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THE POWER AND ROLE OF GEOPHYSICS APPLIED TO REGIONAL AND SITE-SPECIFIC MINERAL EXPLORATION AND MINE GRADE CONTROL IN OUTOKUMPU BASE METALS OY

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1. Outokumpu Mining Oy

ABSTRACT

Magnetic and gravimetric data play an important role in regional geological interpretations. This fact is emphasized in glaciated terrains where there is minimal outcrop. The significance of regional, site-specific and deposit-scale geophysical investigations is reflected in the exploration of sulphide ore deposits of the VMS type in the Pyhasalmi-Vihanti area, Central Finland. The application of geophysics in mine grade control is presented in the Pyhasalmi and some other mines.

The Pyhasalmi-Vihanti area belongs to one of the main metallogenic provinces in Finland. The area is a part of the northwest-southeast structure which crosses Finland and ranges through the earth's crust. Geophysically, this global feature is best indicated by a strong gravity low. Geologically, this structure is located near or at the contact zone of archean and proterozoic blocks. In exploration, gravity data with grids of a few stations per square kilometre or denser, and airborne survey data with flight altitudes of 150 m and 40 m, have been used for regional interpretations. Geophysical data are modelled and image processed, integrating them with geological models to identify and classify VMS-critical rock units and structures.

Geophysical surveys often include certain special methods that are applied to specific problems in local exploration. However, "classical" methods should not be underestimated, especially when sophisticated modelling is used, so that eventually we do not provide anomalies but interesting anomaly sources for drilling. In the Pyhasalmi area, EM, IP, magnetic and gravimetric methods have been used in basic ground surveys. Background resistivities are usually at the level of 10 000 ohm-m; however, inductively resistivity contrasts between country rocks and mineralisation are usually small, except in pyrrhotite-bearing schist zones. Therefore, IP has proved to be a relevant tool in the exploration of near-surface mineralisations. With regard to blind ore bodies, good results have been obtained with a wide-band EM sounding system, called Gefinex 400S, an exploration tool developed by Outokumpu.

The power of geophysics is often noticed during the surveying of barren drill holes. Integrated interpretations of borehole-EM and lithogeochemical data led to the discovery of a new ore deposit also in the Pyhasalmi area at a depth of 500 m. Beside EM surveys, mise-a-la-masse (M-A-M) borehole and ground surveys have been efficiently used to correlate drill hole intersections, and to locate new ore bodies. The latest modelling of M-A-M data resulted in an exploration target at a depth of 700 m; the interpretation was based on an integrated analog and digital modelling developed at VIRG-Rudgeofizika, Russia.

The use of geophysics can even be extended to mine production for purpose of minimizing dilution and ore losses, reducing expensive core drilling, and obtaining immediate analyses results. Outokumpu has gathered more than ten years of experience in geophysical borehole logging for grade estimate and control purposes. Depending on ore type, geophysical borehole logging can be applied to determine ore contacts, to classify mineralisations, to interpret lithology, and even to transform physical responses to metal grades. In the Pyhasalmi Zn-Cu-S mine, density logging in percussion boreholes is used to locate ore boundaries, and to classify ore intersections into massive and semi-massive sulphide ore types. Pyrrhotite-bearing zones are separated from other sulphides by conductivity logs. The use of geophysical logging, specifically the conductivity log, for grade estimate and control has succeeded best in nickel mines.

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INTRODUCTION

The Fennoscandian Shield, which covers a total area of 1 140 000 square kilometres, comprises the Precambrian areas of Finland, Norway and Sweden, and the northwesternmost part of Russia (Figure 1). The metamorphosed Precambrian bedrock varying in age from 1700 to 2800 million years (Kahma, 1973) consists of Proterozoic and Archean rocks, of which the latter occupy large areas in eastern and northern Finland. The Proterozoic portions, which host most of the major outcropping sulphide ore bodies detected so far, are characterized by granitoids and schist belts. Abundant pyrrhotite bearing graphite schists, or black schists, which cause both magnetic and electromagnetic geophysical anomalies and geochemical anomalies, occur in these belts. The Archean part is composed of extensive granite gneiss and greenstone belts. Bedrock is generally overlain (95–97%) by thin Quaternary deposits composed of till, sand and clay, averaging between 6 m and 9 m.

The most economically significant ore deposits in Finland are located in the Main Sulphide Ore Belt, which runs across the country

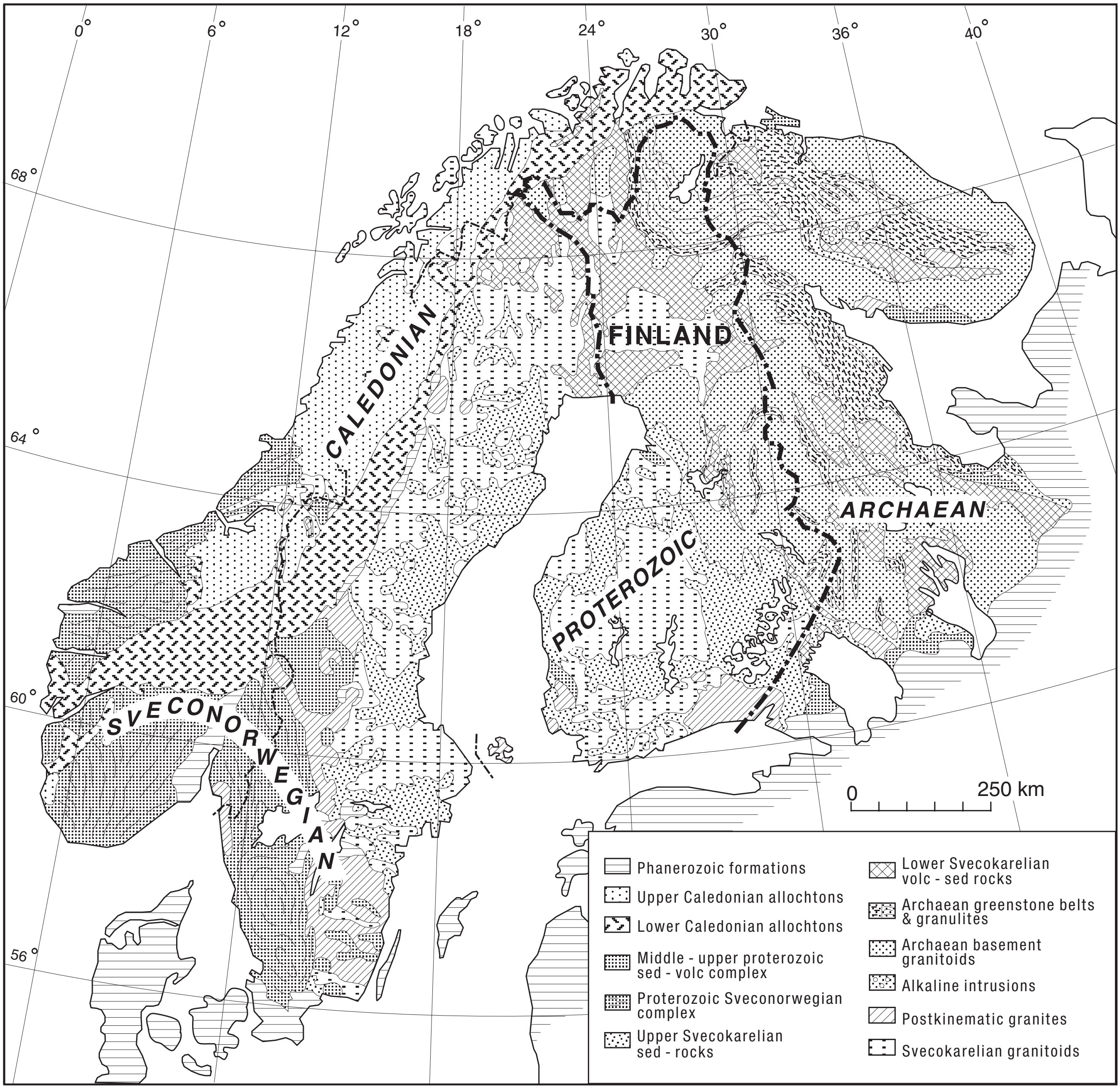


Figure 1: *The geology of the Fennoscandian Shield.*

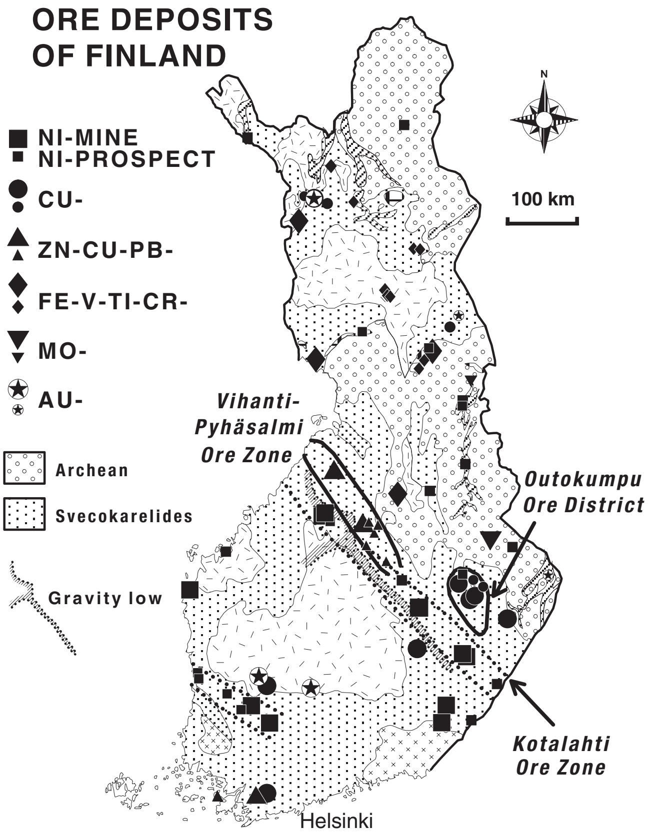


Figure 2: *Main Sulphide Ore Belt and ore deposits in Finland.*

from northwest to southeast (Figure 2). It occupies an area about 40 km to 150 km wide and at least 400 km long running between a gravity low, due to a crustal structure, and the Archean basement complex. It has been divided into three metallogenic zones; Outokumpu Ore District (Cu-Co-Zn), Kotalahti Ore Zone (Ni-Cu) and Vihanti-Pyhasalmi Ore Zone (Zn-Cu-Pb-S). The large deposits of the Main Sulphide Ore Belt contain more than 90 % of the known sulphide mineral resources in Finland. This indicates that conditions for the formation of sulphide ores, as far as supply and transport of ore material and temperature of the surroundings are concerned, has been extraordinary favourable (Kahma, 1973).

The significance of geophysics in the regional, site-specific and deposit-scale exploration phases is reflected in the investigations of sulphide deposits of the VMS type in the Vihanti-Pyhasalmi area. Applications illustrating the successful extension of geophysics to more efficient mine production at the Outokumpu mines using borehole logging for grade control, are also presented.

REGIONAL EXPLORATION

Pyhasalmi-Vihanti area

The Pyhasalmi-Vihanti Ore Zone is located about 25 km northeast of a major gravity low running southeast-northwest, and an associated fault zone (Kahma, 1973). The Ore Zone comprises an area about 40 km broad and at least 200 km long. Several sulphide deposits containing varying amounts of zinc, copper, lead and barium as well as minor gold and silver are known to exist in the highly metamorphosed Svecokarelidic crystalline schists. Many of these deposits are within volcanic rocks (Figure 3). They are often conformable massive sulphide type deposits (Papunen *et al.*, 1986). Five deposits have had past production and two of them, Pyhasalmi and Mullikkorame are presently being mined.

The Pyhasalmi-Vihanti metallogenic (Zn-Cu-Pb-S) zone within the Main Sulphide Ore Belt represents an ancient bimodal volcanogenic rifting environment connected to an island arc type geotectonic frame work (Ekdahl, 1993). It is bordered on the northeast by an Archean cratonic complex and on the southwest-side by the younger Middle Finland granitoid area.

Exploration

Exploration started in the Pyhasalmi-Vihanti area more than 60 years ago. The Vihanti ore body (28 Mt 5.3% Zn, 0.5% Cu, 0.4% Pb, 21.8 g/t Ag, 0.39 g/t Au) was discovered in 1946 by tracing ore float samples. The other remarkable discovery involves the Pyhasalmi ore body (32 Mt 2.5% Zn, 0.8% Cu, 35% S) which was discovered in 1958 by a local farmer when digging his well. Intensive geophysical surveys and drilling were started and continued until the mine was opened. Subsequently, new exploration programs were completed in a phased approach. To date, more than one thousand boreholes have been drilled in the area. At present, all exploration data from the Pyhasalmi-Vihanti ore zone are being reprocessed to identify and classify VMS-critical rock units and structures.

Airborne geophysical surveys have provided background data for regional investigations since the early 1950s when the first survey was made from an altitude of 150 m. At present, geophysical airborne data (mag, EM, radiometrics) is based on surveys at an altitude of 40 m. The combined use of geophysical, geochemical and geological data is required because the graphite-bearing schists hamper interpretation of geophysical methods in direct exploration (Ketola, 1987). The outcropping ore deposits have mostly been discovered with the aid of indications given by ore float. The main sulphide ore belt manifests itself as a distinct Ba-Zn-Cu-anomaly on the national geochemical maps compiled on the basis of one near surface composite sample per 300 km^2. These maps are published by the Geological Survey of Finland. The detailed geochemical mapping (16 samples/km^2) now widely used in Finland indicates the potential ore-bearing zones, but has not succeeded in targeting a specific sulphide ore deposit.

In the current exploration phase, all the regional exploration data has been reprocessed to identify and classify new VMS-critical units and structures. The regional gravity data with 4 stations/km^2, low-altitude (40 m) aeromagnetic, digital elevation and petrophysical data is interpreted using an integrated approach. Low-altitude data, magnetics and EM is processed using principal component analysis.

The survey area is divided into distinct blocks (Figure 4). The petrophysical properties of the blocks are compared by means of cumulative histograms and histogram decompositions from which general petrophysical modes and rock types are identified. Among other things, this interpretation reveals variations in metamorphic grade and granitization, shear lenses, various northeast-southwest, northwest-southeast and north-south faults, the sense of movement or deformation, and other tectonic-stratigraphic features. The major gravity/magnetic lineaments and their intersections, which often characterize VMS deposits in the

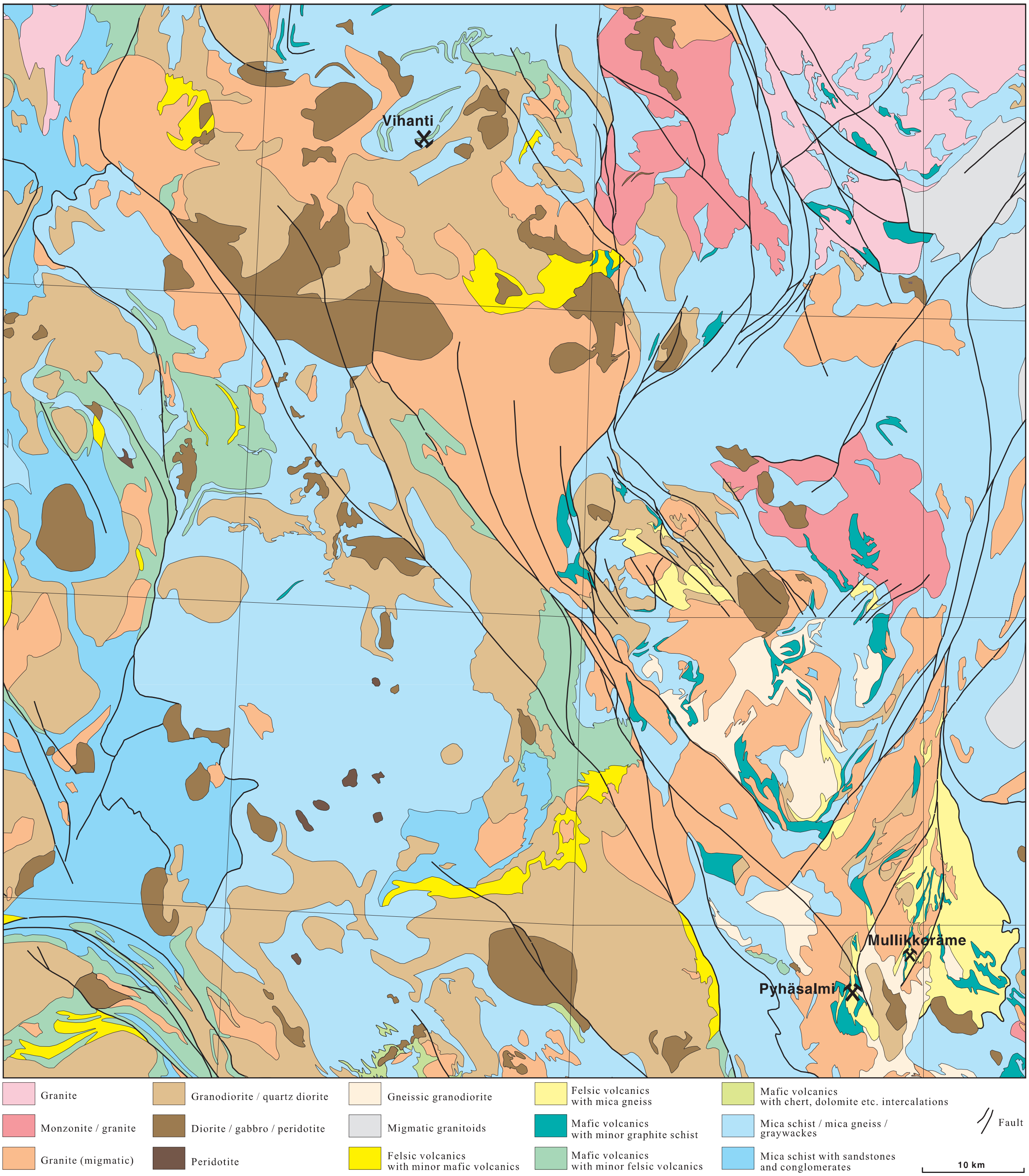


Figure 3: *Geological map of the Pyhasalmi-Vihanti ore zone.*

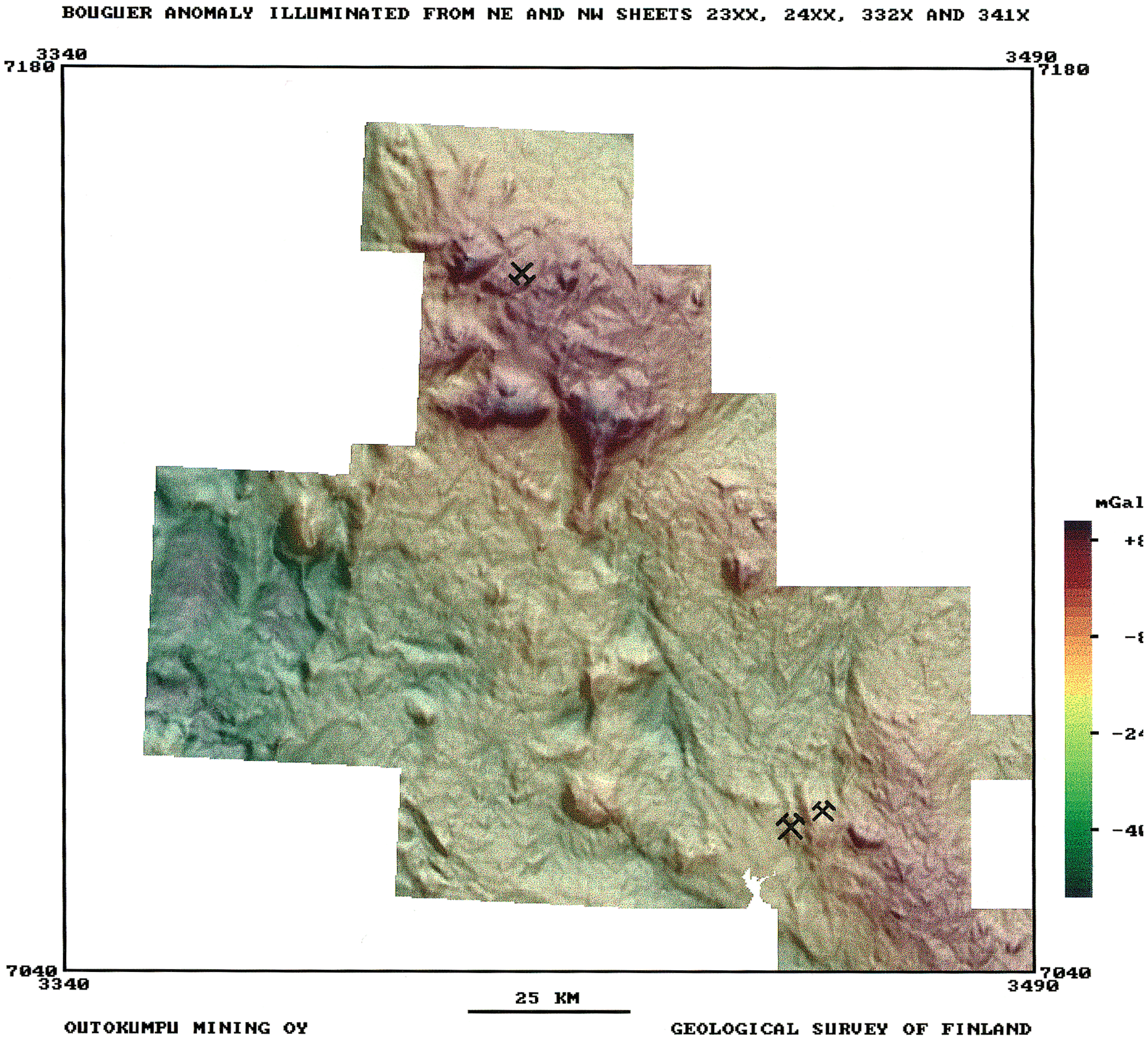


Figure 4: *Bouguer anomaly illuminated from northeast and northwest in the Pyhasalmi-Vihanti area.*

main sulphide zone in Finland, probably represent traces of deep seated fracture zones. Quantitative gravity and magnetic modelling along selected profiles has revealed the three dimensional structure of the different blocks or rock units.

SITE-SPECIFIC EXPLORATION

Geology of Pyhasalmi-Mullikkorame area

The Pyhasalmi area is characterized by considerable amounts of bimodal volcanics, metapelites, tonalitic gneisses, pyroxene granites, gabbros, granites and abundant altered rocks (cordierite, anthophyllite, sericite, chlorite, phlogopite, etc.). All known stratabound Zn-Cu-S ore bodies and mineralized zones are located in these altered rocks (Puustjarvi, 1991). The Archean basement complex about 40 km east of Pyhasalmi is composed of banded granodioritic-trondhjemitic gneisses intruded by a variety of granitoids and gabbroids. Based on deep seismic surveys (Luosto *et al.*, 1984) the border of this Archean craton consists of faults extending into the mantle.

The massive pyritic Zn-Cu-S ore body at Pyhasalmi is 650 m long and up to 75 m wide, becoming narrower to the south and north. The sub-outcropping ore continues down dip almost vertically, while pinching along strike at the same time. The deepest ore intersections are 1200 m below surface. The contact between ore and waste rock is sharp. Host rocks of the ore are acid pyroclastic rocks and quartz porphyries (Maki, 1986). The ore body is surrounded by a large alteration zone in which sericitized quartzites occur closest to the ore, with cordierite-mica schists and cordierite-antophyllite rocks more distant. The isoclinally folded alteration zone is over 6 km long, 100–500 m wide and reaches depths in excess of 1200 m.

The formation of the Mullikkorame volcanics located about 7 km northeast of the Pyhasalmi mine is up to 1000 m wide and almost 3000 m long (Figure 5). Mafic volcanics with variable amounts of pyrrhotite mineralization dominate in the western part of the formation. To the east, the massive stratabound Zn-Cu-Pb-S ores or mineralization hosted by felsic volcanics within a bimodal volcanic sequence are more common (Puustjarvi, 1992). Abundant sericitic and chloritic alteration is typical in the mineralized horizons. One hundred and forty-eight holes with a total length of 26.2 km were drilled in the Mullikkorame formation in 1987–1995. Two hundred seventy thousand tonnes of ore 5.8% Zn, 0.2% Cu, 0.3% Pb, 22% S, 22g/t Ag and 1.3g/t Au were mined out 1991–1992 from the surface ore body as a result of this drilling. The deep ore body (+400 to +600 m) containing 0.7 Mt 8.3% Zn, 0.4% Cu, 1.3% Pb, 17.8% S and 1.2g/t Au is now being mined and exploration studies surrounding this ore body have been initiated.

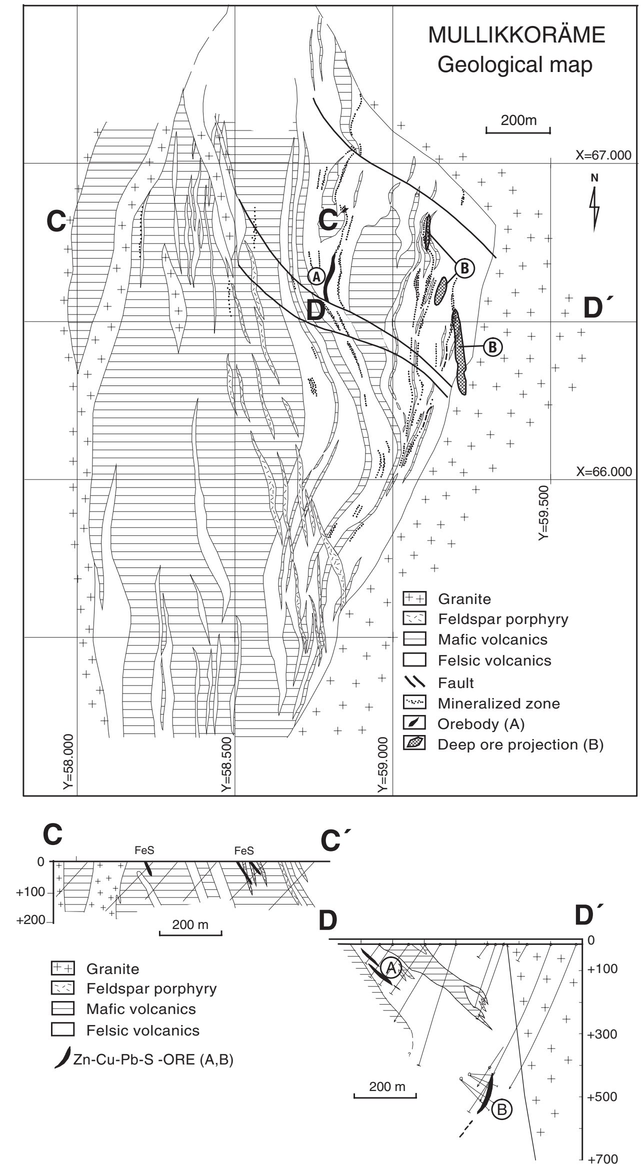


Figure 5: *Geological map of the Mullikkorame area.*

The ore body dips about 60° east at the surface but becomes more horizontal at depth. Rake of the ore lenses is not very well established. At greater depths it varies from gentle to almost horizontal, trending between north and east as inferred from mise-a-la-masse data. The volcanics, surrounded by granites in the east and west is crosscut by numerous uralite porphyrite dykes controlled by factors not yet fully established. An almost 100 m thick conductive mylonite layer in the eastern contact with the granite hampers the use of galvanic methods.

The stratigraphy of the rocks in the area from bottom to top is roughly as follows: 1) the Kettupera mica gneiss (not encountered here), 2) felsic volcanics, 3) Zn-Cu-Pb-S ore bodies, 4) mafic volcanics, and 5) granite.

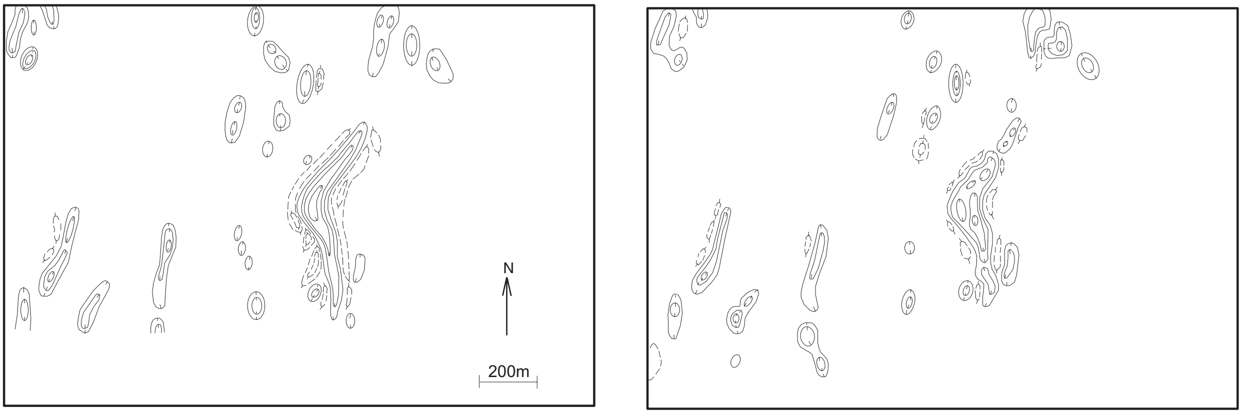
Geophysical surveys at Pyhasalmi and Mullikkorame deposits

The high density (4.0 g/cm^3) and conductive (10–100 S/m) Pyhasalmi ore body can be located relatively easily using HLEM- and gravity methods (Figure 6). The ore body contains 2–4% pyrrhotite, which greatly improves its conductivity beyond that which would be expected from the sulphide ore minerals. Gravity data was interpreted using a prism model to simulate the ore body (Figure 7). The ore body causes an anomaly of one mgal despite a depth to its upper surface of 100 m. At the same time it suggests a depth limit for exploring Pyhasalmi-size and type blind ore bodies by gravity. The results of the geophysical survey measured above the Pyhasalmi ore body in the late 1950s had a decisive impact on instruments and methods used in the following exploration for VMS-deposits in the Pyhasalmi area.

In the Mullikkorame area, low-altitude flights (40 m) in 1978 were followed by HLEM-magnetic-gravity surveys and results were checked with percussion drill sampling. The surface ore body was discovered as a result of this work. The body is indicated by a weak –4% HLEM anomaly of both in-phase and quadrature components (Figure 8). The survey data are influenced by the conductive (2–10 S) pyrrhotite mineralization in the western part of the formation. The poorly conductive (0.1–0.5 S) Zn-Cu-S ore body in the eastern part of the formation can be located only at high frequencies mainly by the out-of-phase component (Figure 9).

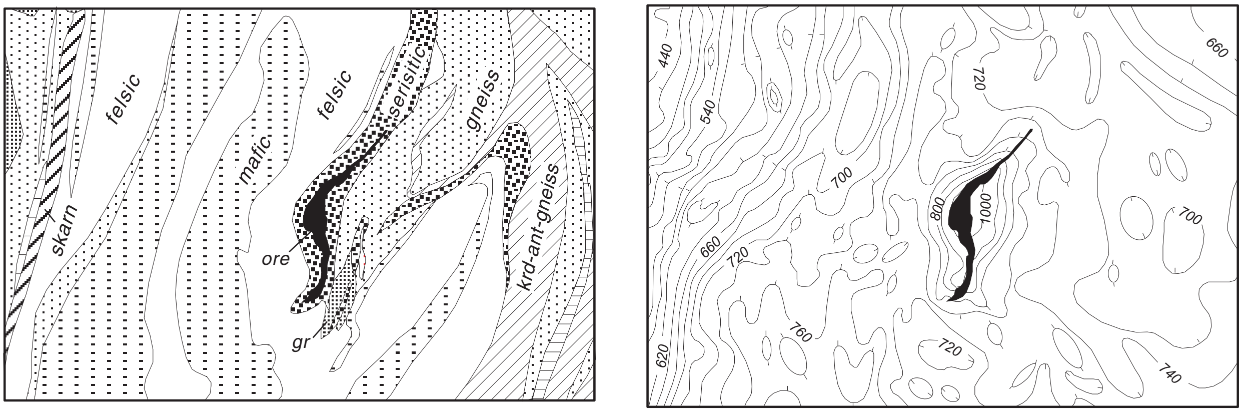
IP measurements outline the surface ore body rather well (Figure 10). The felsic volcanics, with variable amounts of pyrite, is indicated by apparent resistivities in the range 600–800 ohm-m. The resistivity of unmineralized mafic volcanics is usually more than 1000 ohm-m.

The formation of the Mullikkorame volcanics causes a 1.5 mgal gravimetric anomaly mainly due to mafic volcanics (2.9 g/cm^3). According to our interpretation the volcanics continue eastward under the granite (Figure 11). Magnetics and IP give the same interpretation.



HLEM, In-phase component
a = 40 m, f = 1775 Hz
Contours: ±4, ±8, % etc.

HLEM, Out-of-phase
a = 40 m, f = 1775 Hz
Contours: ±4, ±8, % etc.



GEOLOGICAL MAP

Bouguer anomaly
Contours: 0.2, 0.4, 0.6 mgal etc.

Figure 6: *Pyhasalmi ore body and geophysical results.*

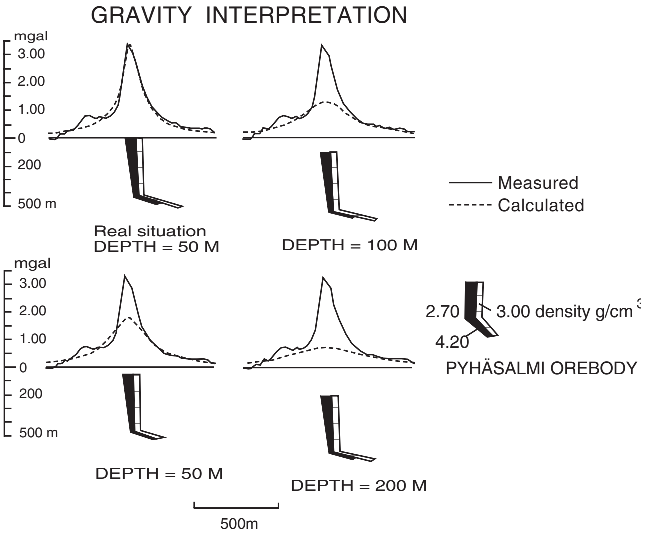


Figure 7: *Measured and calculated gravity field over the Pyhasalmi ore body.*

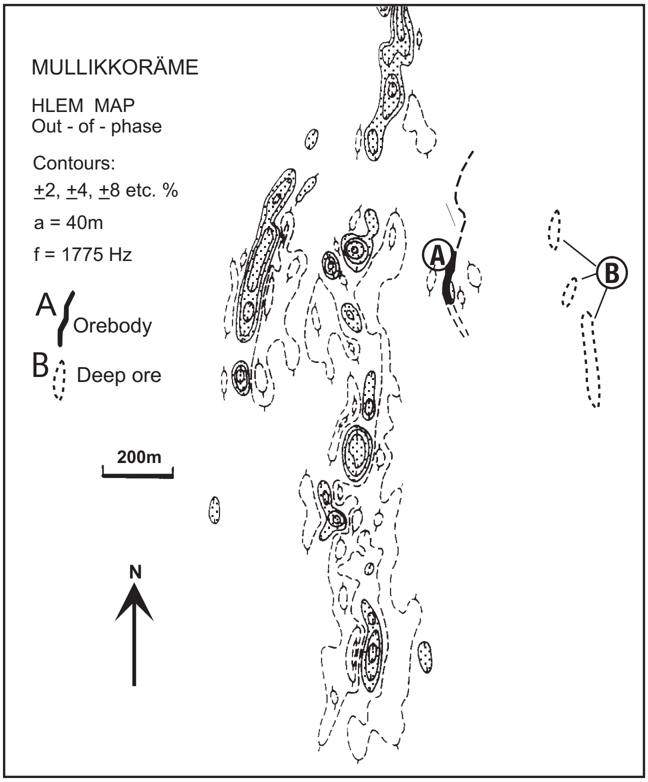


Figure 8: *HLEM result (out-of-phase) in the Mullikkorame area.*

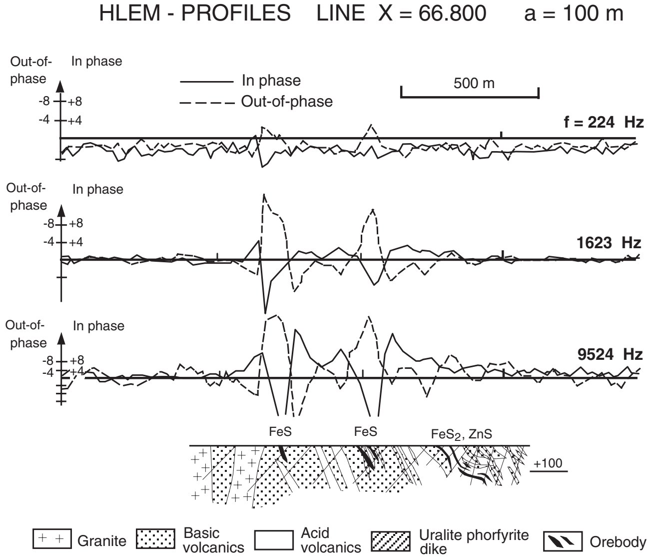


Figure 9: *HLEM results with different frequencies in Mullikkorame.*

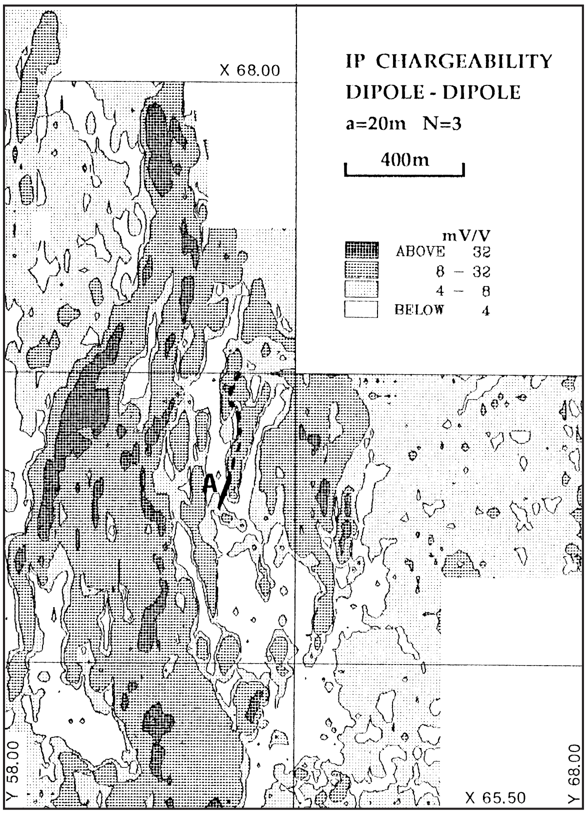


Figure 10: *IP data in the Mullikkorame area.*

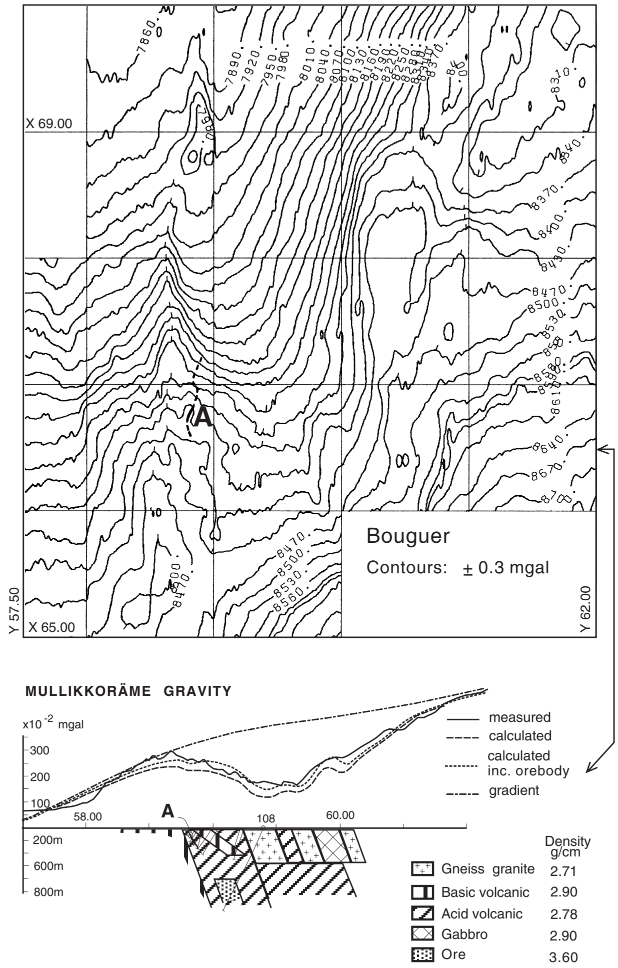


Figure 11: *Gravity data in the Mullikkorame area.*

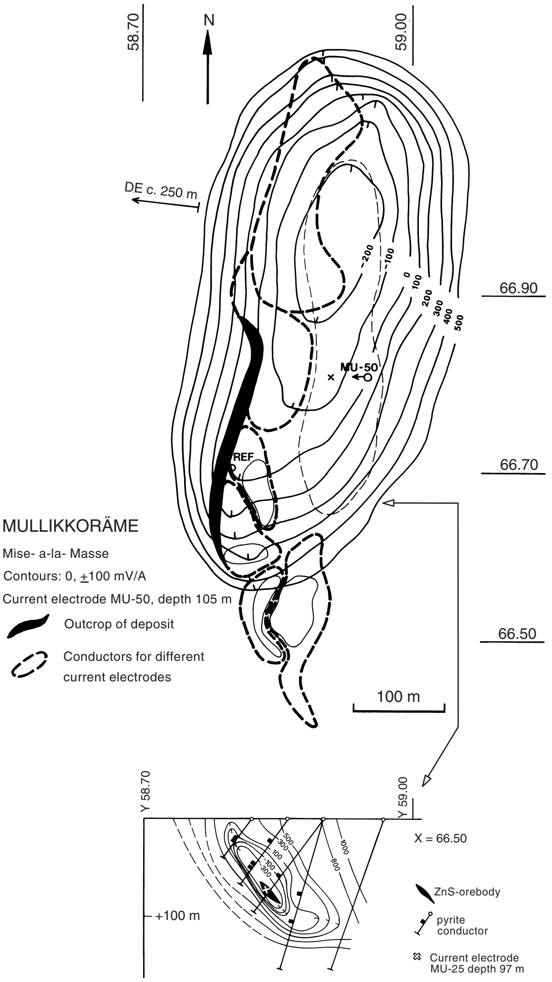


Figure 12: *Mise-a-la-masse data in the surface ore body of Mullikkorame.*

Although the ore body has the highest density (3.6 g/cm^3) in the entire area, this is of no practical value in locating the deposit using gravity, since the deposits are small compared to the whole formation of the volcanics (Rekola, 1992).

Mise-a-la-masse measurements have been made continuously during the exploration program. Measurements in the surface ore bodies delineated the extent of the sulphide formation fairly well (Figure 12). However, it was difficult to distinguish between ores and non-economic pyrite conductors because of similar resistivities. The potential extension of the deep ore body northwards and southward is seen in the surface results (Figure 13). All three intersected horizons of the deep ore body are at the same potential. The surface data of the southeast-part of the area shows the mylonite fracture zone with its lower resistivities (100–1000 ohm-m). Interpretation using analog-digital modelling, which was contracted by VIRG-Rudgeofizika, Russia, gave three conductive blocks under the known deep ore body at a level from +700 to +900 m. The interpretation was checked on one profile (Figure 13) with good confirmation. This type of interpretation will be continued in the other part of the volcanic formation. Mise-a-la-masse was one of the main methods used to connect the different intersections with each other and to guide drilling from the beginning when the hole MU-99, intersected a 45 m thick pyrite-predominant alteration zone containing 0.6% Zn and 0.12 % Pb.

Gefinex 400S wide-band multifrequency EM-measurements were first carried out in the deep exploration programme. The equipment used for these measurements was designed by companies in the Outokumpu Group (Aittoniemi *et al.*, 1987) and is now in use in several exploration projects around the world. It is a completely automated, microprocessor controlled, battery operated, portable dipole-dipole EM-system. The system operates at 81 frequencies in the 2–20 000 Hz range. Coil separation can be increased to more than 1000 m, in which case depth penetration is also about 1000 m. In Mullikkorame wideband EM soundings with Gefinex 400S were made across the mineralized zone with a broadside coil configuration. Coil separation varied between 200–800 m. Measurements show the surface ore body (A) and a pyrite suboutcrop beneath the overburden (Figure 14). There is also a distinct indication of the deep ore body (B) with the longer coil separation (800 m). Results with both separations suggest a conductor

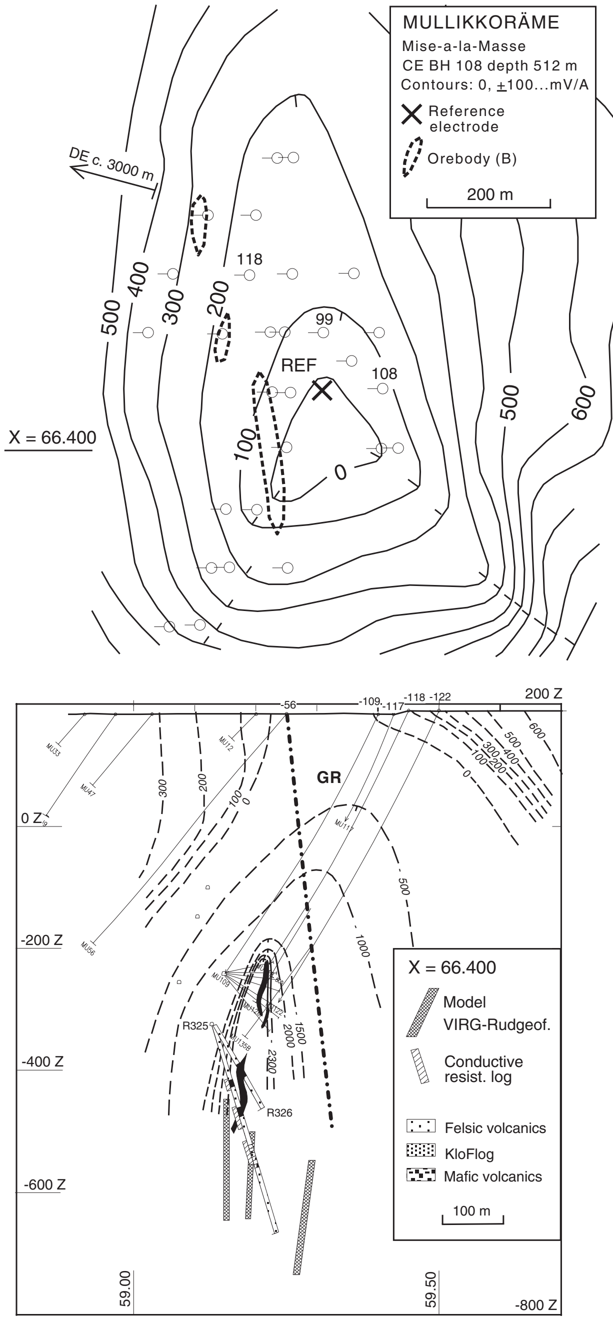


Figure 13: *Mise-a-la-masse data in the deep ore body of Mullikkorame.*

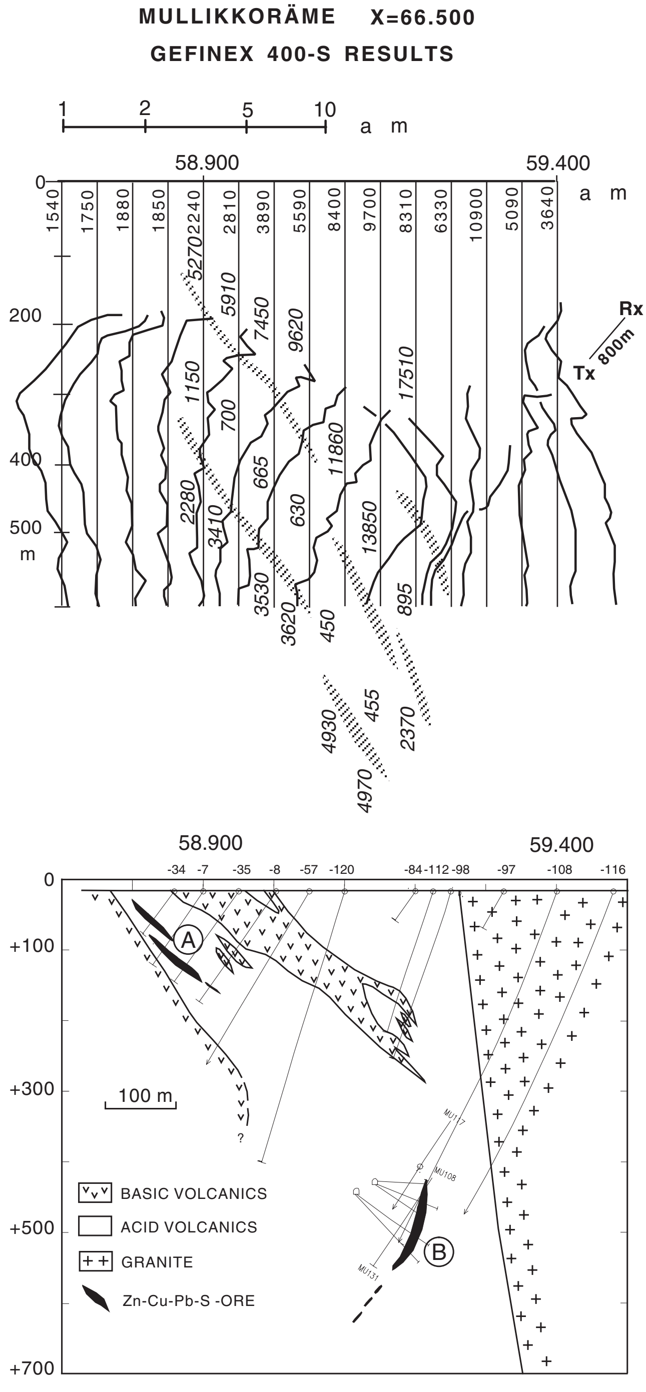


Figure 14: *Gefinex 400S data and interpretation over the Mullikkorame ore bodies.*

between the surface and deep ore bodies. The same sulphide conductor was probably indicated by the DHEM measurements in hole MU-120. Results of the Gefinex 400S measurements contributed to the decision to drill into the deep extensions of the surface ore body.

After intersecting the very anomalous alteration horizon in drill hole MU-99 at a depth of 200–300 m all remaining drill holes were measured by EM-37. These DHEM results were one reason why hole MU-108 was deepened from the 450 m drilled earlier (Figure 15). As a result of this discovery hole, systematic drilling, DHEM and Mise-a-la-masse surveys around the deep ore body were started. The DHEM measurements indicated many small but economic ore lenses in the deeper part of the formation.

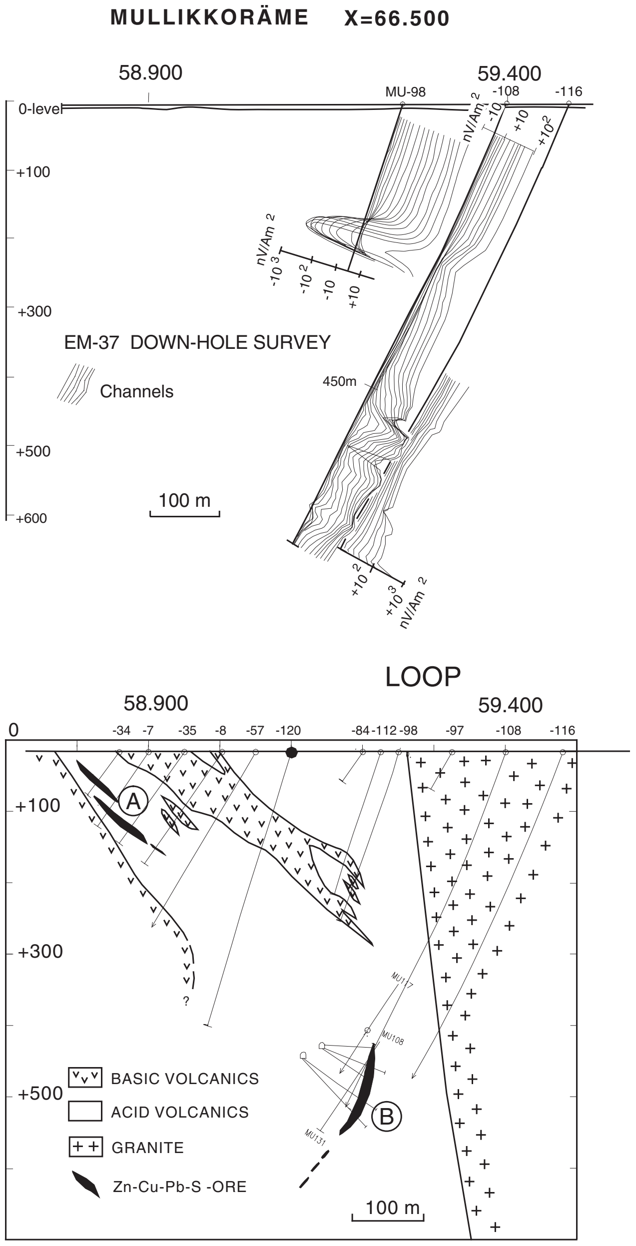


Figure 15: *DHEM data from the boreholes 98 and 108 in the Mullikkorame deposit.*

MINE GRADE CONTROL

In mining, geophysical borehole logging is used at Outokumpu for quickly detecting ore boundaries/qualities in order to reduce rock dilution and ore losses. Waste rock dilution occurs when significant uneconomic rock is mined and processed with economic ore. Ore losses and rock dilution occur throughout the many phases of mining projects as shown by Elbrond (1994).

The basic principle of the borehole logging at Outokumpu Mines with the OMS-logg system (Figure 16) is to measure differences in physical characteristics of mineralization directly from the borehole wall. When a mineral (or minerals) has a dominating property, the boundaries of mineralization can be determined and in best case, grade estimation can also be made by using an empirical calibration procedure. Probes are tailored according to individual ore body characteristics. One objective of the borehole geophysics is to allow the use of percussion drills or production holes so that expensive diamond core drilling is not needed in detailed stope panning or grade control (Lappalainen, 1996). Depending on ore type, OMS-logg applications can be divided into four categories:

- determination of lithological boundaries;
- definition of ore zones;
- estimation of dry bulk densities;
- grade estimation of ore.

The Outokumpu Group has routinely utilized borehole logging methods at mining operations worldwide for the last 11 years (Table 1). Pyhasalmi Zn-Cu-S and Mullikkorame Zn-Cu-Pb-S mines in Finland, and Forrestania Ni mine in Australia are currently using density-conductivity-susceptibility logging. The Tara Zn-Pb mine in Ireland and Kemi Cr mine in Finland utilize gamma-gamma density logging. Kemi is an open pit and the others are underground mines. Enonkoski Ni and

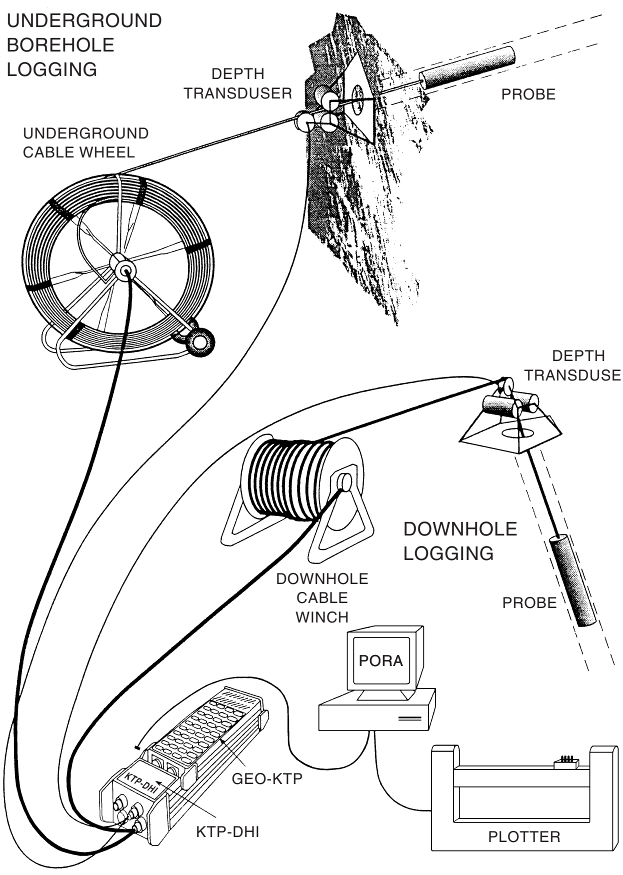


Figure 16: *Schematic overview of the OMS-logg borehole logging system.*

Telkkala Ni mines in Finland, Namew Lake Ni mine in Canada and Viscaria Cu mine in Sweden utilized only inductive conductivity logging. In all these mines logging is mainly carried out in percussion or production drill holes.

The boundaries of the Pyhasalmi pyrite rich massive sulphide ore can be defined well using gamma-gamma density logging (Figure 17), but the ore bodies in some parts contain pyrrhotite which has about the same density as typical pyrite rich ore. For separating pyrrhotite-bearing mineralization from ore to be stoped, conductivity logging combined

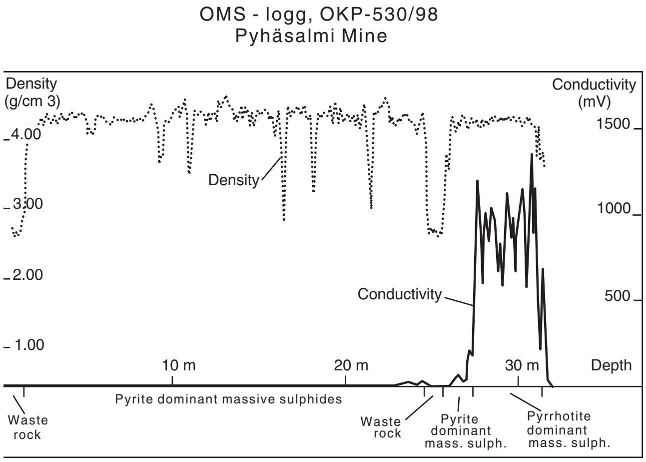


Figure 17: *Conductivity logging combined with gamma-gamma for separating pyrrhotite zones from ore to be stoped at Pyhasalmi mine.*

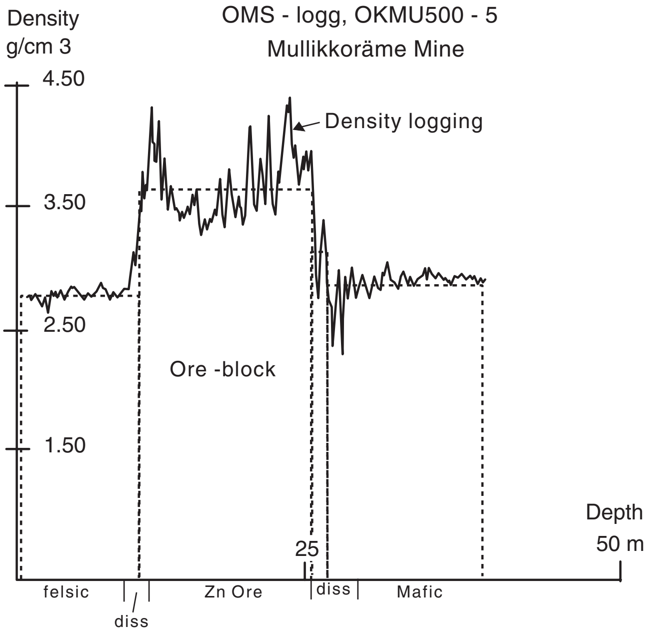


Figure 18: *Correlation of high density blocks with economical ore boundaries at Mullikkorame mine.*

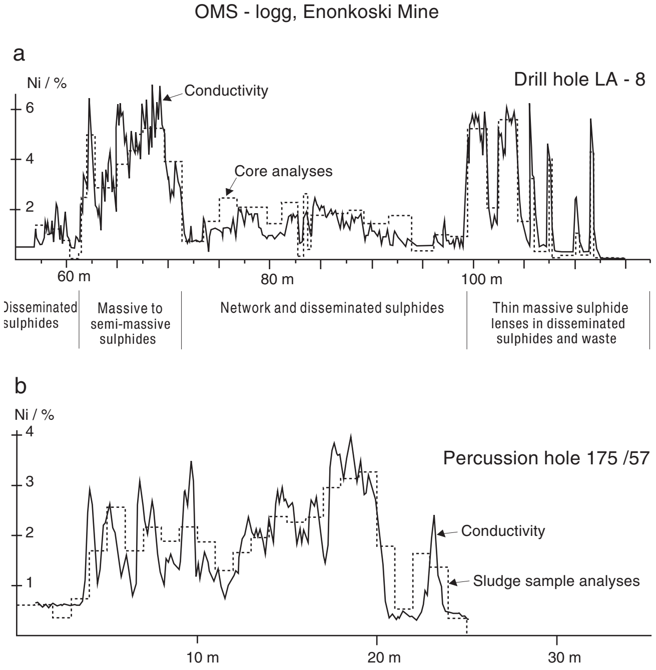


Figure 19: *(**a**) comparison of diamond core analyses and (**b**) comparison of sludge sample analyses versus conductivity calibrated to predict Ni content at Enonkoski mine.*

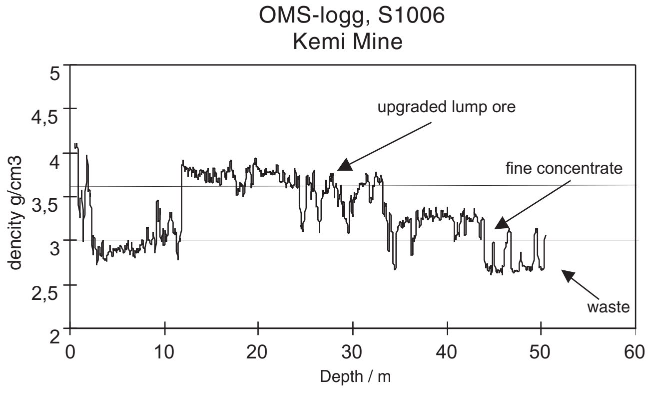


Figure 20: *Density logging profile to define ore-boundaries and classify ore for product control.*

Table 1: ***Chronological summary of OMS-logg installations.***

Mine	Commodity	Mineralisation	Mining methods	Date OMS-logg introduced	Probes	Objectives/ applications
Enonkoski Finland [1]	Ni	Massive and disseminated sulphides	Sublevel stoping	1985	Conductivity	Ore contacts, Ni grade in massive/semi-massive ore
Viscaria Sweden [1]	Cu	Disseminated with massive sulphides	Sublevel open stoping and raise mining	1985	Conductivity	Ore contacts in massive ore zones
Parainen Finland	Limestone		Open pit	1986	Natural gamma, susceptibility	To define waste rock (amphibolite, pegmatite)
Pyhäsalmi Finland [1]	Zn, Cu, S	Massive sulphides	Sublevel stoping	1989	Conductivity gamma-gamma	Ore contacts, DBD and S grades
Namew Lake Canada [1]	Ni	Massive network and disseminated sulphides	Longhole open stoping and raise mining	1990	Conductivity	Ore contacts, Ni grades in massive/network ore
Telkkälä Finland [1]	Ni	Massive sulphides	Sublevel stoping	1990	Conductivity	Ore contacts, Ni grades
Malmberget Sweden	Fe	Mostly magnetite	Sublevel caving	1991	Susceptibility	Ore contacts, Fe grades
Hilton Australia	Zn, Pb, Ag	Massive sulphides	Bench stoping	1994	Conductivity susceptibility	Ore contacts
Tara Ireland [1]	Zn, Pb	Massive disseminated and breccia sulphides	Sublevel stoping	1994	Gamma-gamma	Ore contacts, DBD and Pb + Zn grades in massive ore
Forestania Australia [1]	Ni	Massive network and disseminated sulphides	Uphole open stoping and cut/fill	1994	Conductivity susceptibility gamma-gamma	Ore and lithology contacts, DBD and Ni grades in massive and network/ disseminated ore
Kemi Finland [1]	Cr	Massive, banded oxides	Open pit	1995	Gamma-gamma	Ore contacts Cr-grade

1. Denotes operation is wholly or partly owned by Outokumpu.

with gamma-gamma is utilized. Density logging is also a basic method in the Mullikkorame Zn-Cu-Pb-S mine. High density blocks accurately correlate with economical ore-boundaries (Figure 18).

OMS-logg's conductivity probe has been designed to observe responses of sulphide nickel ores. The coil length of 10 cm allows detection of sharp contacts and narrow veins as well as measurements close to the bottom of the holes. The Enonkoski Ni mine is an example of the mafic and ultramafic intrusion where Ni grade was successfully estimated using conductivity logging calibration in the massive ore (Hattula, 1992). In addition, reliable lithological information was determined regarding waste rock and disseminated mineralization. Figure 19 shows profiles of assay data and transformed logging data in a diamond drill hole (a) and in a percussion drill hole (b).

In the Kemi Cr mine (Figure 20), lithology is classified according to OMS-logg density logging for product control. Density is also transformed into Cr_2O_3 grades to decide which part of the ore stoped will be separated for upgraded lump ore. Logging is mainly carried out from production holes in the open pit.

CONCLUSIONS

In exploration, we should not be looking simply for geophysical anomalies, but for responses related to mineralization, lithology and/or structures which may have economic importance. Geophysics provides many important capabilities in various phases of an exploration program. The use of integrated interpretation of all available geophysical methods, in conjunction with geological and geochemical data create optimum conditions for finding ore bodies even in complex data and/or structural environments. Extensive data bases and interpretation systems provide new approaches from regional surveys to site specific targets.

Borehole geophysics plays an important role in final targeting and delineation of ore bodies. In many cases drill hole geophysical data may result in discoveries without actually intersecting ore mineralization. After the exploration phase, borehole geophysics can be helpful in determining grade control in mine production in many types of deposits.

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