

Advances in Geophysical Technology for VMS Exploration

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ABSTRACT

Over the last decade, new geophysical technologies for mining exploration were developed and are directly applicable for VMS exploration. Borehole magnetic surveys matched with borehole EM find a direct application in VMS exploration. Distributed ground EM system (GEOFERRET), multi-parameters distributed acquisition system for DCIP/MT (TITAN-24 and MIMDAS) or an optimized and powerful EM configuration (INFINITEM) are briefly described with field examples. Most of these new technologies break new limits in depth penetration.

INTRODUCTION

In general, few geophysical techniques are dedicated to specific deposit classes. Rather, we consider how a specific tool is applied to a family of rocks. The majority of geophysical methods are used in volcanic massive sulphide (VMS) exploration, with magnetic, gravity and electromagnetic methods commonly applied, while induced polarisation, seismic and magnetotelluric surveys also find their place.

Mining geophysics has long played a major role in VMS exploration. It is well known that numerous discoveries have been directly due to geophysics, commonly detected by magnetic or electromagnetic surveys. Ten years ago, 'Exploration 97' reported on trends of exploration in mature mining camps. At that time the direction of geophysical research was guided by the ongoing need to discover new reserves near working mines and to extend the lives of existing operations.

Increased interest in base metal exploration, driven by perceived future demand and current favourable prices, has encouraged development of improved geophysical exploration tools. Among these trends, the desire to increase the effective depth of geophysical investigations has brought about several developments.

Although not an exhaustive listing of methods applied to VMS exploration, this paper summarises new technological developments with a number of examples.

Borehole magnetics

Magnetic measurements in boreholes have been used for several decades in geotechnical and mining applications. This technique is already used in nickel sulphide (Mueller et al., 1997) and

diamond exploration (Kellett et al., 2003). The combined use of electromagnetic and magnetic methods for VMS exploration, on surface or downhole is also documented. More recently, we have seen an advance in the borehole technique with the development of borehole orientation probes using a 3-component magnetometer and the availability of computer tools for interpretation. This review presents a recent example for VMS exploration.

The principle of borehole magnetic surveys is the measurement of the natural magnetic field vectors by three orthogonal sensors down the drillhole (Figure 1).

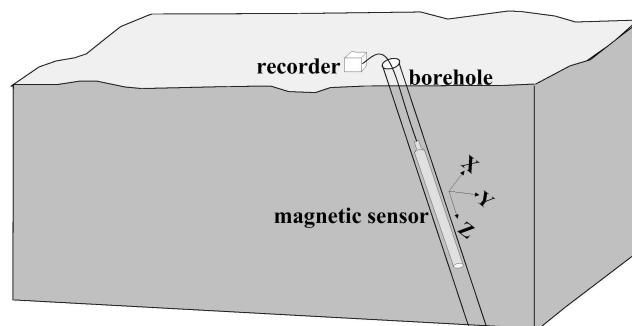


Figure 1: Schematic of measurement of magnetic components of bedrock down a borehole.

At an advanced level of geophysical exploration, borehole EM interpretation can become problematic because of the presence of multiple conductors explained by distal sulphide lenses, stringer veins and parasitic sulphides. Some VMS deposits contain a significant amount of pyrrhothite or hydrothermal secondary magnetite. The use of borehole magnetic survey in conjunction with borehole EM surveying can

make a valuable contribution in locating magnetic bodies coincident with EM conductors

A case-history for VMS provided by Xstrata Zinc Canada shows an example of the complimentary use of borehole magnetics and EM on the Ansil West occurrence in the Rouyn-Noranda camp (Figure 2).



Figure 2: Location of the West Ansil occurrence

Xstrata Zinc Canada has used the magnetic data provided by an orientation probe to locate 3D magnetic bodies. The interpretation of coincident borehole MAG and EM anomalies is a major means of identifying buried VMS occurrences on the Ansil West property.

Figure 3 shows the original magnetic profile obtained in the drillhole AN-05-02. At 520m along the hole, a strong “off-hole” magnetic anomaly is observed.

Figure 4 shows the superposition of the borehole magnetic results and electromagnetic results of the hole AN-05-02. At 520 metres along the hole, an off-hole EM and MAG anomaly is explained by a known VMS lens.

The magnetic data acquired by a borehole orientation probe is actually used by Xstrata to support and optimise borehole EM

interpretation and follow-up drilling decisions. Easier access to probes and recent modelling software make the borehole magnetic method more available and useful for VMS exploration.

Hole AN-05-02 (Borehole MAG)

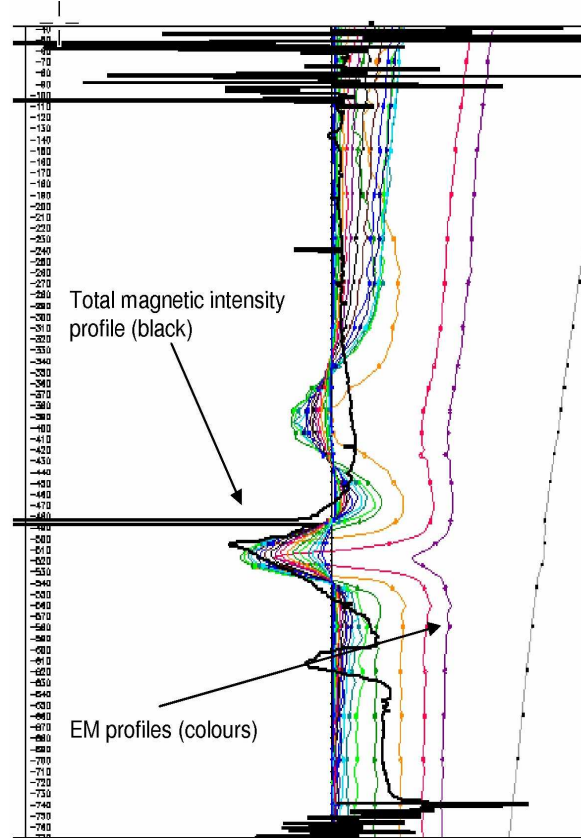


Figure 4: Borehole MAG and EM on West Ansil.

Hole AN-05-02 (borehole data)

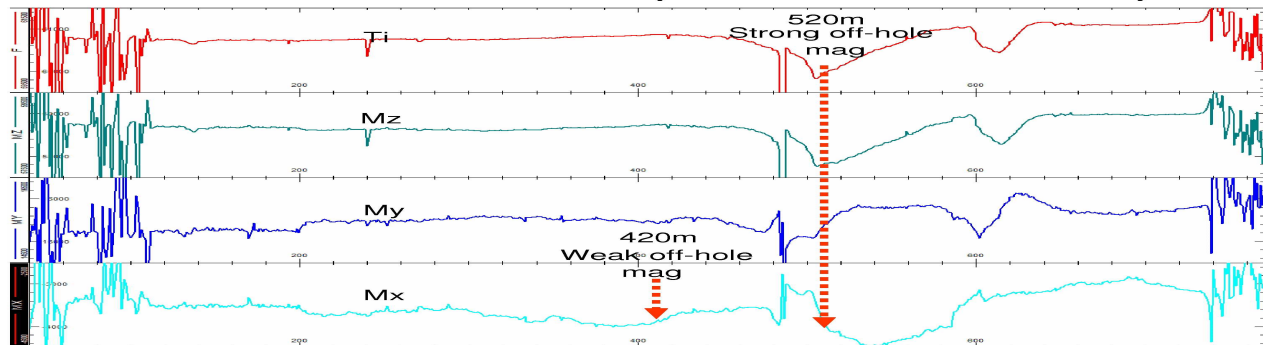


Figure 3: Borehole magnetic data on West Ansil.

Ground Electromagnetic Method

The electromagnetic method has been recognized as a major contributor to VMS discoveries over several decades. This technique directly detects VMS mineralization because of the high conductivity of the massive sulphide deposits. Numerous geophysical case-histories on VMS deposits have been published over the last 50 years (ref., Pemberton, 1989).

In the beginning of this new century, a more defined trend has been noted in EM development (Spies and Macnae, 1997). The challenge of deeper geophysical investigation has brought a series of new geophysical developments in electromagnetic exploration in several countries. This trend coincides with the arrival of the MEGATEM airborne system. In early 2000, the discovery of a new VMS deposit (Perseverance deposit) by MEGATEM in Mattagami district of the Abitibi greenstone belt has opened the door for areas previously covered by historical airborne and ground EM surveys.

A well-supported interest for investigating a deeper slice of favourable geological terrain has forced the development of more powerful time-domain helicopter-borne EM systems. Another paper of the present Exploration 07 conference (Allard 2007) covers the recent development in airborne EM.

After seeing deep penetrating airborne EM systems generate new deeper targets, users of ground EM methods have requested EM capabilities for detecting deeper conductors or for looking through thick and highly conductive superficial materials.

In early 2000, two mining companies, one in Canada and one in Australia initiated new research with industry partners. Their efforts generated two deep penetrating EM techniques, the Geoferret (Australia) and the InfiniTEM (Canada).

GEOFERRET

In 2000, WMC Resources (now merged into BHP Billiton) initiated a research project called "Geoferret" to design a new distributed system for rapid collection of deep-probing transient EM (TEM) data at high spatial resolution (Golden et al., 2005). The system was developed to advance nickel exploration projects quickly to drilling. The system introduced a new EM receiving coil and a distributed data acquisition array to increase depth penetration of EM and to provide greater detail to resolve deep conductors.

The data acquisition design of the Geoferret assembled a large number of autonomous data acquisition units and EM coils are deployed at stations of the survey grid; defined as the "array" (Figure 5). The survey involves a continuous transmitting operation and a staking period of 60 minutes (on average) to record TEM data at every recorded station. This period is about 10 times longer compared to a conventional TEM survey. The staking period increases the data quality considerably and consequently the effective depth of investigation by reducing noise level.

In 2001, in partnership with ElectroMagnetic Imaging Technology (EMIT), a new receiver coil design was tested in

field surveys and compared with industry-standard TEM coil sensors.

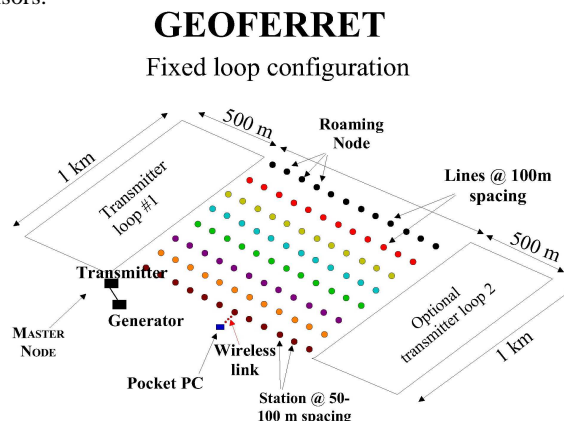


Figure 5: GEOFERRET receiver layout

The new coils measuring the three components were designed to have a low noise level at the important low frequencies required for work in conductive terrain or at depth. The performance of the new coil design was judged by WMC to be a significant improvement over commercially-available coil sensors.

In 2002, an Australian patent application was made and is now accepted. In 2003, the first GEOFERRET field trials were successfully completed over BHP Billiton's Cliffs nickel deposit in Western Australia (Figure6) using a production array of 20 production nodes. This example is not strictly a VMS case, but provides a characterization of the system over massive sulphides. This actual system uses 20 and more new improved low noise EM sensors, a 24-bit acquisition system synchronized by GPS or crystal oscillator using a minimum of cabling and interfaced with commercially-available transmitter systems (Zonge Engineering and Research Organization Inc. and Geonics Limited).

INFINITEM

In Canada, the successful development of new deep penetrating airborne EM systems has prompted the need to develop appropriate techniques for ground follow-up of those deeper targets.

SOQUEM INC., a wholly owned affiliate of the Société Générale de Financement du Québec and ABITIBI GEOPHYSICS INC., a geophysical services company, created a research joint venture to compare and evaluate large loop EM methods to follow-up deep MEGATEM anomalies under thick and conductive overburden..

The Caber deposit, a known VMS deposit located near the Perseverance deposit in the Province of Quebec, Canada was chosen as a test site to compare the two large fixed-loop geometries, "out-of-loop" and "in-loop".

First data profile from *GEOFERRET* over Cliffs mineralisation L6976350N

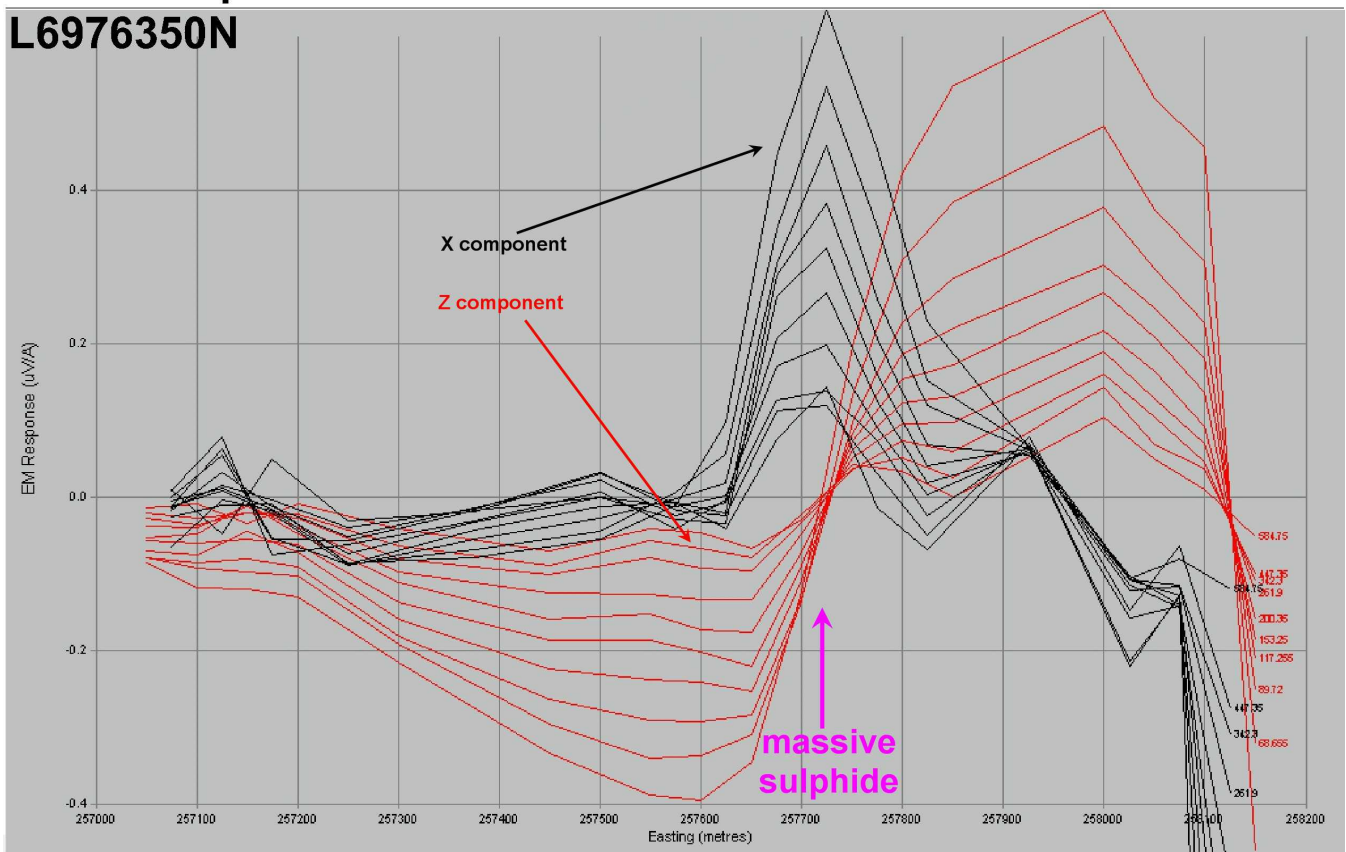


Figure 6: GEOFERRET results over Ni-Cu Cliffs mineralization.

Initial results in 2002 brought surprising conclusions. Both geometries showed some deficiencies. The “in-loop” geometry has a poor coupling for vertical steeping conductors and the “out-of-loop” rapidly decreases in primary EM field intensity.

To resolve some of the deficiencies, the research group in 2003 designed an innovative geometry for large fixed-loop EM surveys inspired by the dual loop configuration (Spies, 1975). Called INFINITEM®, (Malo-Lalonde, 2007) this configuration generates a strong and complex EM primary field using the two lobes of a figure eight-shape loop design. This configuration also offers a good sensitivity for wide range of conductivity and minimizes overburden coupling.

Figures 7 shows a plan view of the loop configuration and Figure 8 shows a vertical section of the primary field generated by an INFINITEM loop. This design was first tested with success over the Caber deposit (buried at 125m vertical) and the Caber North deposit (buried at 350m vertical). Figure 9 shows field results from the Caber North deposit.

The borehole EM version of INFINITEM was also tested and detected sulphides over 400m from the survey hole.

In 2006, the American Patent was accepted while patents are pending in Canada, Australia, Peru and other countries.

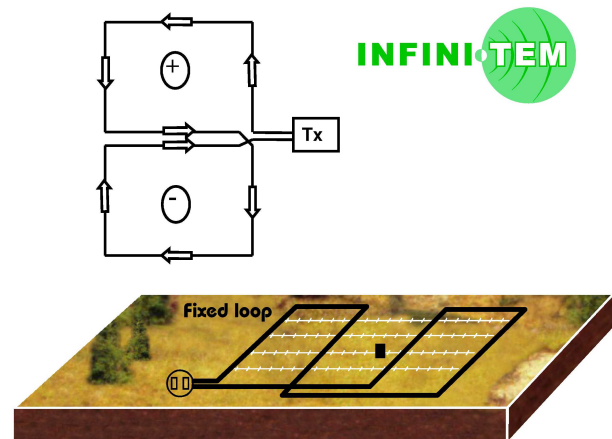


Figure 7: Schematic of INFINITEM layout.

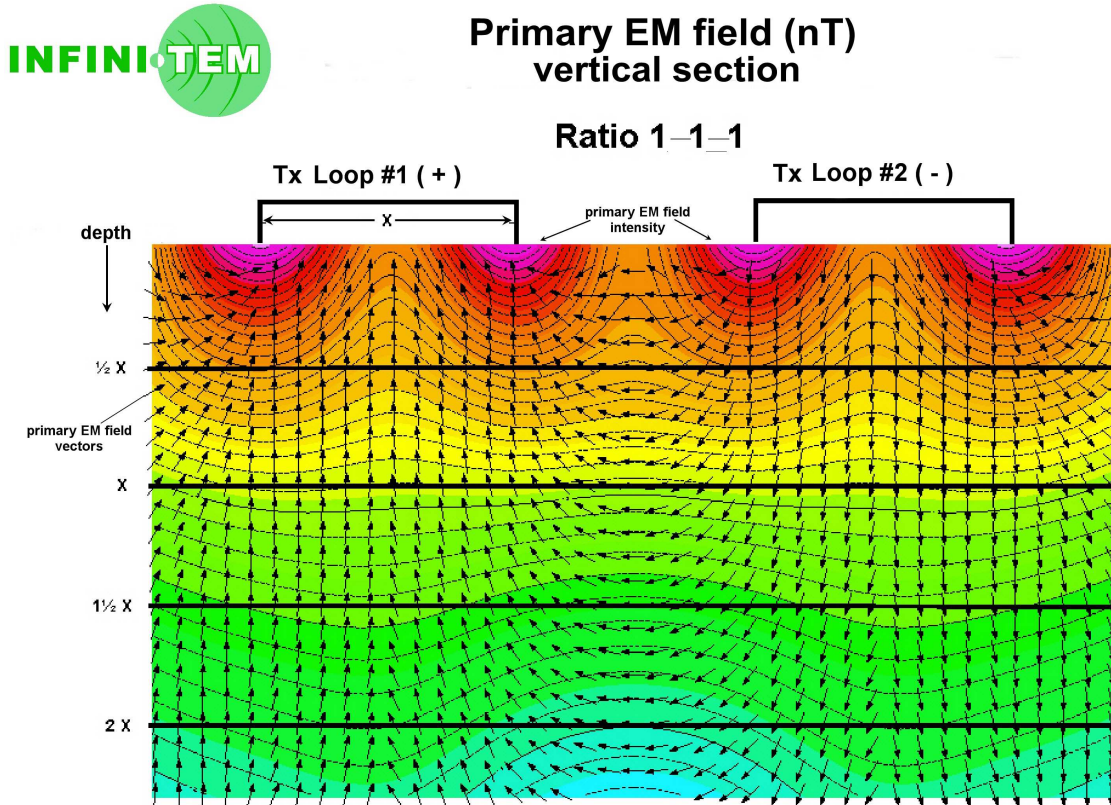


Figure 8: Vertical section of primary field for an INFINITEM setup.

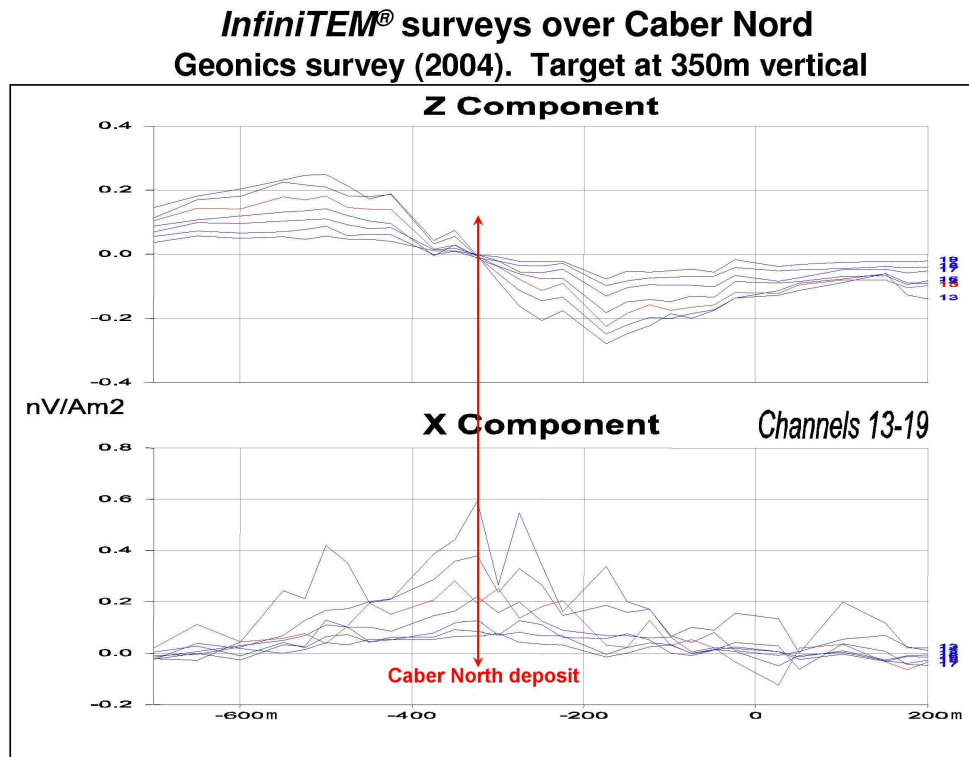


Figure 9: First INFINITEM results over Caber North deposit.

IP/MAGNETOTELLURIC

The last decade saw major advances in increasing signal-to-noise ratios of IP and magnetotelluric geophysical surveys. Increased depth penetration and resolution has resulted from this improvement.

Two multi-channel distributed acquisition systems for broadband Magnetotelluric resistivity, D.C. Resistivity and Induced Polarization chargeability were developed in this period the TITAN-24 and the MIMDAS.

TITAN-24

In late 90's, Quantec Geoscience, a Canadian geophysical contracting and consulting service, started to develop a new technology that combined capabilities for deep penetration, anoise-rejection, multi-parameter display and 3D imaging. Largely conceived in-house by combined industry expertise, the Quantec DAS-MT24 distributed acquisition system was originally designed to provide mining companies with a geophysical tool for increasing reserves around existing mine-sites. This system was later renamed TITAN-24 (see Gordon this volume).

In 1999, in order to offset the high costs associated with the system, Barrick Gold, Noranda, and a venture-capital investment firm provided additional funding for the final development of the TITAN-24.

Quantec used existing circuit boards used inside the mostmodern seismic acquisition systems as its base to successfully develop a multi-parameter 24 bit A/D acquisitionsystem for MT and DCIP measurements. TITAN technology includes advanced digital signal processing combined with a 2D-3D DCIP and MT inversion software. Quantec claims to investigate to 750m depths with TITAN-24 DCIP and 1.5km with TITAN-24 MT.

Between 2000 and 2001, The TITAN-24 was tested at the Barrick Goldstrike and Dee-Rossi gold mines in the Carlin Trend, Nevada. In 2001, the Titan-24 system was brought to Noranda's Bathurst and later Matagami VMS camps.

Figure 10 shows a typical TITAN DCIP/MT field configuration. In-line and cross-line dipoles are laid out along a 2.4km line and connected to a CPU along a LAN (Local Area Network). During the day-time, DCIP data (configured in pole-dipole--dipole arrays) are recorded by individual acquisition modules using multiple current injection sites. MT acquisition is done at night using the same set-up and adding a remote reference site for noise-rejection.

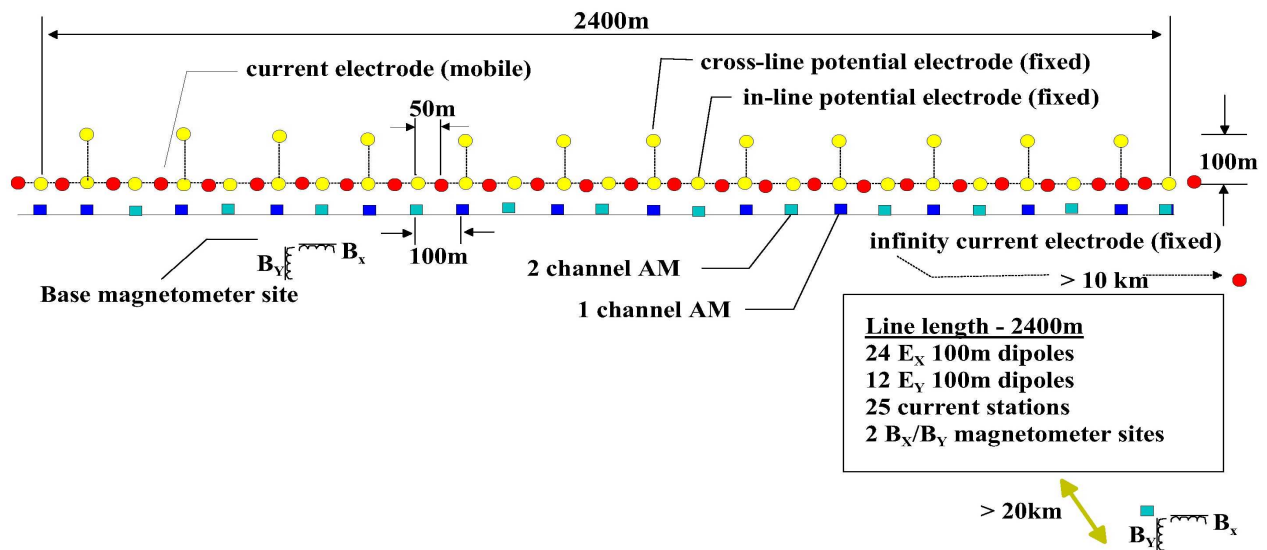


Figure 10.: Schematic of a typical TITAN-24 DCIP/MT configuration.

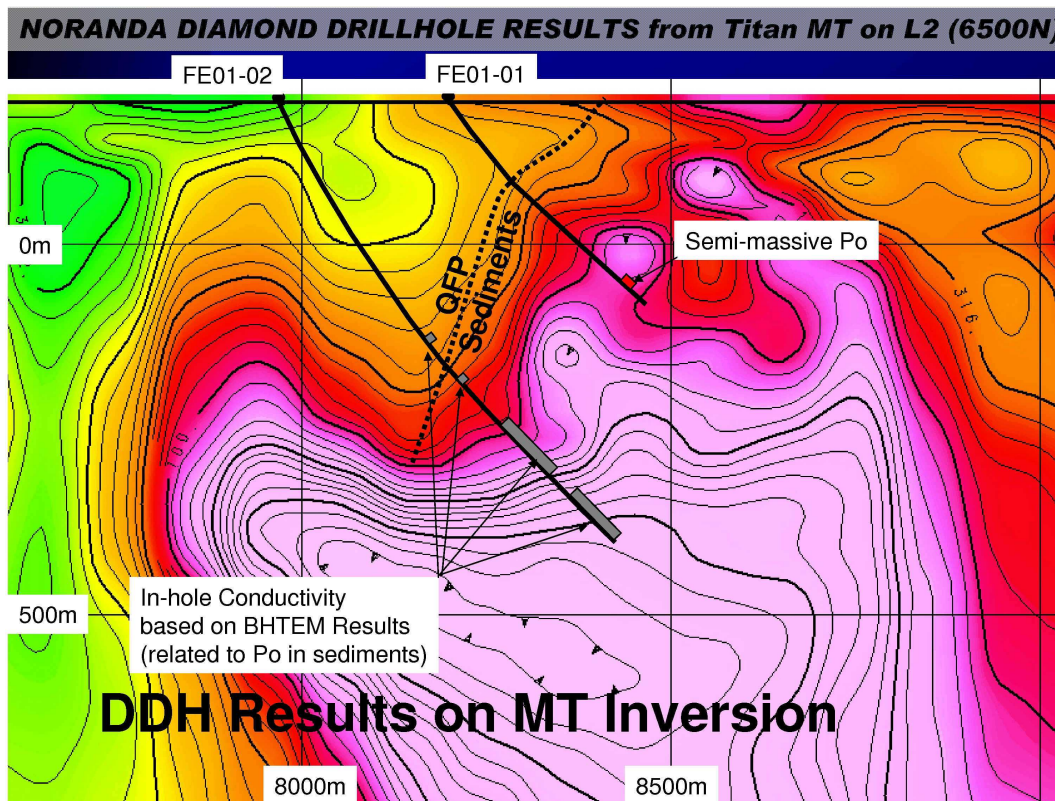


Figure 11: MT resistivity inversion in Brunswick camp with the follow-up drilling.

Typically a survey crew consists of more than 10 personnel and data processing and qc/qa are both undertaken on-site.

In 2001, in its initial VMS application, TITAN-24 test surveys were carried out over the Brunswick No. 6 Mine near Bathurst in New Brunswick, Canada. Figure 11 shows an unconstrained 2D MT resistivity inversion along line 2 (6500N) at Bathurst. The surveys clearly outlined a previously undetected conductivity anomaly at 200m below existing drilling and existing ground geophysical coverage. Further drilling by Noranda has confirmed the presence of sulphides in sediments, thereby proving the effectiveness of the technology as a deep targeting tool. Since then more than 150 Titan 24 surveys have been undertaken around the world.

MIMDAS

In Australia in 1994, M.I.M. Exploration Pty Ltd (MIMEX) initiated the development of a multichannel acquisition system to collect measurements that are accurate and low cost to collect. The hardware for the system was built in conjunction with Refraction Technology. It has been named MIMDAS – MIM.

The system is based upon single channel distributed acquisition units (DAU's) that collect data relayed to central

recording unit (CRU) in a recording truck, via local area network (LAN) cables.

The distributed system avoids multiplicity of cables attached to sensors and the inherent capacitive coupling problems.

Figure 12 shows a generic 3D MIMDAS array and Figure 13 gives a schematic of a MIMDAS MT network layout. Figure 13 shows MIMDAS results over the Ernest Henry deposit, a World Class IOCG deposits in Australia.

The time series data allows simple signal processing procedures to remove cultural noise, which when combined with selective stacking routines and other remote reference noise cancellation schemes produces very high quality data. Considerable area or kilometre of quality data can be captured rapidly. The results of the surveys of this new system were planned to be displayed as 3D style interpretation.

Generic MIMDAS '3D- Array' (Distributed acquisition)

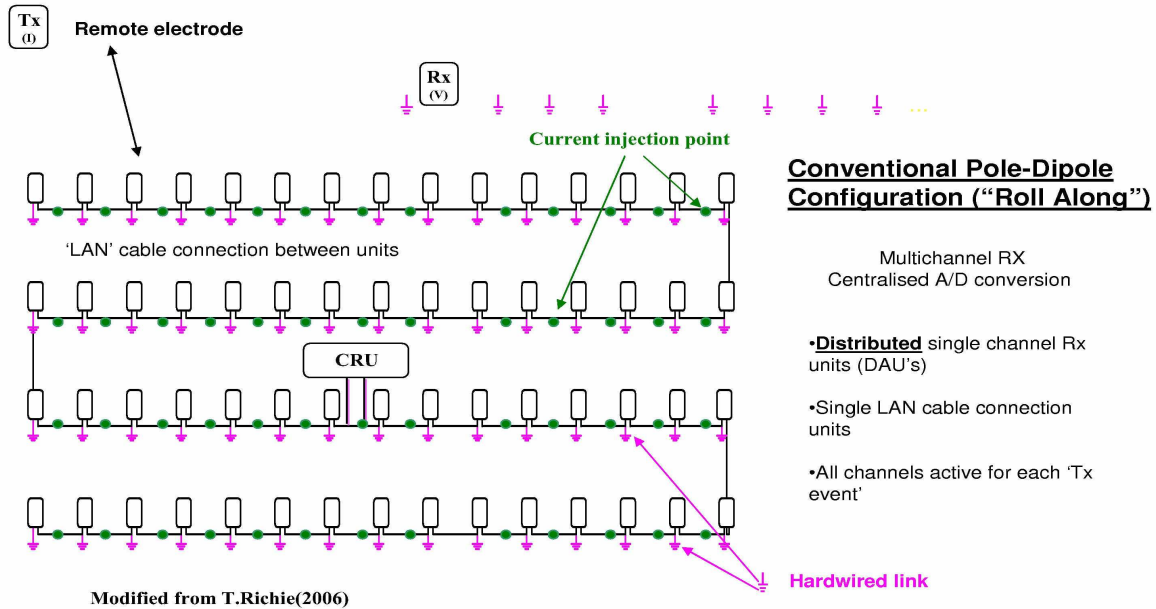


Figure 12: Schematic of a typical MIMDAS layout.

Ernest Henry IP Data Comparison

Outline of Mineralization

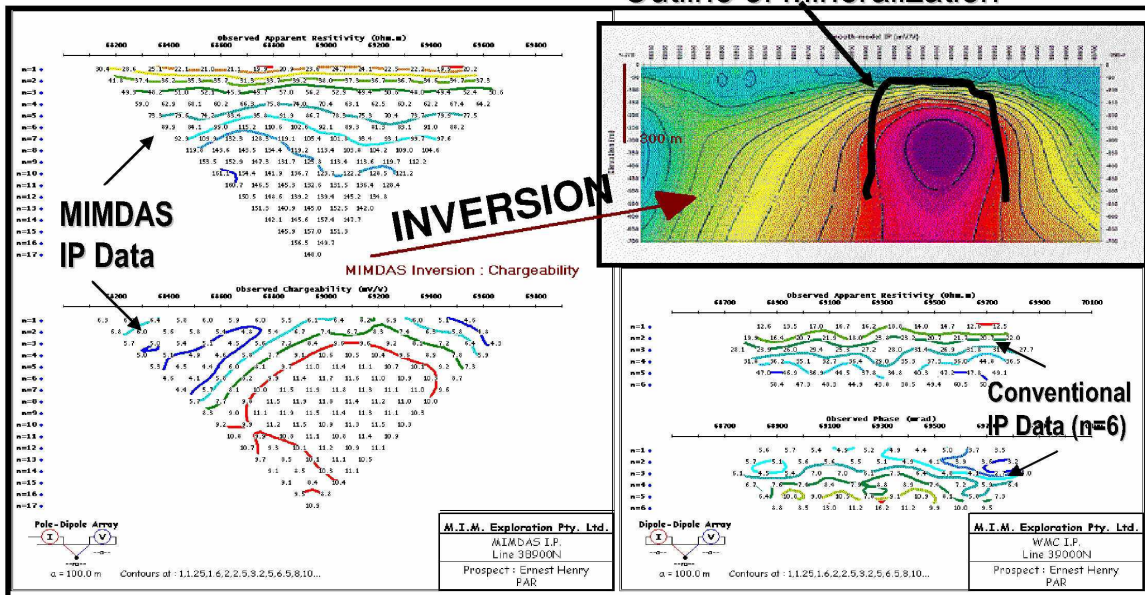


Figure 13: IP comparison between conventional IP data and MIMDAS IP data at Ernest Henry deposit.

CONCLUSION

Most of these new technologies began with existing concepts but evolved as new ways of doing geophysics. VMS exploration will benefit from these new developments, mainly in mature mining camps.

Over the last decade, a major trend in development of new geophysical technologies has been oriented to deep penetration geophysics.

Because VMS exploration is strongly oriented by geophysics, any significant development in geophysics and in particular in EM techniques will have an impact on VMS exploration success. Improvement of depth penetration geophysics is a key factor to explore below actual geophysical coverage.

ACKNOWLEDGMENTS

The author thanks Xstrata Zinc Canada (Michel Allard), BHP Billiton (Jon Hronsky), Abitibi Geophysics (Circe Malo-Lalande), Quantec Geosciences (Jean M. Legault), GRS Pty. (Terry Ritchie) and Metco Resources for their authorizations and support in publishing their results. A special thanks to SOQUEM inc. for his financial support, Tom Lane, Laurie Reed and Tyson Birkett for the review.

REFERENCES

- Allard, 2007, Advances in Airborne Electromagnetic Systems in Proceedings of Exploration '07: the Fifth Decennial International Conference on Geophysics and Geochemistry of Minerals, ed. B. Milkereit, Toronto 2007 (this volume).
- Golden, H., Herbert, T., Duncan, A., 2005, Geoferrret, Rapid low-noise deep geophysics: Presented at the 2005 Western Australia meeting of Australian Society of Exploration Geophysics
- Kellett R., Zahynacz R., and Steensma G., 2003, The role of borehole geophysics in improving the geophysical imaging of kimberlites in a sedimentary setting: Alberta, Canada: Presented at the 8th International Kimberlite Conference, June 2003.
- Malo-Lalande, C., 2007, A new approach in TDEM INFINITEM: Presented at the KEGS (Canadian Exploration Geophysics Society) meeting, February 2007, extended abstract.
- Mueller, E.L., Morris, W.A., Killeen, P.G. and Balch, S., 1997,: Combined 3-D Interpretation of Airborne, Surface, and Borehole Vector Magnetics at the McConnell Nickel Deposit: in Proceedings of Exploration '97: the Fourth Decennial International Conference on Geophysics and Geochemistry of Minerals, Toronto 1997.
- Pemberton, R.H., 1989: Geophysical response of some Canadian massive sulphide deposits, p. 517– 531, in Proceedings of Exploration '87:Third Decennial International Conference on Geophysics and Geochemical Exploration for Minerals and Groundwater, ed. G.D Garland, Ontario Geological Survey, Special Volume 3, 960 p.
- Ritchie, T., 2006, Deep looking electrical exploration using MIMDAS : Presented at the KEGS symposium, March 2006.
- Spies, B.R., 1975, The dual loop configuration of the transient electromagnetic method: Geophysics, 40, 1051–1057.
- Spies, B.R. and Macnae, J.C., 1997: Electromagnetic trends – spatial, temporal and economic, p. 489 – 496, Proceedings of Exploration 97, Fourth Decennial International Conference on Mineral Exploration, ed. A.G Gubins, Prospectors and Developers Association of Canada, 1068 p.