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A Comparison Between Old and Recent Airborne Time-Domain Electromagnetic Surveys Flown in the Chibougamau Region, Eastern Canada

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ABSTRACT

The Chibougamau region, located at the eastern end of the Abitibi Greenstone Belt, north-western Quebec, Canada, has been flown by various electromagnetic (EM) surveys. Government-funded surveys were flown to help base metal exploration and data are available in the public domain. A time-domain EM survey flown in 1972, resulted in the discovery of the Lemoine mine. As a result of this success the rest of the region was systematically surveyed by time-domain surveys between 1977 and 1980. A modern time-domain EM survey covering 9000 km2 was flown in 2006. This recent survey allows assessment of the benefits of flying a state of the art EM system over a previously surveyed area. A first comparison, strictly based on the number of EM anomalies, reveals that the recent survey detected 25% more anomalies than the older ones. A second comparison is based on interpreted depths derived from the recent survey data compared to what is known of the depth of penetration of older systems. More than 1000 anomalies are interpreted to have their sources deeper than 75 m, and more than 450 have sources deeper than 100 m. This interpretation is based on a thin vertical rectangular plate model in a resistive host rock. This is a reasonable hypothesis as the geology of the region is sub-vertical and very little conductive overburden is present. The depth of penetration of older systems was likely to be between 75 and 100 m and we conclude that the recent survey detected at least 400 anomalies related to deep sources. However, this number of new anomalies does not imply new exploration targets, since a given conductor generally produces more than one anomaly due to its length and dip. Some new anomalies are due to shallow sources. Modern EM surveys detect new exploration targets at depth and, also, shallow conductors missed by previous surveys.

INTRODUCTION

A MEGATEM II time-domain EM and magnetic survey was flown by Fugro Airborne Surveys for the Geological Survey of Canada during the winter of 2006 over the Chibougamau area. The objectives were to identify new base metal exploration targets, to increase mining exploration and to help geological mapping. Many deposits have been mined in the region. One of them, the Lemoine mine (Cu-Zn), now closed, was discovered in 1973 as a result of an INPUT Mk V survey flown in 1972 for the Quebec Department of Natural Resources. This INPUT Mk V survey and a series of INPUT Mk VI surveys flown later totally overlap the new survey. These older surveys and the recent MEGATEM II survey provide a measure of the improvement in information obtained when an area flown more than 25 years ago is reflown by a state of the art deep penetrating EM system. Simple anomaly maps were produced for the INPUT surveys. A wealth of products can be derived from modern EM systems; usual ones are anomaly, time constant and apparent conductance maps. Anomalies can also be interpreted in terms of conductance and depths. The use of GPS navigation produces highly regular flight paths, contrary to the older systems which were flown using visual navigation and photomosaics for flight path recovery. This resulted in irregular flight paths and non-uniform coverage.

Geology

The Chibougamau region is located at the eastern end of the Abitibi Greenstone Belt. The area is part of the Chibougamau-Matagami Greenstone Belt (Goodwin and Ridler, 1970). In the study area the volcano-sedimentary assemblage has been divided in two groups (Allard et al., 1979; Gobeil and Racicot, 1983): the Roy Group at the base and the Opémisca Group at the top. The Roy Group includes two volcano-sedimentary cycles subdivided into the Obatogamau, Waconichi, Gilman, Blondeau and Bordeleau Formations. The Obatogamau is composed of basalts and comagmatic gabbros. The Waconichi is composed of

In "Proceedings of Exploration 07: Fifth Decennial International Conference on Mineral Exploration" edited by B. Milkereit, 2007, p. 863-867

massive rhyolite and felsic pyroclastics. The Gilman is mostly a sequence of andesite-basalt and comagmatic gabbro and diorite dykes. The Blondeau is mainly composed of rhyolitic and chert tuff, graphitic agillite, intermediate to felsic lavas. The volcano-sedimentary rocks are contain many intrusions of various compositions. The most important are the Doré Lake and Cummings Complexes, and the Lake Springer intrusions that have a mafic composition. The Chibougamau, Presqu'île and Opémisca plutons are of felsic composition. The Doré Lake Complex is a four-zone stratiform magmatic intrusion: an anorthositic zone at the base, then a layered zone (pyroxenite, gabbro and magnetite rich-layers with iron-vanadium-titanium) followed by a ferrodiorite zone and finally the superior zone (sodagranophyric and upper zones). The Cummings Complex includes three differentiated sills: Roberge, Ventures and Bourbeau. The most mafic one is the Roberge and the least mafic is the Bourbeau. Major structural elements have an east-west schistosity, east-west folds and east-west and north-east faults.

Previous surveys

Four time-domain EM surveys are located within the survey area. A first survey using an INPUT Mk V system, was flown in 1972 (Questor, 1972) and the others, using the INPUT Mk VI system, were flown between 1977 and 1980 (Questor Surveys Ltd., 1977, 1978; Relevés Géophysiques Inc., 1980). The present study is based on a comparison between INPUT and MEGATEM II survey results. Both systems use a half-sine pulse and a vertical axis transmitter. The transmitting loop is attached to the nose, wing tips and tail of an aircraft. The receiver is in towed bird about 120 m behind the aircraft and 70 m below. The use of analog filters in the receiver resulted in a spatial distortion of the anomalies (Jensen and Becker, 1979). Starting in 1974, EM and magnetic data were recorded digitally. All surveys were flown at mean terrain clearance of 120 m and a line spacing of 200 m. Navigation was visual, the compilation was originally done on photomosaics and later transferred to 1:20 000 topographic maps. System parameters (Becker, 1979; Lazenby et al., 1983) are given in Table 1.

The MEGATEM II survey

The study area was divided into four separate blocks (Figure 1) selected because of their high base metal potential, their good access and their historical exploration work. Flight lines, spaced 200 m apart, were oriented north-south except in block C where line orientation was N 150o, i.e. perpendicular to the main geological trend within that block. Flight lines were flown in alternating directions. The mean terrain clearance of the aircraft was 120 m. Differential GPS navigation was used to obtain a uniform coverage. The system uses a fully digital three component receiver and the digital filters used in post-processing the data are designed to minimise anomaly distortion. The use of a strong dipole moment results in deep penetration. A study based on a series of height tests over the Iso deposit, a 5.8 MT ore body, has shown that the depth of penetration of the system, in the Abitibi context is about 250 m (Cheng et al., 2006). Other characteristics and advantages of the system are well documented (Smith and Keating, 1995).

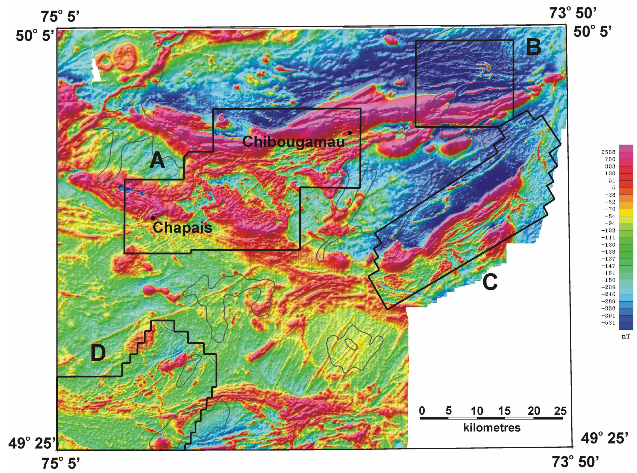

Figure 1: Location of the 4 survey blocks superimposed on the residual total magnetic field from 200 m line spacing INPUT surveys flown at a height of 120 m.

RESULTS

New anomalies

The simplest metric for comparing surveys is to evaluate the number of anomalies detected by the two systems. Within the study area there are 4000 INPUT anomalies and 5021 MEGATEM II anomalies, cultural anomalies being excluded. Interestingly, there is about the same number of INPUT and MEGATEM II anomalies in block A. This is due to the presence of several 735 kV power lines built after the INPUT surveys were flown over that block. Because of this, data is rendered useless for up to 500 m on each side of a power line. A second approach is to compare interpreted depths of the EM anomalies from the new survey to what is known about the depth of penetration of the INPUT systems. Interpreted depths were calculated by the survey contractor using an automated nomogram fitting procedure based on the use of an inductively thin vertical plate model in free space. The use of this model is justified by the fact that the geology of the area is sub-vertical and the overburden is rather non conductive as it mainly consists of sand, gravel and till (Paradis, 2002). The process was systematically used for all anomalies that have a strong enough signal to noise ratio without distinguishing between true anomalies and anomalies caused by the asymmetry of the system. It is found that 1134 anomalies from the MEGATEM II survey have their source deeper than 75 m and 463 anomalies are caused by sources deeper than 100 m. In the study area, the depth of penetration of the INPUT system is estimated to be between 75 and 100 m. Even if our results are from interpreted depths, it is likely that many new anomalies originating from deep sources were detected. This does not correspond to the number of new conductors as a given conductor, because of its length, relative to the line spacing, can give rise to more than one anomaly.

Known deposits

The Lemoine mine was discovered in 1973 as a result of an INPUT Mk V survey flown in 1972. The conductor is located under thin overburden. It was a high grade VMS that produced 757 585 tons of ore from November 1975 to March 1983, for a total of 29 932 tons of copper, 53 869 tons of zinc and 2739 kg of gold. Mineralization consists of chalcopyrite, sphalerite, gold, silver, pyrite and pyrrhotite. The discovery anomaly was an easy-to-identify four-channel INPUT anomaly. Although there are no reserves left, the conductive sulfide horizon of the mine still gives a strong MEGATEM II response on both the X and Z component and its conductance, based on the vertical plate model, is 16 S.

The Scott deposit a small, non economic, zinc ore body (750 000 T) is located within the survey area. This VMS deposit is mainly composed of sphalerite. Its discovery was the result of an INPUT Mk VI survey flow in 1978. Its responses was an isolated two channel anomaly and its estimated conductance was about 4 S. A similar fast decaying anomalous response was detected in the recent survey. It is shown in Figure 2 where a 4-channel response on the X component and a 3-channel response on the Z component are observed.

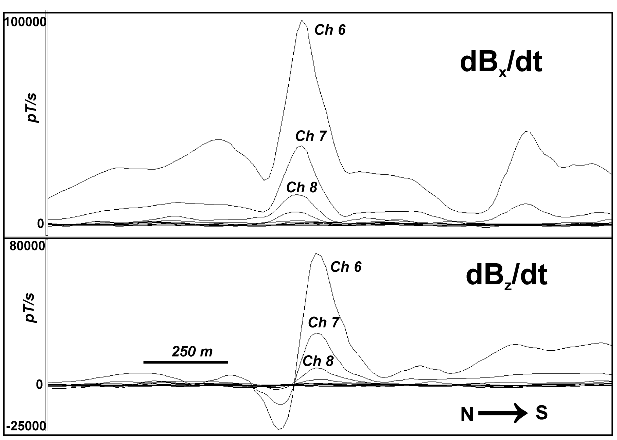

Figure 2: MEGATEM II response over the Scott deposit. Channel 6 is the first off-time channel of the system.

Extension of previously known conductors

Two groups of INPUT anomalies about 16 km northeast of Chapais illustrate the benefits of better anomaly positioning and increased transmitter moment. A first group located north of a small lake consists of 4 INPUT anomalies (Figure 3A). Two strong 6 channel anomalies are nearly superimposed as the result of the intersection of two flight lines. The two-channel anomaly about 200 m to the north is likely a dip effect. A fourth anomaly is about 400 m to the west. The same conductor is intersected by 4 survey lines of the MEGATEM II survey (Figure 3B), the observed anomaly pattern is a clear indication of a vertical conductor. For the INPUT survey, interpreted conductances vary from 9 to 34 S, and range from 25 to 50 S for the MEGATEM II survey while interpreted depths are about 100 m. Since the conductor is sub-vertical this interpretation based on the vertical plate is likely close to reality. Three other INPUT anomalies are located about 750 m northwest of this conductor. They do not seem to be caused by a single conductor as some flight lines do not show any response. In two cases, flight lines are less than 100 m apart and a response is observed on only one flight line.

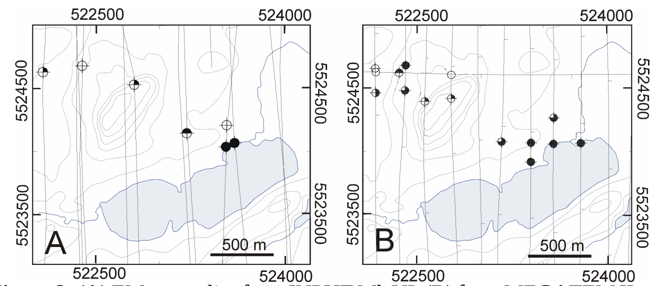

Figure 3: (A) EM anomalies from INPUT Mk VI, (B) from MEGATEM II survey. Coordinates are UTM, Zone 18.

The situation is much clearer in the MEGATEM II data where a single conductor is intersected by 4 survey lines. In addition, the conductor is also detected on a nearby control line. The INPUT survey indicated the possibility of 3 separate conductors with conductances ranging from 1 to 4 S. On the other hand, the MEGATEM II survey clearly indicates the presence of a 600 m long conductor. Its conductance varies from 17 to 48 S, and interpreted depths vary from 91 to 149 m. These improvements result from the use of GPS navigation and a more powerful transmitter.

The new survey also allows a better definition of previously known conductors. A typical example is the Lemoine mine horizon (Figure 4). At the mine, mineralization is within an exhalative horizon concordant with the stratigraphy and its dip is 50o-70o north. Mineralisation is mainly composed of chalcopyrite, pyrite and pyrrhotite, which are all highly conductive, and sphalerite that is weakly conductive. The discovery anomaly was a four channel INPUT anomaly. The MEGATEM II response is strong on both the X and Z components. The estimated conductance is 16 S and the conductor has a dip of about 60o N. However, to the northeast, the MEGATEM II profile suggests that the conductor dips to the south. The mine horizon is known to be cut by faults. In addition, new EM anomalies from the recent survey show that the conductive horizon extends further to the southwest and the northeast (Figure 4). The continuity of the conductor is better defined by the recent survey than by the INPUT survey.

Deep conductors

An example of a new conductor that was not detected by a previous INPUT survey is located 2 km northwest of the Lemoine mine. The conductor, shown in Figure 5, intercepts three flight lines. There are two anomalies on line 30830, one of them being a dip effect; in this case the aircraft was flying up dip. Only one anomaly is seen on the adjacent lines along which the aircraft was flying down dip.

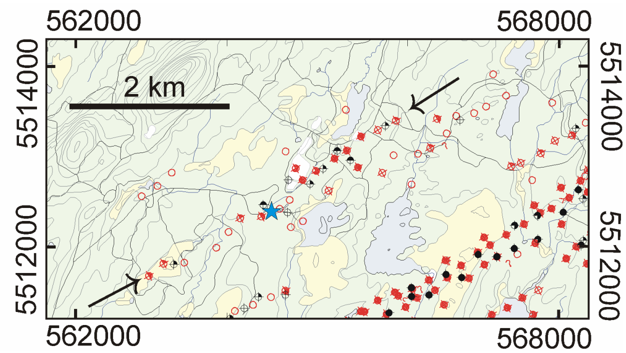

Figure 4: New anomalies along the Lemoine mine horizon. Arrows point to the horizon. The blue star locates the mine. MEGATEM II anomalies are black, INPUT anomalies red. Coordinates are UTM, Zone 18.

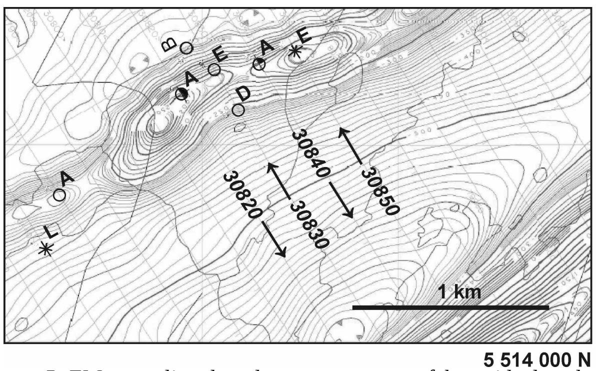

Figure 5: EM anomalies plotted on a contour map of the residual total magnetic field. Anomaly D from line 30830 is a dip effect, the conductor axis is located under anomaly E. Coordinates are UTM, Zone 18.

Also, a weak anomaly (E) interpreted as surficial, is seen on line 30850 to the east. It may be just east of the end of the conductor or it may be its continuation. Its length is estimated to be about 500 m. Depths of 148 and 103_ m were interpreted for lines 30820 and 30840 using the vertical plate model. Interpreted conductances are respectively 30 S and 26 S. The middle line, L-30830, was not interpreted by the contractor. An inversion, based on the dipping thin plate model (Keating and Crossley, 1990) was calculated for this line. The plate had a strike length of 500 m and a depth extent of 250 m. The X and Z components were used in the inversion. The calculated depth is 150 m, the dip 70o south and the conductance 50 S.

Geological mapping

Modern EM data can be used to compute apparent conductance and decay constant maps that can help geological mapping. For the Chibougamau MEGATEM II survey apparent conductance was calculated from the on-time and off-time response of the horizontal and vertical components using a thin horizontal sheet model. The calculated conductance is equal to the conductivity thickness product and, therefore, the values of the conductivity and the thickness cannot be separated. The apparent conductance is related to conductive overburden and bedrock. Although the quaternary geology of the area is mostly non-conductive, moderate responses are observed over lake bottom

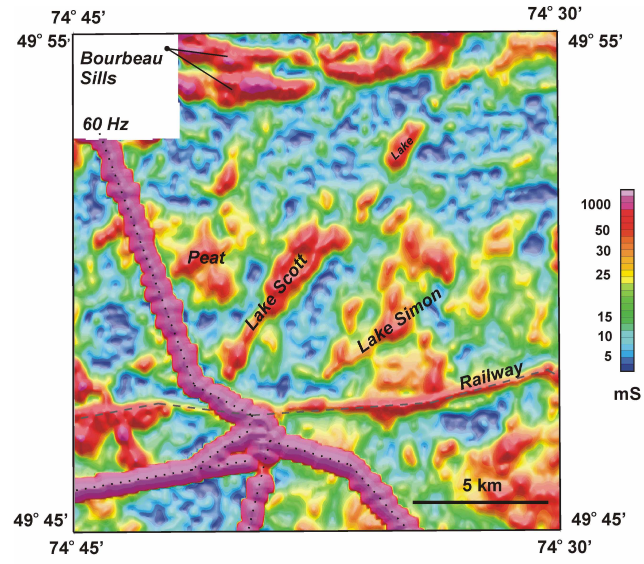

Figure 6: Apparent conductance over a portion of Block A. Note the effect of power lines and the railway. Glacial direction is north east and geological strike east west.

sediments and some surface features such as peat-bogs and tailing ponds (see Figure 6).

Apparent conductance anomalies associated with the overburden are generally elongated and oriented northeast, parallel to the last glaciation ice flow direction. Conductance anomalies associated with bedrock features are in the direction of the local geological strike often at an angle with the ice flow direction. High conductances are observed over some geological units. Examples are the Bourbeau Sills (see Figure 6) east of Lake Opémisca and in the Cummings Complex east of Chibougamau. In both cases, the responses are explained by the presence of graphite, and sulfides in some cases.

CONCLUSION

New conductors detected by the MEGATEM II survey can be grouped into three categories. Firstly there are low amplitude, high conductance, deep conductors that could not be detected by the previous EM surveys because of their depth. A second group includes shallow low conductance weak anomalies. The presence of a shallow low conductance zinc deposit in the area suggests that these anomalies should be investigated. Another possible source of many of these anomalies may simply be conductive overburden. To discriminate between these possible sources, one should carefully inspect the shape of the anomaly as it may be diagnostic of its origin. A last group consists of MEGATEM anomalies located near previously known conductors. In that case, the new anomalies better define these conductors and can provide important exploration clues.

The new survey has detected new exploration targets at depth and also shallow conductors missed by previous surveys. New targets at depth are the result of the use of a more powerful transmitter and the use of a multi-component digital receiver. The detection of new shallow conductors is a direct consequence of the use of differential GPS navigation that insures a uniform coverage of the survey area. The comparison between EM data acquired from surveys flown more than 25 years apart has shown the utility of flying new modern surveys over these areas.

ACKNOWLEDGEMENTS

This project was funded by the Targeted Geoscience Initiative 3, Abitibi project, of Natural Resources Canada. This is contribution 20070087 of the Geological Survey of Canada. We thank our colleagues M. Pilkington and M. Thomas for their suggestions. We also thank the reviewer, P. Diorio, for suggesting improvements to the original manuscript.

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Table 1: INPUT and MEGATEM II system parameters.

	INPUT Mk V	INPUT Mk VI	MEGATEM
Base frequency (Hz)	144	144	90
Pulse length (msec)	1	1	2.2
Moment (A m2)	0.2 × 106	0.21 × 106	1.65 × 106
Time constant (sec)	3	0.6	0
Measured components	X	X	X, Y, Z