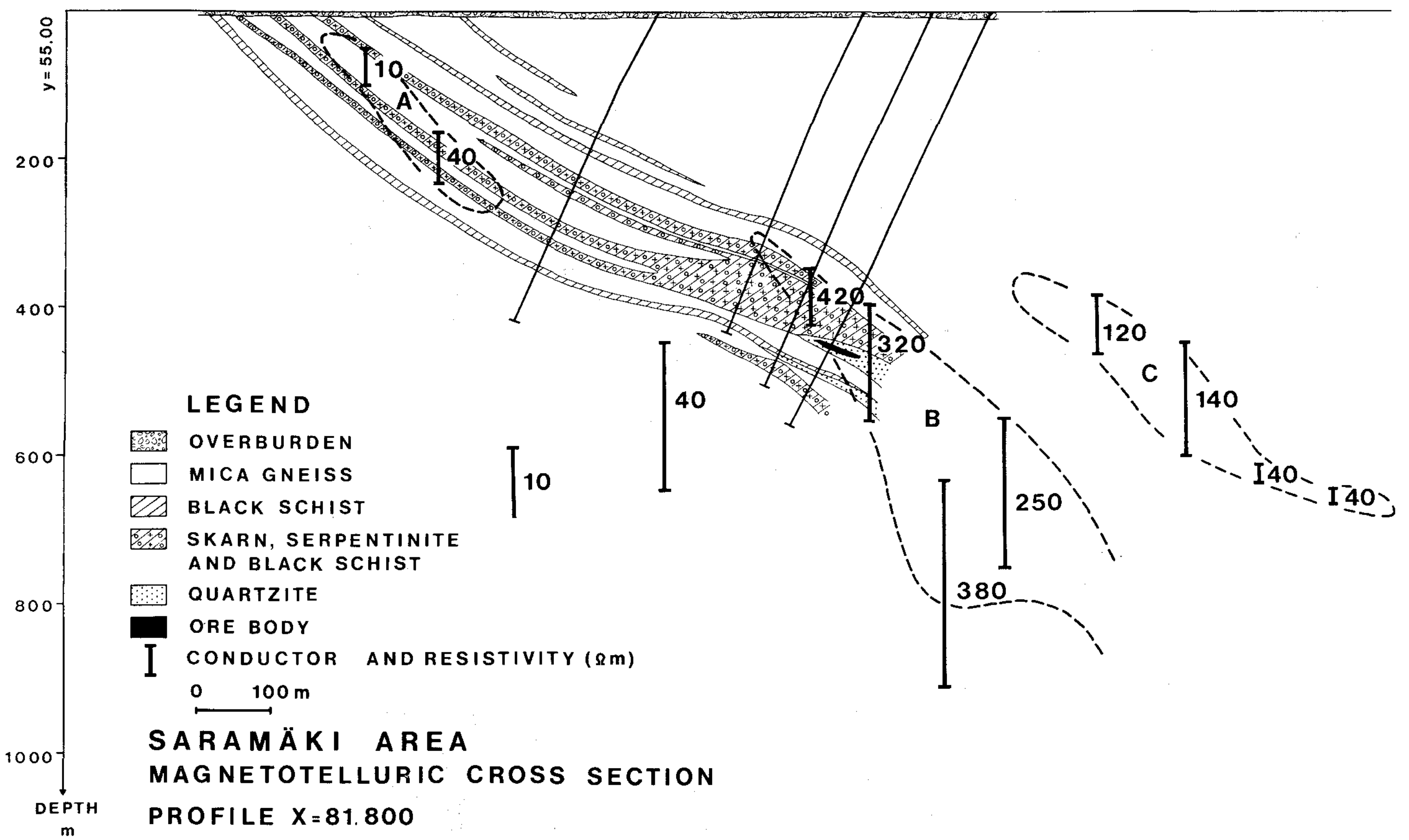


Figure 31.14. *Magnetotelluric cross-section in the Saramäki area.*

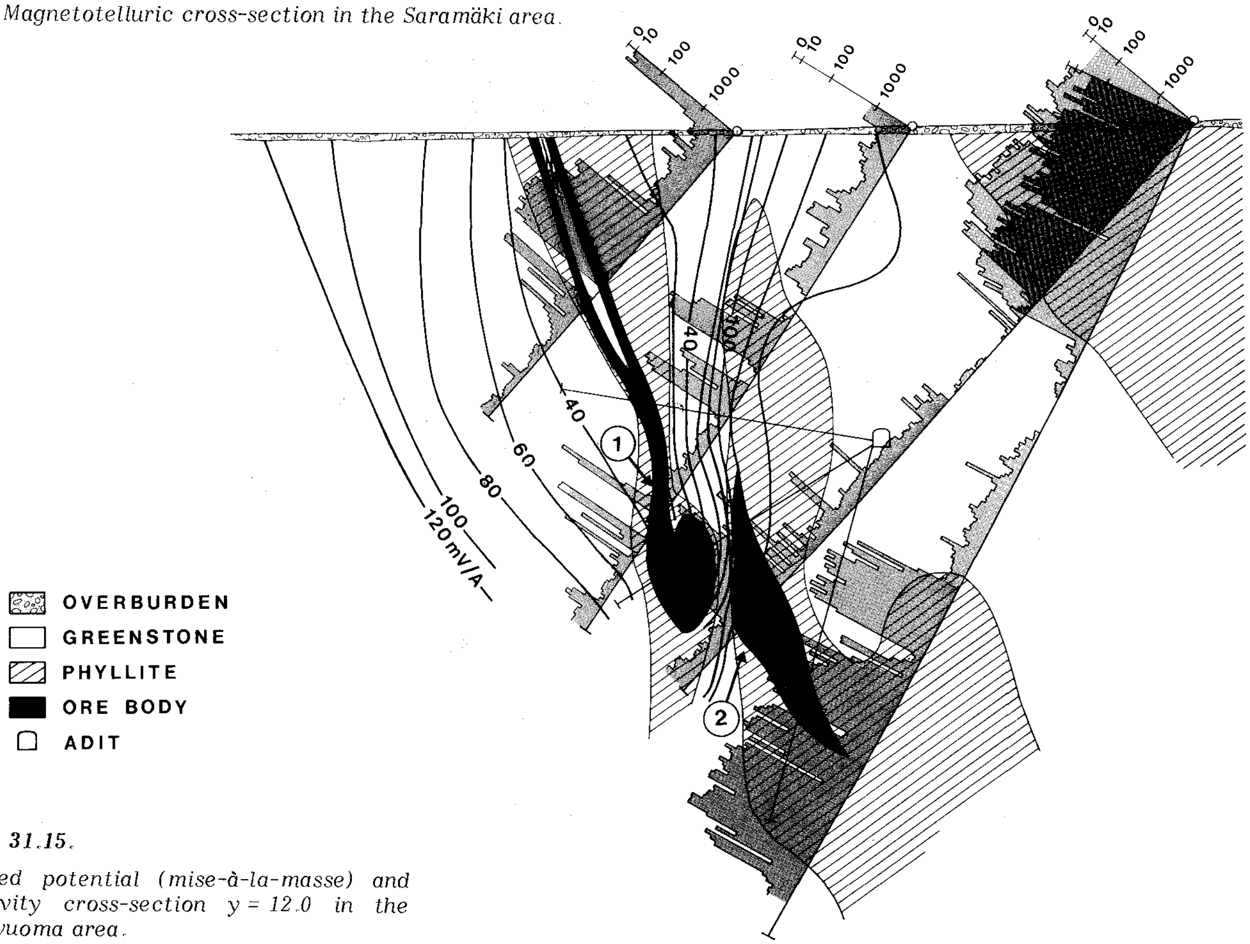


Figure 31.15.

Charged potential (mise-à-la-masse) and resistivity cross-section y = 12.0 in the Pahtavuoma area.

Contents

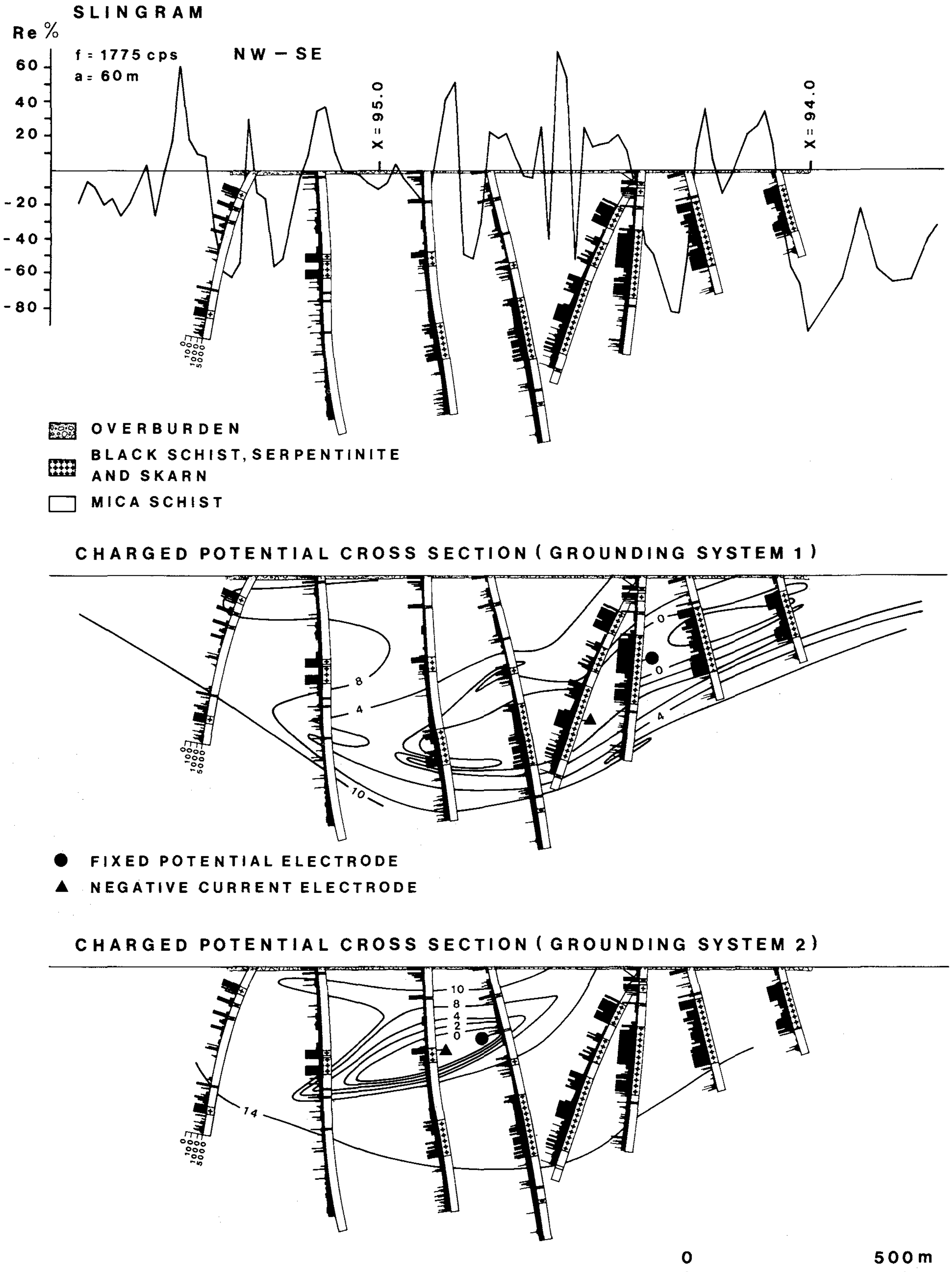


Figure 31.16. *Charged potential (mise-à-la-masse) and resistivity cross-section y = 176.0 in the Outokumpu area.*

Contents

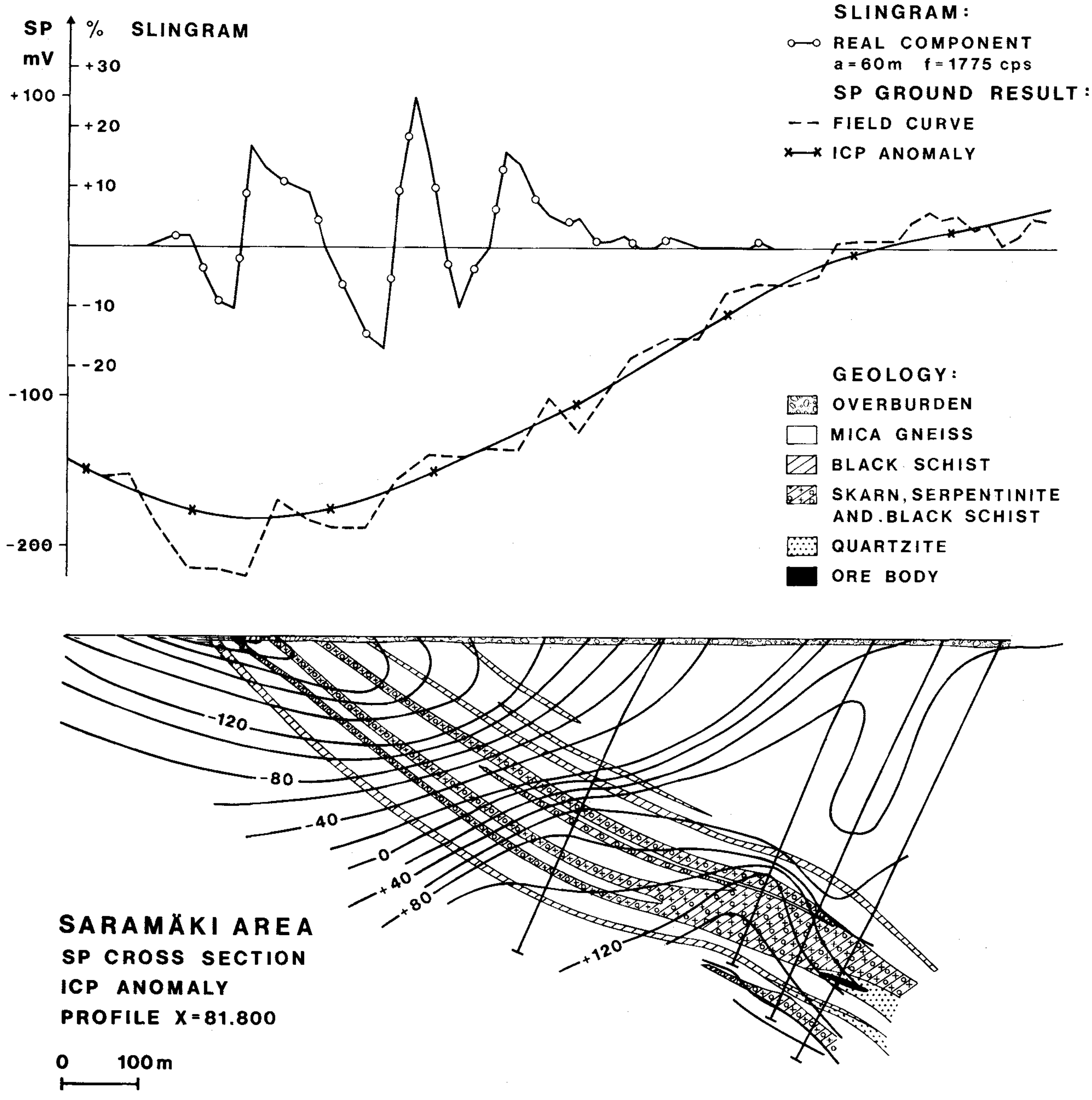


Figure 31.17. Self-potential and slingram results from profile $x = 81.8$ in the Saramäki area.

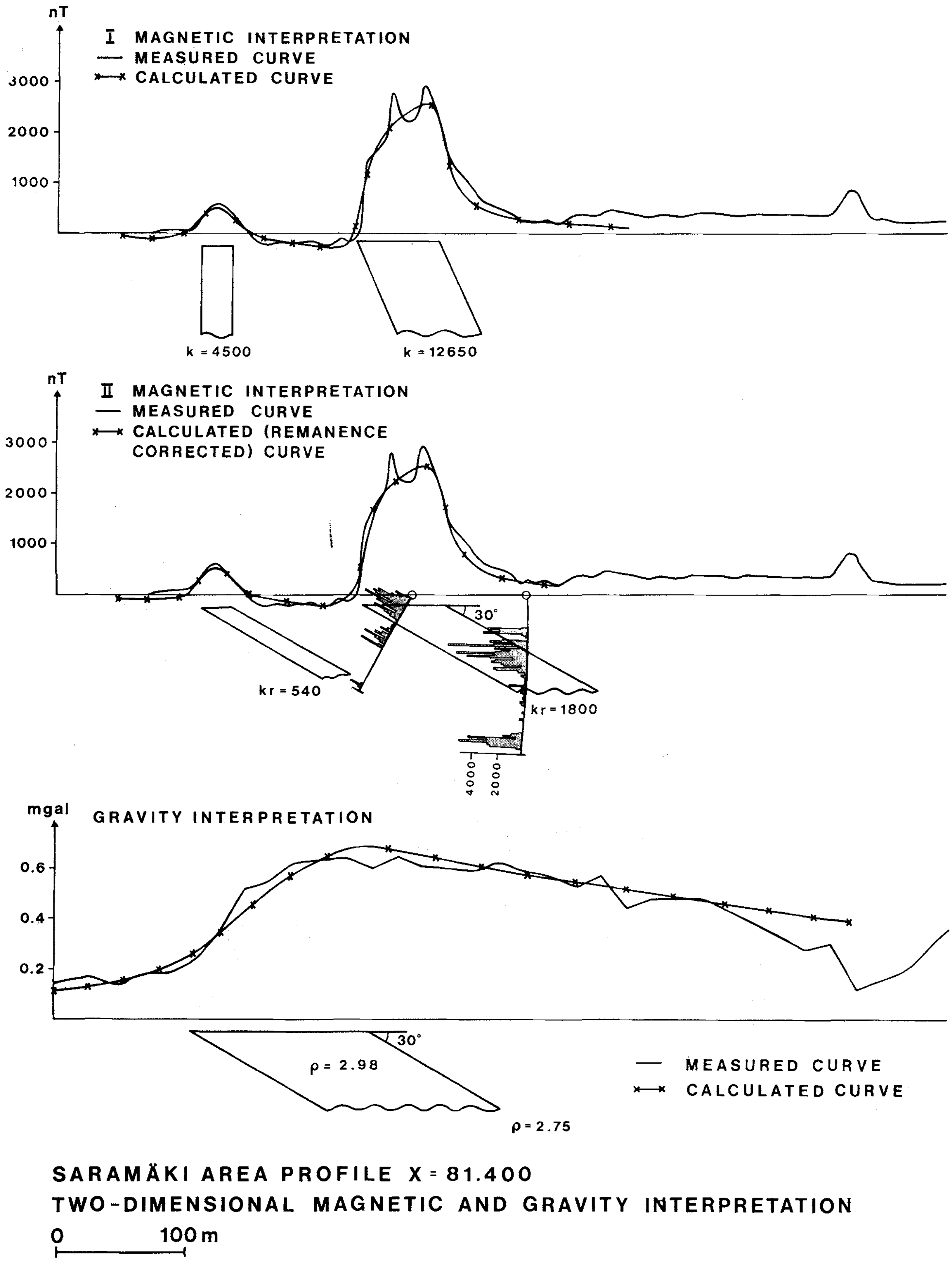


Figure 31.18. *Interpretation of magnetic and gravity data from profile x = 81.4 in the Saramäki area.*

Contents

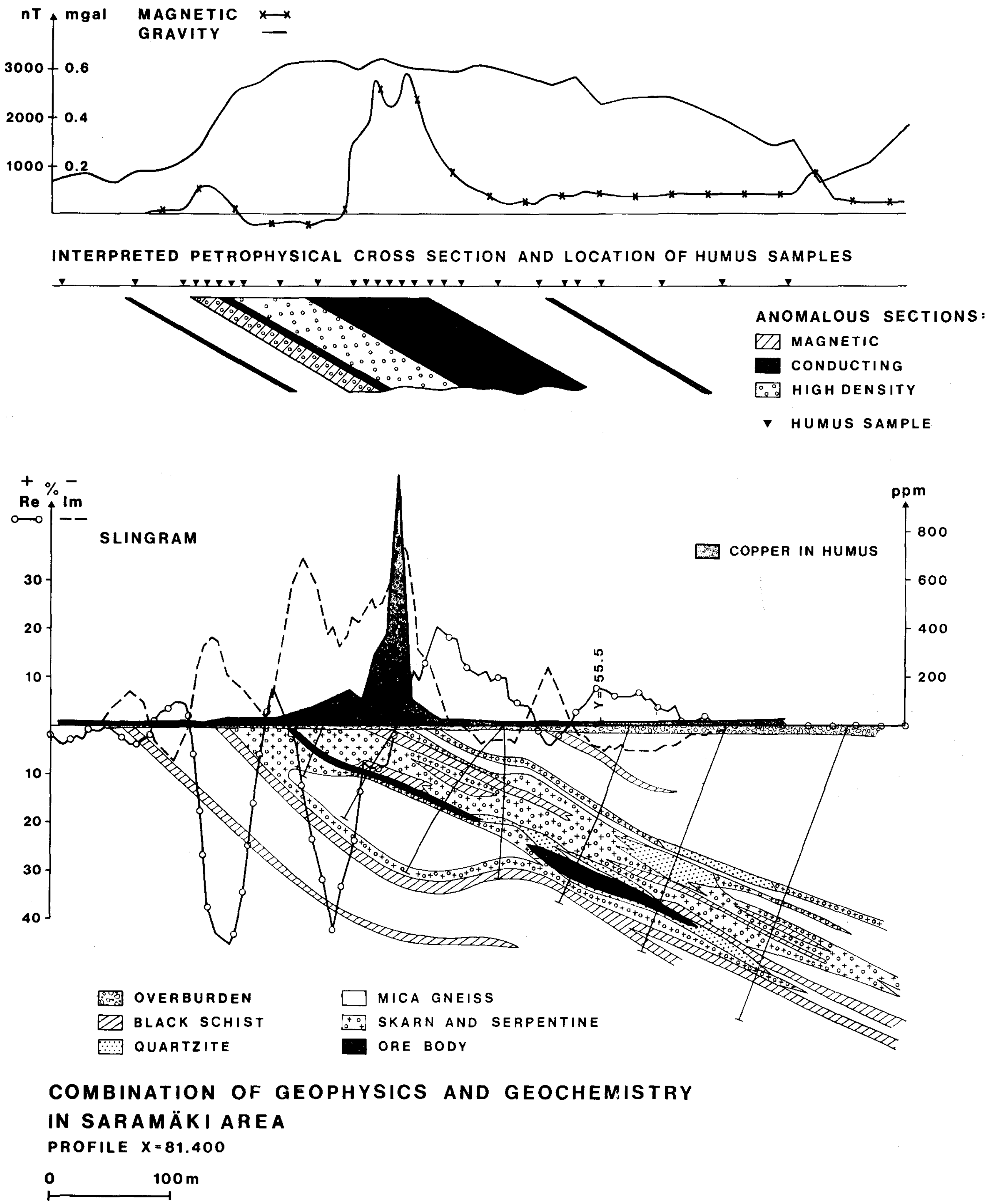


Figure 31.19. *Use of geophysical interpretation results in the planning of geochemical sampling.*

CONCLUSIONS

In this paper, an attempt has been made to demonstrate the feasibility of geophysical methods in the indirect exploration of sulphide ores in a graphite-bearing schist environment. It is evident that as exploration becomes more difficult, geophysics has increasingly to be applied to indirect exploration.

The simultaneous and effective use of different sciences, such as geology, geophysics and geochemistry, is necessary in order to find new orebodies.

ACKNOWLEDGMENTS

Thanks are due to Outokumpu Oy, Exploration, for permission to publish the data included in this paper. The author is especially grateful to Mr. M. Laurila, the Head of the Geophysical Department, who has led and taken an active part in geophysical investigations in all survey areas and whose positive attitude made it possible to complete this paper. Examples were collected from the extensive archives of Outokumpu Oy, which cover the last 25 years. I am happy to acknowledge my gratitude to Mr. M. Liimatainen, the geophysicist responsible for the charged-potential measurements at Pahtavuoma and the SP investigations in the Saramäki area, Mr. T. Ahokas, the geophysicist who planned the charged-potential measurements in the Outokumpu-zone and Messrs. E. Lakanen, A. Ruotsalainen and P. Kaikkonen, the geophysicists who performed the magnetotelluric measurements in the Saramäki area and interpreted the results. Mr. J. Longi performed the magnetic and gravity interpretation calculations and Mr. Kokkola, geochemist, the humus investigations in the Saramäki area. The manuscript was translated by Mrs. G. Häkli and Mrs. M. Sarkki, whom I thank for their pleasant co-operation.

REFERENCES

Fraser, D.C.
1959: Contouring of VLF-EM data; Geophysics, v. 34(6), p. 958-967.

Gaál, G., Koistinen, T., and Mattila, E.
1975: Tectonics and stratigraphy of the vicinity of Outokumpu, North Karelia, Finland; Geol. Surv. Finland, Bull. 271, 67 p.

Häkli, A.
1963: Distribution of nickel between the silicate and sulphide phases in some basic intrusions in Finland; Geol. Surv. Finland, Bull. 209, p. 1-54.

Huhma, A. and Huhma, M.
1970: Contribution to the geology and geochemistry of the Outokumpu region; Geol. Soc. Finland Bull., v. 42, p. 57-88.

Isokangas, P.
1975: The mineral deposits of Finland; Lis. thesis, Univ. of Helsinki, Finland, 128 p.

Ketola, M.
1972: Some points of view concerning Mise-à-la-masse measurements; Geoexploration, v. 10(1), p. 14-21.

Ketola, M., Ahokas, T., Liimatainen, M., and Kaski, T.
1975: Some case histories of the interpretation of magnetic and gravimetric anomalies by means of two- and three-dimensional models; Geoexploration, v. 13(3), p. 137-169.

Ketola, M., Liimatainen, M., and Ahokas, T.
1976: Application of petrophysics to sulfide ore prospecting in Finland; Pageoph, v. 114, p. 215-234.

Kokkola, M. and Korkalo, T.
1976: Pahtavuoma copper in stream sediment and till; J. Geochem. Explor., v. 5(3), p. 280-287.

Lakanen, E.
1975: Geofysikaalinan tulkinta graafisen tietokonekäsittelyn avulla; Geofysiikan päivät, Oulu.

Logn, Ø, and Bolviken, B.
1974: Self potentials at the Joma pyrite deposit, Norway; Geoexploration, v. 12(1),p. 11-28.

Parasnis, D.S.
1974: Some present-day problems and possibilities in mining geophysics; Geoexploration, v. 12(213), p. 116-118.

Puranen, M.
1959: Aerosähköisistä mittausmenetelmistä, Espoo.

Ryss, Yu.S.
1973: The search and exploration for ore bodies by the contact method of polarization curves; Nedra, Leningrad.

Semjonov, M.V.
1975: Osnovy poiskov i izutsenija koltsedanno-polimetallitseskin rudnyh polei geofizitseskimi metodami; Nedra, Leningrad, p. 118-141.

U.S. Exchange Delegation in Mining Geophysics
1976: A Western view of mining geophysics in the U.S.S.R.; Geophysics, v. 41(3), p. 320-321.

Vähätalo, V.
1953: On the geology of the Outokumpu ore deposit in Finland; Geol. Surv. Finland, Bull. 164, p. 7-10.

Wennervirta, H.
1973: Sampling of the bedrock-till interface in geochemical exploration; Papers presented at a symposium in "Prospecting in areas of glacial terrain", organized by the Institution of Mining and Metallurgy, Trondheim, Norway.