Geophysical Case Study of the Iso and New Insco Deposits, Québec, Canada, Part I: Data Comparison and Analysis

L.Z. CHENG1, R.S. SMITH2, M. ALLARD3, P. KEATING4, M. CHOUTEAU5, J. LEMIEUX2, M.A. VALLÉE6, D. BOIS1, AND D.K. FOUNTAIN2

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Abstract — A test survey using the MEGATEM® airborne electromagnetic system was flown over the Iso and New Insco massive sulfide orebodies in the Rouyn-Noranda mining camp, Canada. The results were compared with data from historical systems (INPUT, DIGHEM) used to discover the deposits. The historical data show that the two deposits have comparable conductances. However, the modern MEGATEM® system reveals that the New Insco deposit has a much slower decay than the Iso deposit, and it is, therefore, interpreted to be more conductive. The MEGATEM® anomaly maps provide estimates of the location, depth, dip, and strike of the two deposits, information that was not available from the historical anomaly maps. The signal-to-noise ratio of the MEGATEM® data is greater than the historical data, yielding more sharply defined anomalies.

The investigations also included a comparison between 90 Hz and 30 Hz MEGATEM® data. The 90 Hz data were found to be useful for mapping the less conductive parts of the Iso body, whereas the 30 Hz data demonstrated that the New Insco body is more conductive.

Analysis of height attenuation data over the Iso body indicates that the body could be seen by the MEGATEM® system if it were buried an additional 230 m deeper (in highly resistive material). On the other hand, the INPUT system would detect the Iso body only if it were buried no deeper than an additional 60 m. Tests with the transmitter turned off showed that, for this flight, the MEGATEM® system noise levels on the processed data are about 300 pT/s. ©2006 Canadian Institute of Mining, Metallurgy and Petroleum. All rights reserved.

Key Words: Geophysics, Airborne Electromagnetic survey, Iso, New Insco, Volcanogenic massive sulfide deposit, Rouyn-Noranda mining camp.

Sommaire — Dans le cadre d’un projet de recherche, un ensemble de levés d’essais électromagnétiques aéroportés employant le système de MEGATEM® a été effectué au dessus des dépôts d’Iso et de New Insco, Rouyn-Noranda, Canada. Les données ont été comparées avec les réponses des systèmes qui ont découvert ces deux dépôts (INPUT et DIGHEM). Les données antérieures montrent que le dépôt d’Iso a une conductance comparable à celle de New Insco. Cependant, les données de MEGATEM® démontrent que le dépôt de New Insco a une haute valeur de la constante de décroissance, ce qui reflète une plus forte conductivité. La carte d’anomalies de MEGATEM® indique la localisation, la profondeur, le pendage et l’orientation des deux dépôts, ce que la carte d’anomalies antérieure ne montrait pas. Le rapport de signal à bruit de MEGATEM® est plus grand que celui des données de INPUT et de DIGHEM; de plus, les pics sont mieux définis.

Les tests ont également permis une comparaison entre les fréquences de base de 90 Hz et de 30 Hz. Les données de 90 Hz se sont montrées utiles pour cartographier la partie du dépôt Iso dont la conductivité est la plus faible, tandis que les données de 30 Hz montrent clairement que le dépôt de New Insco est plus conducteur.

Les analyses de l’atténuation du signal avec la hauteur ont indiqué que le dépôt d’Iso pourrait être détecté par le système MEGATEM® s’il était enfoui à 230 m sous la surface (dans un milieu hautement résistant). D’autre part, le système INPUT pourrait seulement détecter le dépôt d’Iso s’il était situé à 60 m de profondeur. Les tests avec l’émetteur fermé démontrent que le niveau de bruit est des l’ordre de ±300 pT/s. ©2006 Canadian Institute of Mining, Metallurgy and Petroleum. All rights reserved.

1Université du Québec en Abitibi-Témiscamingue, Rouyn-Noranda, Québec J9X 5E4.
2Fugro Airborne Surveys, 2060 Walkley Road, Ottawa, Ontario K1G 3P5.
3Noranda Inc., Division de l’Exploration, 3296 avenue Francis Hughes, Laval, Québec H7L 5A7.
4Geological Survey of Canada, Natural Resources Canada, 615 Booth Street, Ottawa, Ontario K1A 0E9.
5École Polytechnique de Montréal, Département des Génies Civil, Géologique et des Mines, Montréal, Québec H3C 3A7.
6Fugro Airborne Surveys, 5610 Chemin Bois-Franc, St. Laurent, Montréal, Québec H4S 1A9.
Introduction

In 2003, the University of Québec in Abitibi-Témiscamingue initiated a project to document and enhance the capability of the MEGATEMII (Fugro Airborne Surveys) airborne electromagnetic system. The major objectives of the project consist of:

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

The participants in the project are Développement Économique Canada (DEC) and Développement économique et régional et Recherche du Québec (MDERR) (funding agencies), and Fugro Airborne Surveys, Noranda Exploration Inc., École Polytechnique at Montréal, and the University of Québec in Abitibi-Témiscamingue (project manager). Two papers (Part I and Part II) describe the results of objectives 1 and 2 for the Iso-New Insco site. Paper I describes the MEGATEMII data and compares them with historical data. Paper II describes the modelling of MEGATEMII and other data, such as gravity and magnetic data. The outcomes from the two other sites (Gallen and Aldermac) will be reported separately.

The Iso and New Insco deposits, located in western Québec (Fig. 1), were discovered by airborne geophysical methods (INPUT and DIGHEM) in 1972 and 1973, respectively (Telford and Becker, 1979). Subsequently, geophysical surveys and extensive drilling have been completed in order to define their geophysical and geometrical properties such as horizontal location and depth extent. The Iso deposit has also been used as a site for testing new geophysical equipment. The ground methods used on the deposits include horizontal loop EM, vertical loop EM, low-frequency EM, IP, self potential, magnetic, gravity, seismic, and borehole EM (Fountain and Fraser, 1973; Fraser, 1974; Lalonde, 1974; Telford, 1977). Telford and Becker (1979) summarized the exploration history and compared the geophysical methods using a profile over the center of each body.

MEGATEMII represents a relatively new fixed-wing time-domain airborne system. The system uses the same waveform and receiver as the GEOTEM system, but is mounted on a larger Dash-7 aircraft (Smith et al., 2003a). This means that more powerful transmitters can be carried and that the transmitter loop on the aircraft is larger; hence, the dipole moment is more than twice that on the GEOTEM system. In order to document characteristics of the system and to characterize the system’s efficacy, a series of investigations was undertaken in the present study. These tests included height attenuation tests, reverse flight direction tests (to study the asymmetry effect), flights along the strike of the deposits, flights with the transmitter switched off, and a comparison of responses for two base frequencies (90 Hz and 30 Hz). Analysis of these tests yields new insights into the capability and characteristics of the MEGATEMII system.

The Iso and New Insco Deposits

The Iso and New Insco deposits are located within the Abitibi greenstone belt of western Québec. The geology of the area is shown in Figure 2. The Iso and New Insco sulfide zones lie close to the contact between felsic volcanic rocks (rhyolite) and mafic volcanic rocks (andesite). The massive sulfide bodies subcrop beneath 10 to 20 m of glacial cover. They are sheet-like bodies, dipping south at 45° to 50°. The Iso body strikes east–west over a distance of more than 500 m, with a thickness of up to 35 m and maximum downlap extent of at least 800 m. The New Insco body strikes east–west over a distance of about 117 m. Its thickness varies from 5 m to 38 m and the maximum downlap extent is at least 250 m. The Iso deposit has not been mined, whereas Noranda mined 103,574 tons of ore grading 2.64% Cu from a small open pit (about 10 m deep) at New Insco between 1976 and 1977.
Airborne Electromagnetic Systems

INPUT, DIGHEM, GEOTEM, and MEGATEM -II are airborne electromagnetic systems. Each method induces currents in the subsurface by radiating a time-varying primary field. For the DIGHEM system used at Iso and New Insco (Fraser, 1972), the field varies sinusoidally at 918 Hz, so the system is termed a frequency domain system. The INPUT, GEOTEM, and MEGATEM -II systems induce current in the ground by transmitting a short half-sinusoidal pulse. These types of systems are termed time-domain or transient systems. The time-domain systems generally have a greater depth of penetration because they have a larger dipole moment and a greater transmitter–receiver separation. The principle of geophysical electromagnetic methods is that the time-varying field induces secondary currents in conductive material. In the case of time-domain methods, these secondary currents decay after the initial pulse, and hence the secondary magnetic field measured by the receiver also decays. The currents in good conductors decay more slowly, whereas the currents in poor conductors decay faster. The strength of the field falls off with distance from the source; hence, deeper conducting bodies generally have smaller amplitudes. Therefore, the amplitude of an anomaly and the decay constant are important characteristics in recognizing and interpreting a relatively good bedrock conductor. The INPUT system only measures the rate of change of the magnetic field (dB/dt) in a single component (directed along the flight direction). The base frequency of the INPUT system used at Iso-New Insco was 144 Hz, the pulse width was 1 ms, and the dipole moment was $2.1 \times 10^5$ Am$^2$. The system used an analog receiver with a low-pass electronic filter to reduce the noise. The electronic filter had a time constant of 1.1 s, which introduced a phase shift and, therefore, distorted the shape of the anomalies. More recent systems (e.g., GEOTEM and MEGATEM) acquire multicomponent measurements using a fully digital receiver. Digital filters are used to reduce the noise level. These filters do not change the phase of the anomalies and can be designed to minimize the distortion of the measured anomalies. The modern systems also use differential GPS navigation, resulting in flight lines that are much more evenly spaced and accurately located. The multicomponent data can be used to estimate geometric characteristics of the subsurface conductor. The GEOTEM and MEGATEM- II systems acquire the dB/dt response as well as the undifferentiated B-field responses (Smith and Annan, 2000). The MEGATEM- II system flies at a nominal height of 120 m and the receiver is located in a bird towed 130 m behind the aircraft at a height of 70 m above ground. Also, a magnetic sensor is located in a

Fig. 2. Geology of the Iso and New Insco area (adapted from SIGÉOM of Ministry Geology of Québec, 2004: http://www.mrnfp.gouv.qc.ca/produits-services/mines.jsp).
second bird approximately 100 m behind the aircraft at a height of 70 m. The transmitter dipole moments are $1.6 \times 10^6$ Am$^2$ and $2.1 \times 10^6$ Am$^2$ at base frequencies of 90 Hz and 30 Hz, respectively, 8 to 10 times the moment of the older INPUT system.

**Comparison of MEGATEM$^H$ with Other Systems**

The Iso deposit was discovered following an INPUT MK V survey flown for the Government of Québec (Questor Surveys, 1971) and published in August 1972 (Fountain and Fraser, 1973; Telford and Becker, 1979). Figure 3 shows the EM anomalies from a more recent INPUT MK-VI survey flown in 1985 (Relevés géophysiques Inc., 1986). In both cases, navigation and flight path recovery were accomplished using visual means. The cluster of anomaly symbols shown is similar in presentation to those on the 1971 survey. The degree of in-fill of the symbols indicates the number of anomalous channels, and the numeric label is an estimate of the conductance of a 600 × 300 m vertical plate that would have a decay similar to that of the measured response. The 1985 survey did detect a response over the New Insco body, but the 1971 survey did not, primarily because the deposit was located halfway between two adjacent flight lines in the latter case. We refer only to the 1985 INPUT survey results in the following system comparison.

The DIGHEM survey (Telford and Becker, 1979) identified an anomaly over New Insco, which led to the discovery. The conductance estimate derived from the DIGHEM data is about 30 S (Siemens) for the Iso body, which is comparable to the estimate of 26 S for New Insco. The amplitude of the DIGHEM response over the New Insco deposit was one fifth of the amplitude measured over the Iso body (Fraser, 1974).

The anomaly map derived from the MEGATEM$^H$ data (Fig. 4) shows estimates of the depth, dip, and strike of the conductor, and the estimated conductance for various locations along the length of the conductor. Additional information about the geometry of the plate was derived from the multicomponent data (Smith and Keating, 1996). Note that the y-component data were used to place the anomalies off the traverse lines. Anomaly A02 associated with line 100501 is centered on the traverse, but the other anomalies are all shifted from their respective traverse lines towards anomaly A02. This indicates that the five anomaly symbols may all be associated with one continuous conductor. It may also be an indication that eddy currents are concentrated in the western part of the deposit, which corresponds to a more conductive part of the massive sulfides. Anomalies in the MEGATEM$^H$ map were interpreted assuming a 600 × 300 m dipping plate, but because of differences in the configuration of the MEGATEM$^H$ and INPUT systems, we would not necessarily expect that the conductances posted on the MEGATEM$^H$ map should be the same as those on the INPUT map. Nor would we necessarily expect the DIGHEM conductances also derived from a vertical thin plate model to be the same. However, the conductance estimates from the INPUT, DIGHEM, and MEGATEM$^H$ dB/dt all show that the New Insco conductance is roughly comparable to the conductance estimated at Iso (using the same system). Interestingly, conductance estimates from the ground EM methods (horizontal-loop EM, Geonics EM-25, etc.) are roughly the same, lying in the range 3 to 80 S, with an average of 32 S (Telford and Becker, 1979). The conductance was also estimated from a 200 ft cable-length MaxMin survey (Betz, 1976) over the Iso body. The conductance calculated for a 222 Hz frequency and assuming a dip of 60º was 48 S over the western part of the deposit, which is more pyrite- and sphalerite-rich, and 140 S over the eastern part, which is more chalcopyrite rich. Over the central part of the New Insco orebody, using the same parameters the MaxMin conductance was 260 S (Betz, 1976).

The INPUT and MEGATEM$^H$ systems fly alternate lines in alternate directions. Line 5401 of the INPUT data is close to line 100401 of the MEGATEM$^H$ data, and both were flown in the same direction. The MEGATEM$^H$ anomaly on Line 100401 (Figure 5) shows two clear peaks in the profile, which are indicative of an “updip” conductor, which in this case implies that the conductor is dipping to the south. The signal from the INPUT system on line 5401 was noisier and strong analogue filtering was applied to the signal, so the two peaks are barely distinguishable. The last delay time shows a signal that is about three times the background noise level. On the other hand, the signal on the last MEGATEM$^H$ channel is 200 times greater than the noise. The difference between analogue and digital filtering is even more apparent on the southbound lines (Fig. 6). The digitally filtered MEGATEM$^H$ response
(line 100501) shows better spatial resolution than the broader analogue-filtered INPUT anomaly on line 5502.

A comparison of the INPUT anomalies directly over New Insco (Fig. 7) shows that the INPUT and MEGATEMII systems both detected the deposit. However, the MEGATEMII signal is much greater than the noise, whereas the INPUT response does not have such a clear anomaly. This is even more evident on Figure 8, which compares line 6201 (INPUT) with 101501 (MEGATEMII). This example is particularly interesting because the profile is offset by 125 m from the profile of Figure 7, and the geological section shows that there is no mineralization below the traverse. The MEGATEM system is able to see the deposit off section, whereas the INPUT system is not.

**Comparison Between Base Frequencies of 90 Hz and 30 Hz**

Studies by Becker et al. (1984) and Smith and Annan (1997) indicated that when a body is highly conductive, increasing the pulse width and/or lowering the base frequency can increase the response of a relatively conductive target. Two base frequencies were employed at the Iso-New Insco test site to allow us to study the effect of changing the base frequency when exploring in the Abitibi region.

Figures 9, 10, and 11 show comparisons of 90 Hz and 30 Hz dB/dt responses over the Iso and New Insco deposits. The horizontal and vertical scales are identical for both frequencies. Lines 100301 and 100501 (Figs. 9, 10) are over the Iso orebody, and line 101501 is over the New Insco orebody. On line 100301, the 90 Hz amplitudes appear to be larger, whereas on line 100501, the 30 Hz amplitudes increased significantly so that the early-time amplitudes on 90 and 30 Hz appear comparable. On line 101501 (Figure 11) the 30 Hz anomaly appears to be larger. This line provides an interesting comparison of the amplitude of the sharper orebody response (to the left) with the response of the shallow surficial conductor. From the 90 Hz data, the amplitudes of the surficial conductor appear to be bigger than the response of the orebody. However, in the 30 Hz data, the response of the orebody has been enhanced in comparison to the surficial response.

The decays of the x-component dB/dt responses at the peak locations on lines 100301, 100501, and 101501 have been summarized on Figure 12. The 90 Hz responses can be recognized as those that end at 3 ms, whereas the 30 Hz responses continue past 11 ms. On line 100301, the decay rates and amplitudes (except at the earliest times) are comparable. Over the more conductive part of the Iso body (line 100501), the decay rates appear roughly comparable prior to a delay time of 3 ms. There is a slight increase in amplitude at 30 Hz, but this would be negated by the higher noise levels at 30 Hz, so that the signal-to-noise ratio at the two frequencies would be comparable. Over the New Insco body (line 101501), the 30 Hz data show a slower decay and a greater amplitude than the 90 Hz data. Once again, the greater noise levels at 30 Hz would negate most of the amplitude advantage that the 30 Hz data have. The real advantage of the...
30 Hz data is that it shows that line 100301 quickly drops into the noise, whereas the decays on lines 100501 and 101501 persist to ≥8 ms. This implies that the material under line 100301 is less conductive than the material under the other lines. It is not possible from these dB/dt data to determine whether the material under line 100501 or 101501 is the more conductive, because the rates of decay of the two curves appear to be comparable. However, the B-field data can help in this regard. Figure 13 shows that the 30 Hz decay of the New Insco deposit (line 101501) is significantly slower than the Iso deposit (line 100501). From this, we can conclude that the New Insco deposit is more conductive and that the low-frequency B-field response is best for discriminating between good (100501) and very good (101501) conductors. On the other hand, the fact that the dB/dt amplitude is greater for 90 Hz over line 100301, and hence that the signal-to-noise ratio would be much greater, indicates that this base frequency is better for detecting poorer (more rapidly decaying) conductors.

In summary, there does not appear to be a significant difference in the ability of the different base frequencies to detect these conductors, but the advantage of using lower frequencies appears to be in discriminating between good and poor conductors.
Fig. 9. Comparison of 30 and 90 Hz dB/dt MEGATEM® responses over the Iso deposit (line 100301).

Fig. 10. Comparison of 30 and 90 Hz dB/dt MEGATEM® responses over the Iso deposit (line 100501).

Fig. 11. Comparison of 30 and 90 Hz dB/dt MEGATEM® responses over the New Insco deposit (line 101501).

Fig. 12. A comparison of the dB/dt response measured at 90 and 30 Hz. The decays ending at 3.1 ms are the 90 Hz decays and those ending at 11.5 ms are the 30 Hz decays. The solid line is the maximum anomalous response on line 100301 (Iso); the dotted and dash-dotted lines are for lines 100501 (Iso), and 101501 (New Insco) respectively.

Fig. 13. A comparison of the B-field response measured at 90 and 30 Hz. The curves are as for Figure 12.

**Height Attenuation Tests (MEGATEM® Survey)**

As part of the project, a series of flights at different altitudes were flown to help estimate the maximum depth at which the MEGATEM® system might detect an orebody.

The tests were flown over the Iso body along line 100501 to document how the response of this body changes as the flying height increases. The x-component B-field profiles are shown for five different flying heights in Figure 14. The amplitudes of the responses are greatest at the standard flying height (120 m), but reduce with increasing height. At a flying height of 366 m, the anomalous response is barely above the noise level. At 465 m, there is a broad, slow decay in the final few windows, but it is more difficult to identify because the signal level is comparable to or below the short wavelength noise level. Also, the noisier early-time
windows obscure this broad response. The width of the anomalous response increases with increasing flying height.

Figure 15 shows the attenuation of the B-field x- and z-component responses as a function of increasing flying height. The rate of decrease of the amplitudes is approximately equal to the inverse fourth power of the height, although the x-component falls off more steeply and the z-component slightly less steeply. It is also interesting to observe that on the logarithmic scale (for the amplitudes), the distance between the curves only changes by about 10 percent. Thus, for this orebody, when the airborne EM system is at a greater height above the body, the decay rate is not significantly different. This suggests that the decay rate of a body is, to the first order, independent of the distance from the system.

The curves in Figure 15 can be used to estimate how high the system can fly and still detect the body. For example, we might somewhat arbitrarily say that four curves must be above the noise level (3 pT), for the body to be visible. On Figure 15, the fourth x-component curve disappears into the noise (making the body invisible) at 360 m; the fourth z-component curve is still visible to a depth of 430 m.

Height attenuation tests such as these are sometimes used to infer how deep a body may be detected when the system is flying at the normal survey altitude. The argument is that if the x-component can detect a body when the system is flying at 360 m above terrain (which is 240 m higher than the standard flying height), then the same system, flying at the standard height, should also be able to detect a body that is buried 240 m below the ground surface. This argument can be validated with model results. Figure 16 shows the fall-off of the response as a function of increasing flying height (solid lines) and the fall-off of the response as a function of increased depth of burial (dashed lines) for a 320 × 200 m and 65 S conductive plate. Essentially the two curves are the same, so the argument is valid in this case. Here, the background was highly resistive and there was no conductive overburden. The model curves of Figure 16 differ from the measured curves in Figure 15 in one major aspect: at great height, the rate of height attenuation for the measured data is reduced. This effect can be simulated to some extent by introducing a conductive overburden into the model. The solid lines on Figure 17 show the height attenuation models with no overburden, and the dashed lines are for the case when there is an inductively thin overburden of conductance 1.2 S. The latter case shows a reduced attenuation at great height: the agreement between the model and measured data is not exact, but the effect is similar.

Using this modification to the geological model, the responses of Figure 16 were recomputed. Figure 18 shows a comparison between increasing the flying height (solid lines) and increasing the depth of burial (dashed lines). The effect of the overburden is much greater in the case of increasing the
system if the body is buried less than 230 m below ground surface. Window 14 in MEGATEMII is at an equivalent delay time to channel 5 of the INPUT system. At the standard flying height of 120 m, INPUT channel 5 is about 3 to 5 times above the noise level on line 5502. Assuming the same fourth power fall off with height, the INPUT system would not detect the target when it is buried at depths greater than 40 to 60 m below surface.

**Reverse Flight Direction Tests**

The geometry of the MEGATEMII system is asymmetric, which means that the response measured when flying in one direction will be different from that measured in the reverse direction. When the aircraft flight direction is in the updip direction of a dipping body, there are double peaks on the x-component profile. When the aircraft is flying downdip, there is only one peak. All northbound MEGATEMII responses over the Iso and New Insco orebodies showed two clear peaks in the x-component profile, and this is consistent with the known dip of the orebodies. On the other hand, this asymmetry effect can make interpretation difficult, especially when looking at images. For this project, the Iso-New Insco survey was repeated a second time so that all lines were flown in both directions. This reverse line direction data have also been used by Smith and Chouetteau (2004) to remove or reduce the effect of system asymmetry.

**Transmitter Off**

The survey area was also flown with the transmitter switched off. This data set is being used primarily for research to understand signal noise better and develop methods to deal with it, either to remove it, or perhaps to extract information that is currently discarded but which could potentially be used to provide geological information. These results will be reported elsewhere.

These data can also be used to provide an idea of the intrinsic noise levels of the airborne receiver while flying at survey altitude. As an example, Figure 19 shows the x-, y-, and z-component responses over line 100501 for the dB/dt data. The curves shown are for windows 6, 12, and 20. For these transmitter-off data, the stacking was done in the same way as for the 90 Hz base frequency. The early-time windows (e.g., window 6—the short dashed curve) show more noise because these windows are narrower, whereas the late-time window (20, the solid curve) is less noisy because the window is wider and contains more samples. The late-time noise level of the processed data is about 300 pT/s for dB/dt. On a flight flown in more turbulent conditions, the noise levels might be higher. Over the Iso body, the late-time signal levels are 30,000 pT/s on line 100401, so the signal-to-noise ratio is 1,000:1. The late-time INPUT anomaly on line 5401 is only about 5 times the noise level (Fig. 5).
Conclusions

Comparisons between data obtained with the MEGATEM II system and historical data show that the MEGATEM data have a better signal-to-noise ratio than INPUT data, and the measured anomalies are sharper. The MEGATEM II 30 Hz data are better able to distinguish between the conductive Iso body and the highly conductive New Insco body. The more conductive New Insco deposit has a slower B-field decay at 30 Hz, so these data appear better able to discriminate between good and better conductors. The multicomponent data are useful for determining the location, depth, dip, strike, and conductance of a body. Furthermore, a line flown 150 m away from the New Insco body shows that the INPUT system cannot see the conductor, whereas the MEGATEM II system can.

Height attenuation tests have been used to show that the MEGATEM II system would image the Iso body if it were buried up to an additional 230 m below the ground for conventional flying height (120 m) surveys. However, we conclude that the INPUT system would only see the body if it were an additional 60 m below the ground. These tests also indicate that the rate of decay of an anomaly does not change significantly when the distance of the system from the conductive target changes.

Tests with the transmitter switched off showed that, on these flights, the noise levels on the processed data of MEGATEM II were about 300 pT/s on the dB/dt data.

This type of systematic test can give the exploration community a better understanding of the efficacies of the MEGATEM II system. Knowing the characteristics of the system will allow the data to be interpreted with greater confidence. It will also aid in developing new or improved systems.

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