MINE SITE EXPLORATION
AND ORE DELINEATION

PAPER 83

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OPTIMIZATION OF VMS EXPLORATION USING DOWNHOLE EM

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ABSTRACT

The downhole electromagnetic method allows efficient exploration for conductive sulphide bodies of a roughly cylindrial volume some 100–150 m in radius. Three-component measurements of the EM field and computer-assisted interpretations allow rapid determination of the location and characteristics of conductors. Recent exploration by SOQUEM in the Abitibi Greenstone Belt illustrates the capacities of DHEM to optimise property-scale VMS exploration.

INTRODUCTION

Below the first 200 m, exploration for conductive bodies is little helped by surface geophysics. Thus downhole EM methods (DHEM) become the cost-effective way to improve exploration efficiency.

Increased deep exploration in mining camps and highly prospective areas has stimulated new applications of the DHEM method. Improvements in instrumentation, survey procedures and interpretation have supported the users in those applications.

Today, explorationists are integrating geological concepts and DHEM to evaluate exploration potential for conductive massive sulphides, to optimize exploration campaigns and to design deep drilling programs and patterns. It can also rapidly define or delineate a new conductive body in the early stages of exploration.

Here we present applications of the downhole EM method for optimizing VMS exploration. Examples from the Abitibi Greenstone Belt are discussed.

DOWNHOLE EM METHOD

The geophysical method exposed in this paper is generally described as the large loop electromagnetic method for drillholes. It applies the EM prospecting concept to investigate a volume of rock surrounding a diamond drillhole. The receiver (designed to suit the constraints of the hole) is moved along the drillhole.

The magnetic field (primary EM field) generated from the surface transmitting loop induces an electric current in any buried conductor. The new magnetic field (secondary EM field) thus generated will disturb the primary magnetic field in the vicinity of the buried conductor. If the drill hole intersects or is located close enough to the conductor, the receiver will record the disturbance caused by the secondary EM field. Figure 1 shows the large loop downhole EM method in section.

The interpretation of an anomalous response is based on the understanding of EM prospecting theory in 3-D, the use of primary EM field sections, good experience and 2-D–3-D models. The main challenge of the technique in the last decade was to increase the radius of investigation around the drill hole (by increased signal/noise ratio) and to increase confidence in the interpretation of the location of any anomaly detected by the system.

TECHNICAL IMPROVEMENTS OF DHEM

In the 1980s, the downhole EM technique gained maturity in instrumentation and interpretation. The need of the exploration industry for a more sensitive and more appropriate system for deep surveys as well as the efforts of contractors and manufacturers to improve surveys gave significant improvements. Higher transmitting power, upgraded receivers, better cables and receiving probes were developed to carry out surveys in deeper holes. All these changes have contributed to increased efficiency in the technique at greater depth.

The measurement of the EM signal through multi-component receiving probes was a significant improvement for the users and interpreters. The additional information given by these probes has increased the interpreter's confidence in locating anomalous sources and helped to decrease cost and time to follow-up off-hole anomalies. Most of the instrument manufacturers are now offering a three-component (X,Y and Z) probe, capable of characterizing the signal of a conductor in space. Figure 2 shows the theoretical signatures of different conductors at different locations.

The developments in computers during the 1980s are now giving an easier access to EM modeling programs. The simulation of field data in 2-D or 3-D can now support interpretation of complex responses.

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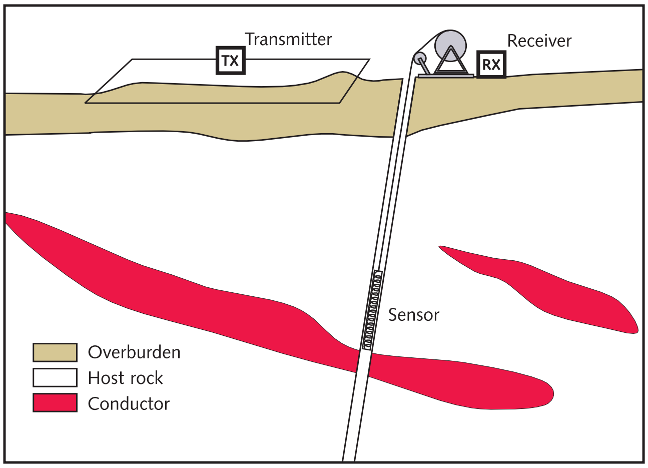


Figure 1: *Schematic section illustrating the use of large loop downhole EM (Dick 1991).*

EXAMPLES OF SOQUEM'S EXPLORATION USING DHEM

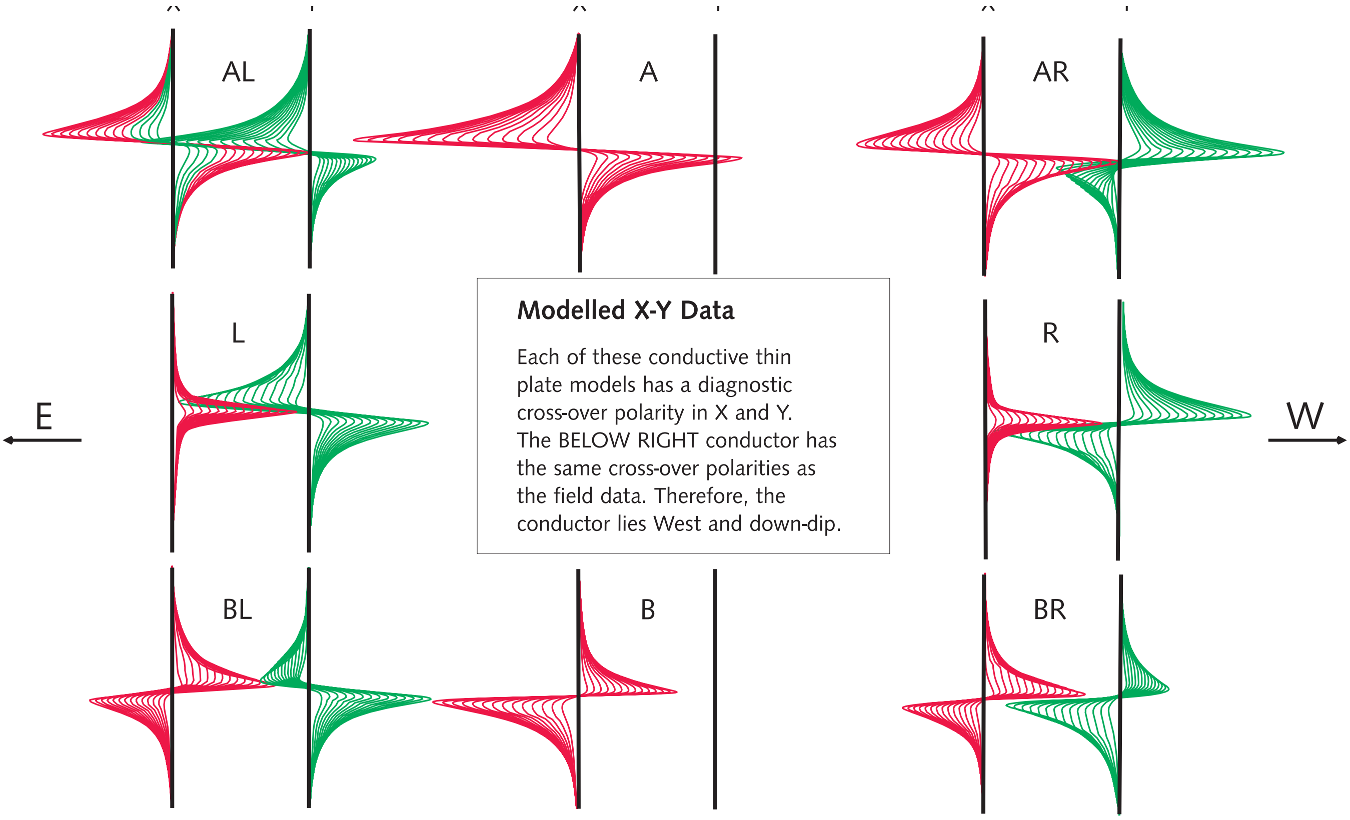
The challenge to the modern explorationist is the integration of more sophisticated geophysical, geochemical and geological concepts into a coherent program. In the following examples, statistical approaches, technical considerations and ore deposit models are used together to explore for deeper conductive bodies at the lowest cost.

From the compilation of previous exploration to the delineation of new discoveries, there are several steps where DHEM can be involved. The geophysical surveys shown in the following examples were carried out with a PEM Crone Geophysics time domain system using an impulse-type EM signal.

APPLICATION OF DHEM IN GEOLOGICAL COMPILATION, DRILLING APPROACH AND DRILLING GRIDS

The first application has been taken from SOQUEM's VMS exploration program on the Lemoine property. This property is located in the Chibougamau area, in the north-east portion of the Abitibi Greenstone Belt, Québec, Canada (Figure 3).

The property was the host of a small Zn-Cu-Ag-Au volcanogenic deposit (750 000 tonnes at 9.6% Zn, 4.2% Cu, 86 g/t Ag and 4.2 g/t Au) mined between 1975 and 1983. The geology is very prospective but previous exploration work did not discover other VMS ore bodies in the



Modelled X-Y Data

Each of these conductive thin plate models has a diagnostic cross-over polarity in X and Y. The BELOW RIGHT conductor has the same cross-over polarities as the field data. Therefore, the conductor lies West and down-dip.

Figure 2: *Crone case history of X and Y responses for each axial solution (Bishop 1993).*

Figure 3: *Location map: Chibougamau.*

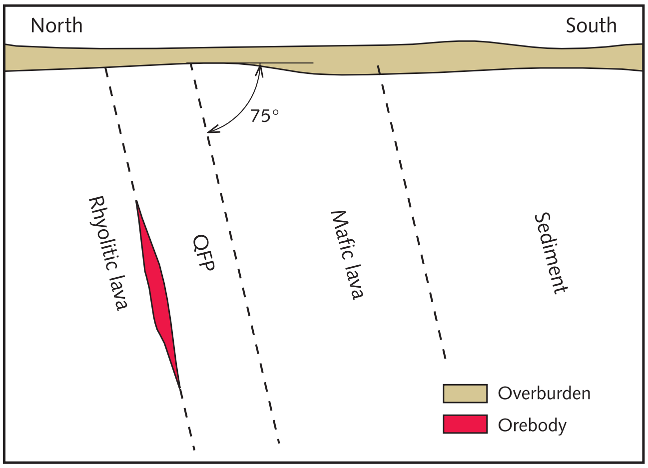


Figure 4: *Schematic section of the target model.*

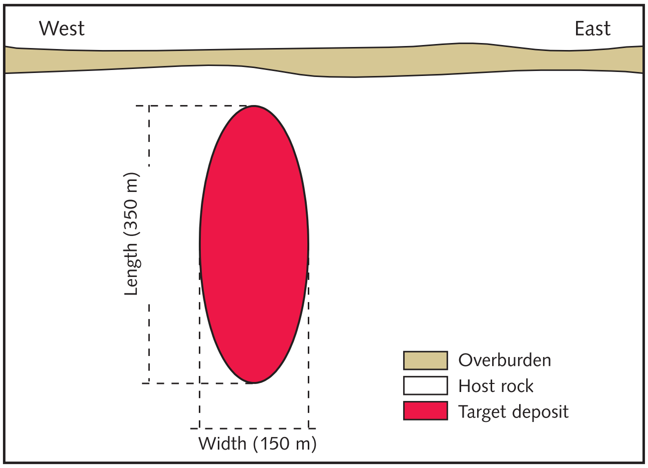


Figure 5: *Longitudinal section of the idealized target model.*

same area. Most of the work has been focused in the vicinity of the ore body. The remaining part of the property has been mainly covered by surface geophysics and shallow drilling. Acquired by option by SOQUEM in 1993, an ambitious exploration program was built by SOQUEM's staff. The strategy, driven by M. Gaétan Lavallière, was based on geological modeling of the target and the efficiency of the Downhole EM method (Lavallière, 1996). The result was a proposal for systematic exploration for a deep conductive massive sulphide ore body.

One of the first steps was to determine a physical model of the target according to the known deposit, local geology and economics of the target. The host of the Lemoine ore body is an exhalative unit formed between a rhyolitic lava and a tuff (or andesitic lava) of the Waconichi formation. Strata are steeply dipping to the south. Figures 4 and 5 illustrate the target model for the Lemoine property.

Because of the importance of the DHEM method in this project, a definition of the effectiveness of the geophysical technique was proposed, mainly based on the known case histories, the technology available and the experience of the people concerned. The radius of investigation of a survey was determined to be 125 m on the Lemoine property. Since the target horizon is well defined, the effectiveness of the method is evaluated for this geological unit and for the stringer zones associated with a VMS system.

Starting with the known geology and the effective radius of the DHEM, a compilation of the remaining VMS potential was completed. The compilation was mainly based on historical drilling, lithogeochemistry and the geophysical coverage of the favorable geological unit. Figure 6 shows a compiled longitudinal section of the favorable geological contact. The prospective contact was defined over 7 km and most of the horizon has not been explored at depth. The objective was to propose the least expensive way to explore with the highest probability of discovery. The solution was to design diamond drillholes in a way to cover, with DHEM, the maximum possible surface of the targeted contact. Instead of drilling perpendicular to the geological horizon, it was proposed to drill parallel to stratigraphy and more particularly under the tuff and/or andesitic lavas. By this approach, the DHEM survey was effective all along the drillhole instead of along a small portion of the hole. This type of drilling is not designed to intersect a possible ore body directly, but is planned to detect any conductive ore body by geophysics and to intersect alteration pipes and stringer zones, usually associated with volcanogenic massive sulphide deposits. One hole is thus required to investigate 900 vertical metres of the horizon instead to 3 holes. Figures 7 and 8 show the proposed drilling approach compared to the historical approach. This concept of drilling and surveying parallel to stratigraphy has been developed by some Canadian mining companies involved in VMS exploration.

The final component of the proposed exploration program was to define an optimized drilling grid to cover the favorable stratigraphy adequately. A diamond drill grid pattern was proposed on:

- the compilation of potential on the longitudinal section,
- the radius of investigation of the actual DHEM technique,
- drilling parallel to stratigraphy, and
- the physical model of the target deposit (length and width).

This drilling program optimized all the ingredients to come to the most effective exploration program. On the Lemoine property, the optimized pattern has been defined as drillholes 900 m deep spaced 400 m apart. Geometry of the target and DHEM technique have played a major role in this definition. The drilling proposal is shown in Figure 9.

Figure 10 shows an example of application on the Lemoine property and Figure 11 shows the results of the DHEM survey.

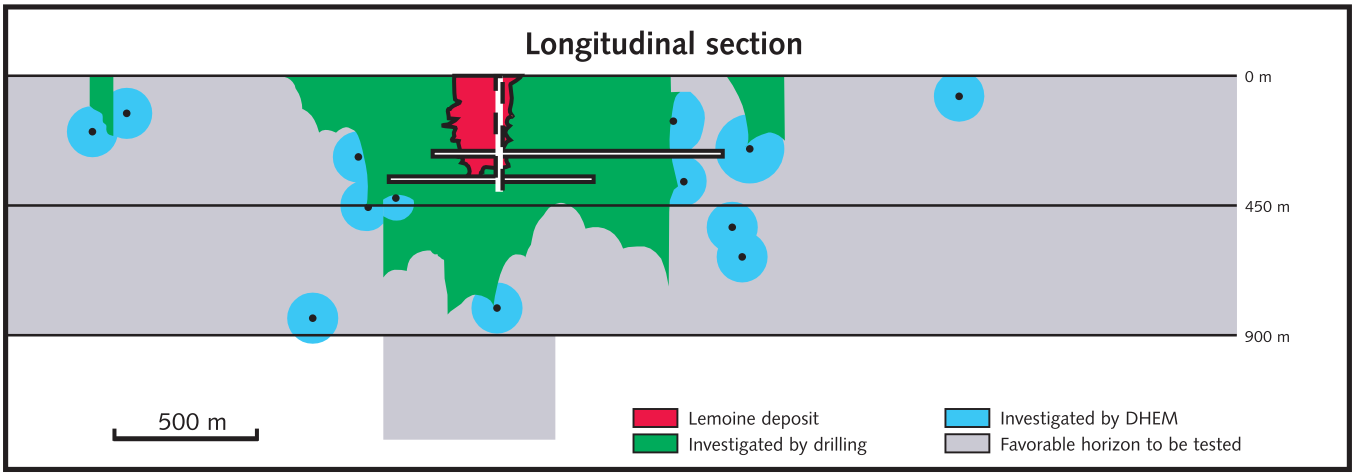


Figure 6: *Compiled longitudinal section of the favorable horizon on the Lemoine property.*

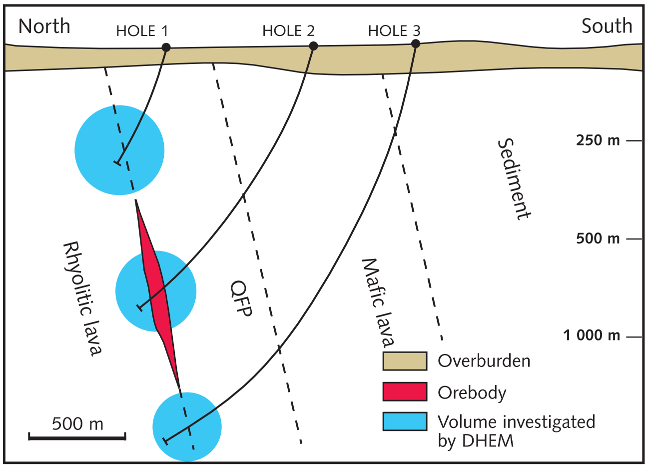


Figure 7: *Historical approach to drilling on the Lemoine property.*

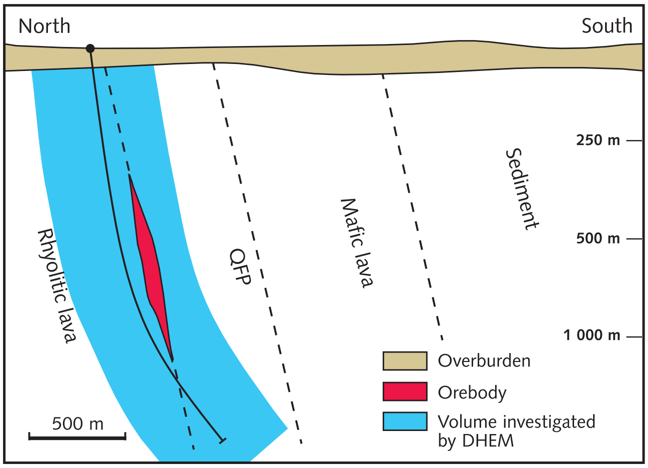


Figure 8: *Proposed drilling approach on the Lemoine property.*

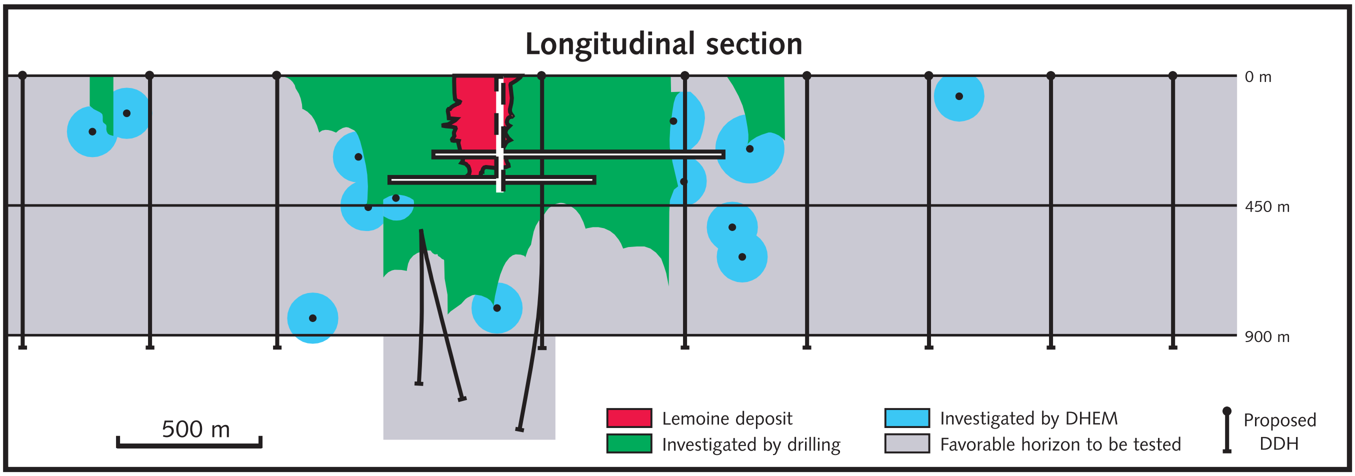


Figure 9: *Drilling proposal on the Lemoine property.*

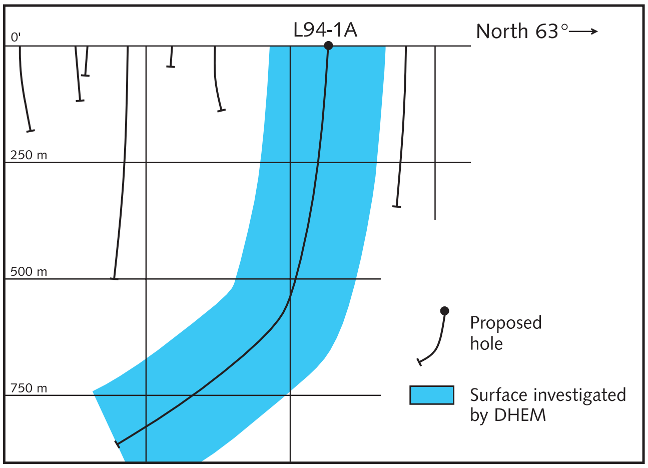


Figure 10: *Proposal of hole Lem94-1A on the Lemoine Property.*

Hole LEM94-1a was drilled to fill a gap in the eastern part of the property. Only one deep hole sub-parallel to the stratigraphy was necessary to complete the coverage of the exhalative unit. Figure 11 shows the hole, the DHEM result and the interpretation of the off-hole anomaly observed. A 33 seimen conductor was interpreted to be located at 33 m to the east of hole L94-1, at a low angle with the hole. A follow-up hole was drilled perpendicular to the stratigraphy, and intersected a network of very conductive stringer zones in andesitic lava. This approach explored the maximun surface of prospective rock and lead to an optimized follow-up of the geophysical conductor detected.

ORE DELINEATION

The determination of the electrical nature and the location of any EM anomaly detected by DHEM is the main issue of the technique. This determination is facilitated by adequate design of a multi-loop and or multi-component DHEM survey.

In a mining camp or a highly prospective environment, the method can be used to characterize a conductor, whether intersected or not in drillhole, and leads to a quick estimate of the importance of the discovery. With the use of multi-loop surveys and multi-component probes, more accurate information on the location of the conductor edges and the electrical center of an off-hole or in-hole DHEM anomaly is possible. With a minimum number of drillholes, the volume of conductive materials can be reasonably estimated. The cost and time to evaluate a very deep conductive sulphide intersection can be minimized by this approach.

The determination by geophysics of the size of the sulphide body intersected or detected is restricted to the conductive part of the body. The presence of a complex distribution of sulphides in several lenses increases difficulties in resolving the sources and locations of conductors.

The following example shows the application of DHEM on one of SOQUEM's properties in Canada. The Clairy property is a base metal project, located in the Frotet-Evans Greenstone Belt, north of Chibougamau (Figure 3). The belt is host of the Troïlus deposit (45 Mt, 1.4 g/t Au and 0.15% Cu) and numerous small deposits and occurrences of base metals (pers. comm., Inmet Mining Corp. 1997).

Drilling on Horizontal Loop EM anomalies (interpreted as an exhalative horizon) lead, in 1996, to the discovery of a small Zn-Cu-Ag deposit near surface under 20 m of overburden. After the discovery hole (hole 1171-96-01 at 10% Zn, 1.3% Cu and 24 g/t Ag over 9.1 m), a drilling grid was proposed based on the radius of investigation of DHEM. In total, seven holes were drilled and surveyed with a multi-component DHEM method. In this example, the measurement of the three components of the EM signal has generated a simple and comprehensive interpretation. Figure 12 shows a plan view of the hole locations and transmitting loops. Figures 13 and 14 show DHEM results of some holes. Figure 15 shows a longitudinal section over the main ore body and the limit of the conductive body interpreted by the survey (Lambert, 1996).

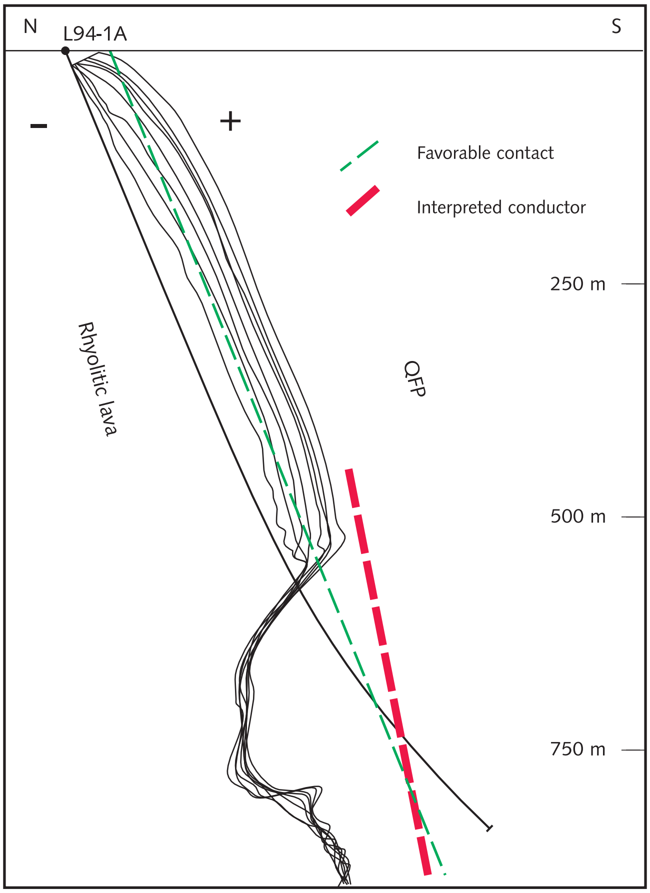


Figure 11: *Results and interpretation of DHEM (Z component) of hole Lem94-1A (Boileau 1994).*

In applying the rules of the art in the DHEM survey and interpretation on the Clairy property, SOQUEM has evaluated rapidly and with a minimum budget, the size of the massive sulphide deposit discovered. The use of the X, Y and Z signal from the receiving probe lead to a coherent interpretation.

SUMMARY

The downhole EM method can be used, in conjunction with geological concepts, to optimize exploration efficiency and probability of discoveries in the search of deep conductive sulphides. With the information of multi-component receiving probes and computer modeling, the interpretation of the geometry of the conductor permits a quick delineation of any body detected.

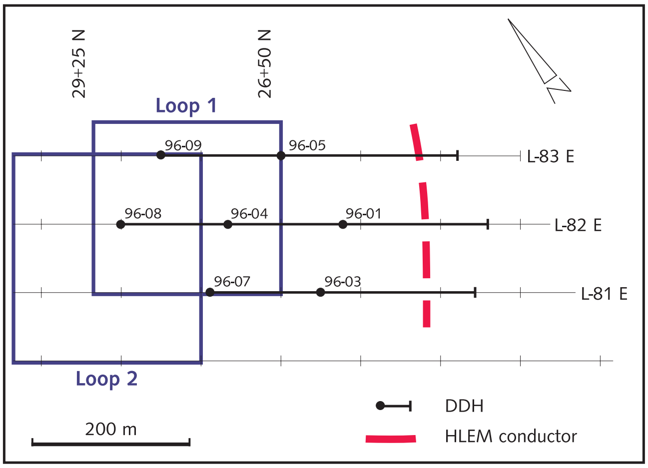


Figure 12: *Plan view of holes and Tx loops on the Clairy property.*

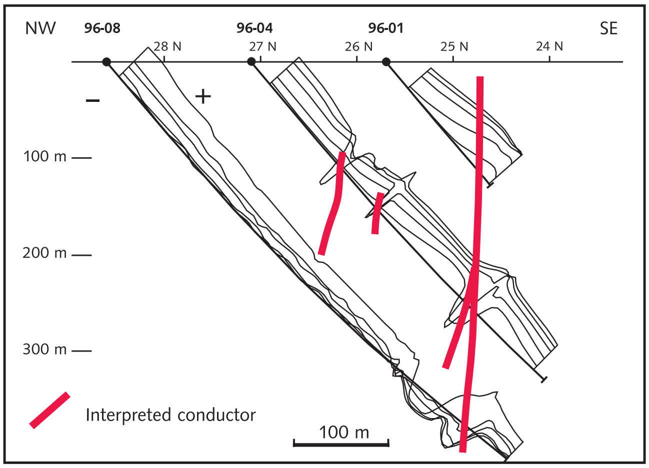


Figure 13: *Example of DHEM results (Z component) and interpretation of conductors on Line 82E.*

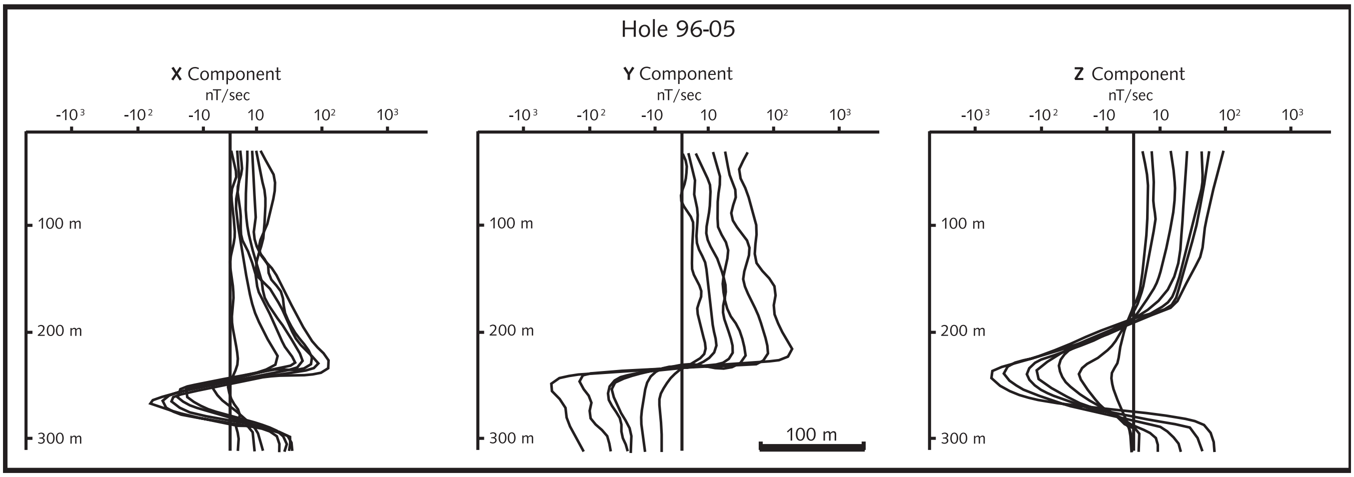


Figure 14: *Examples of X, Y, and Z components results on the Clairy property.*

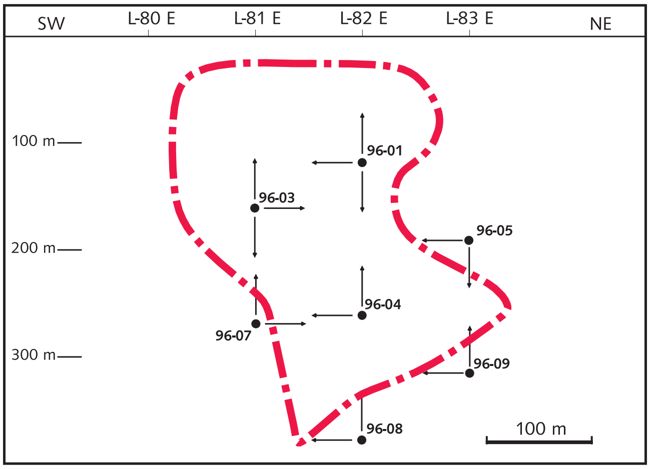


Figure 15: *Example of delimitation of a conductive body by DHEM displayed on a vertical section. Arrows show conductive trends interpreted by EM.*

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