Lessons learnt from three massive sulphides test sites
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Introduction

In 2003, the University of Quebec in Abitibi Temiscamingue (UQAT) initiated and coordinated a project to document and enhance the capability of the MEGATEM system. The project was primarily funded by the Canadian and Quebec governments and also involved Fugro, Noranda (now Xstrata) and Ecole Polytechnique in Montréal. A series of investigations using the MEGATEMII system were undertaken in three test-site areas. These tests include a comparison of responses using the two base frequencies (90 Hz and 30 Hz), flights in alternate directions perpendicular to or along the strike of the deposits. Traverses were also flown with the transmitter off to look at the noise level and some traverses were completed at multiple altitudes. The project is divided into three parts:

- Completion of a detailed MEGATEMII survey on three well documented test sites containing volcanogenic massive sulphides (VMS), in the Rouyn-Noranda area, Québec, Canada. These sites are: Iso New-Insco, Gallen and Aldermac.
- Evaluation of the technology by comparing the MEGATEMII responses obtained from the three test sectors to the available geoscientific information.
- Development of data processing tools and data interpretation methods to improve the application of the MEGATEMII technology.

Data from the Iso and New Insco site were used to 1) develop presentations free of asymmetry, 2) estimate the depth of penetration of the MEGATEM (230m) for bodies like Iso, 3) compare the geophysical data with the geoscientific information using EM modelling software, 4) determine that 30 Hz was better than 90 Hz for detecting better conductors, while 90 Hz sees the poor conductors better; and 5) demonstrate the MEGATEM is significantly better than the older INPUT system.

A number of geophysical surveys were completed over the Gallen site, but mining activity has taken place in between these surveys, so comparison of the surveys is problematic. The principle result from the study was to show that a high fence which circles the open pit does not have a significant impact on the data, nor does the acidic water in the bottom of the open pit (except at early delay times). Reprocessing of raw data showed that a new method for removing the field emanating from the powerline gave good results.

The Aldermac deposit consists of a number of deep small massive sulphide bodies, and the ground surface was covered by overburden comprising contaminated tailings. Identification of the ore body has been made more difficult because the upper parts of the Aldermac ore bodies have been mined out, and the remaining undisturbed massive sulphides’ are situated at more than 200 m depth. 3D simulation results showed that MEGATEM is able to detect a small deep body. Near surface conductive materials, such as an alteration halo above or around the deposit, make it difficult to interpret the weak response from deep bodies, there might be some indication of the existence of a deep body by a strong response at the earliest times.

The deposits

The mapped geology for the Iso and New Insco test area is shown on Fig. 1. The Iso and New Insco sulphide zones are sheet-like bodies. The deposits occur close to a rhyolite/andesite contact. Iso strikes east-west over about 500m and dips south at 45 to 50°. The thickness is about 35 m and the down dip extent as much as 800 m. The New Insco body is more tabular with a shorter strike length (117m), greater thickness (38m) and less depth extent (250m). Iso has not been mined, but the top 10 m was stripped from the New Insco body in 1976-77.

The mains lens of Gallen ore is approximately 250 meters long, 80 meters thick and 100 meters deep with a small deep lens located to the southwest at 280 m depth (Fig. 2). The Gallen deposit was discovered in the late 1920s and early 1930s. Underground development by MacDonald mines between 1954-59 extracted 125 tonnes of copper, 28700 tonnes of zinc and also gold and silver. Then Noranda acquired the property, but did not develop an open pit until 1981. Less than a year later, production ceased after extracting 156 000 tonnes of ore at 4.4 % Zn, 33 g/t Ag, 1.1 g/t Au. Open pit mining recommenced from 1997 to 2000 when 2.4 Mt of ore were extracted (more than half the total ore extracted).

The upper part of Aldermac deposit was mined from 1933 to 1943 (more than 2Mt of ore). The average Cu grade in the lens and the pods is 1.7%. The hypothesis is that all the Aldermac lenses and the pods are hosted in rhodacitic volcanioclastics covered by a felsic dome (Fig. 3). The main ore is comprised of pyrite with lesser pyrrhotite and carrying minor chalcopyrite, sphalerite and magnetite in a gangue of quartz.

Comparison of frequencies
A comparison of 90 and 30 Hz data at the Iso and New Insco site shows that the 90 Hz amplitudes are greater than 30 Hz over the less conductive parts, whereas the 30 Hz data are greater over the more conductive parts. This enhancement is most evident at late times, whereas the more conductive parts show slower decays. A better means of discriminating conductivity is to look at the B-field data. This component indicates the New Insco deposit is the most conductive, as it has the slowest B-field decay (Cheng et al. 2006a).

The responses of 30 Hz at the Gallen site are larger than 90 Hz, primarily because of the stronger primary field at 30 Hz. However, the most important characteristic of an interpretable response is not the signal level, but the signal to noise ratio (SNR). At early time, the 90 and 30 Hz data are roughly comparable, except the z component 30 Hz gives the best signal to noise if there is no geological noise. At delay times between 2 and 3 ms, the 90 Hz SNR is better, and after 3 ms, only 30 Hz provides data. In general, the z component gives better SNR than the x component (Cheng et al. 2007).

Compared with the 90 Hz anomalies at the Aldermac site, the late time anomalies on the 30 Hz data appear to be easier to identify as they are broader and more markedly different from the background noise. The fact that the anomalies are better to see on the 30 Hz data implies that the conductor might have a high conductance, as our tests at Iso and New Insco also indicated.

Reverse flight direction tests
The test survey over the three sites was repeated with all lines being flown in the opposite direction. This confirmed that the response of dipping bodies is quite different when the flight direction is reversed. These data were used by Smith and Chouteau (2006) to devise a technique for removing directional dependency.

Transmitter off tests
The Iso - New Insco and Gallen areas were flown at survey altitude with the transmitter switched off. This will give an indication of the noise levels. The system noise at Iso and New Insco area is about 0.3 nT/s on the late time dB/dt data; the noise for one line (line 300401) at the Gallen site shows less than 1 nT/s, except for near a power line, on which there is the residual noise left after the conventional stacking filter. One of the outcomes of the project was a new scheme to remove 60 Hz and higher harmonics from the data (Boucherda, 2005). When an implementation of this method was applied to the data, the amplitudes of the residual noise near the power lines are substantially less.

Height attenuation tests
Traverses were completed over the most conductive part of the Iso body at greater and greater height to determine the depth that the MEGATEM system might be able to detect this body. At standard height, the anomaly was large, but as the flying height increased, the response decreased and broadened. At an aircraft height of 465m, the response was barely detectable. Fig. 4 shows the amplitude decreasing with height. This type of height attenuation test does not take into account the effect of the conductive background. In this case, we modeled the background as 1.2 S overburden overlaying highly resistive bedrock, then, we undertook a modeling experiment placing the body deeper in the bedrock. This indicated that in this circumstance, windows positioned prior to 1.5 ms after switch off would be adversely affected by the overburden. Our attenuation tests show that window 14 becomes less than the noise when the system is 350 m above the ground. This is equivalent to the Iso body being buried 230 m below a system flying at the standard flying height (Cheng et al. 2006a).

Modeling and data interpretation
Use of a 3D modeling tool is helpful to quantify the AEM responses of specified sources. We also found it useful to approximate the total response by adding plausible multiple 3D sources with an assumed shape and conductance or conductivity. Because of the non-uniqueness of the interpretation, we used several 3D modeling tools to generate simulated responses. We also interpreted more than one flight line simultaneously in order to gauge the consistency of modeling results.

EMQ modeling
The EMQ modeling tool is a fast modeling and inversion tool that uses a model comprised of a sphere or a sphere with dipping current flow (Smith et al. 2003). Using this tool, the Iso body was shown to be dipping 50° to the south with its center 96 m below the surface. This is consistent with the 45 to 50° dip from the geological model. The New Insco body could be poorly modeled with the simple sphere model (with and without dipping currents). This suggests that the body is something between a thin sheet and a sphere. This is consistent with the more tabular nature of this body.

MAXWELL modeling
A good fit was obtained for the Iso response using the Maxwell package and 55 S thin sheet model dipping at 50°. Using Maxwell, we found it difficult to model multiple lines simultaneously. Both Maxwell and EMQ are capable of forward modeling and inverse modeling using iterative improvement from an initial guess for a sphere or a thin sheet model.
EMIGMA modeling

The EMIGMA package is only capable of 3D forward modeling, so considerable trial and error modeling is required to get a good fit to the data. However, EMIGMA is capable of handling multiple lines and multiple (non-interacting) bodies. It can also model thick prisms with large conductivity contrast.

For the Iso body, four plates were used to approximate the ore body; they are shown superimposed on the dip-plane section on Fig. 5. Plate 3 is the most conductive (55 S) and corresponds to the copper rich zone, while plate 2 (40 S) corresponds to the iron and zinc rich zones. The outer plates are modeling smaller thinner parts of the body and are less conductive (20 to 30 S). The measured and modeled data are shown on Fig. 6 (below). The greater depth extent of plate 2 is consistent with the geological model. The full 600 m depth has not been matched, but the geology below 500 m is actually not well constrained by the drilling. At the same time, AEM methods are unlikely to be sensitive to material this deep when there is more conductive material above. The strike extent and dip have been well resolved by the model (Cheng et al. 2006b).

EMIGMA thick prism models were used to simulate the Gallen body and the acidic water in the open pit. The top of the water in the open pit is 15 m below the surface of the earth, but we found we could only get a good match of the MEGATEM data to the model data when the bottom part of the pit was made conductive (Fig. 7). This is consistent with work by Lu (2004), who found that there was more contamination of heavy metals at the bottom of an open-pit lake in Sweden. To get the good fit, it was also necessary to incline the body that approximates the water slightly to the north. The reason for this is not clear. Modeling of the MEGATEM data shows that the response is primarily due to sulphides, but a significant portion of the early time response could be due to acidic water in the open pit (particularly on the z component). The impact of the fence surrounding the open pit is judged to be small (Cheng et al., 2007c).

At the Aldermac site, the MEGATEM responses show quick decay prior to delay times of 1.0 to 1.2 ms and then the decay slows down markedly after 1.2 ms indicating possible deep conductive materials. The modeling work allows us to infer the effect that the contaminated tailings have on the ore body response and how deep the conductive materials are. Modeling results show that overburden having a resistivity of 50 Ohm-m and a thickness of 5 meters has same effect as a resistivity of 10 Ohm-m and a thickness of one meter. A resistive layer of 100 Ohm-m and 5 meters in thickness gives even more effect to EM airborne surveys than a very conductive (10 Ohm-m) but very thin overburden (1 meter in thickness). By plotting the MEGATEM responses measured on line 401 and 501 on the same set of scales as the overburden models (Fig. 8) we use the fit to the early-time data to estimate that the resistivity of the contaminated tailings is between 10 to 30 Ohm-m, and its thickness is between 1 to 5 meters. However, the late-time MEGATEM response is much slower, and this is interpreted to be the response from the deep ore bodies.

Conclusion

Within the MEGATEM technology enhancement project (2003 to 2006), we have documented the capability of the MEGATEM system and made a number of improvements in the processing. From a research perspective, the project has been very productive, generating 7 scientific papers (4 published, 3 papers will be published) and two master students’ thesis. This is a successful collaboration between mining industries and universities which lead to a deep comprehension of survey method and its efficiency.

References


Smith, R.S., and Chouteau, M.C., 2006, Combining airborne electromagnetic data from alternate flight directions to improve data interpretability: the virtual symmetric array: Geophysics, in press.

Fig. 1: Subcrop geology map of the area containing the Iso and New Insco deposits.

Fig. 2: The Sub-crop geology map and the surface projection of the Gallen deposit prior to mining. Superimposed are the location of the MEGATEM flight lines.

Fig. 3: Geological hypothesis for Aldermac deposit

Fig. 4: Height attenuation data for MEGATEM.

Fig. 5: The GoCad model showing the mineralized zones of the Iso deposit and the four EMIGMA late models. Note the locations of lines L30101, L40101 and L50101.
Fig. 6: There is very good agreement between the measured (left) and modeled (right) data for three lines at Iso.

Fig. 7: Comparison of the MEGATEM response at the Gallen site (top 3 panels), with the modeled response (bottom 3 panels) for the synthetic model shown at the bottom.

Fig. 8: Overburden models and the estimation of tailings resistivity.