# GEOPHYSICAL REPORT ON HELICOPTER-BORNE ZTEM™ TIPPER AFMAG SURVEY RESULTS OVER AXIS LAKE

## INTRODUCTION

ZTEM (Z-Tipper Axis Electromagnetic) surveys were conducted over the Axis Lake Test Block, belonging to Pure Nickel Inc. (Toronto, ON) and situated in the Fond du Lac region of northern Saskatchewan in May, 2008 (Milicevic et al., 2009). The survey comprised airborne Tipper AFMAG (audio frequency electromagnetics) measurements using the ZTEM system (Figure 1), as well as aeromagnetics using a caesium magnetometer. The survey consisted of thirty four (34) approximately 10.5 km long, North-South oriented flight lines, totaling 358.7 line-km, that were obtained at nominal 250m line spacings over an approximately 8 x 10km area (Figure 2). The property hosts known copper-nickel sulphide showings (Axis Lake East & West, Rae Lake and Currie Lake – see Figure 2), has been previously surveyed flown using VTEM, with ground follow-up using UTEM, and has subsequently been drill-tested (Vivian and Lo, 2007). The property was chosen to test the ZTEM capability to identify and defined potential along-strike and deep extensions of the known Cu-Ni mineralization below 500m depths.

The Z-axis tipper measurements of the vertical (Z) component were obtained using Geotech's patented Z-TEM induction aircoil system (Figure 1), suspended at approximately 100m elevation above ground level. The vertical component data (Hz) were then ratioed to fixed horizontal field measurements (Hx-Hy) obtained using identical reference coils, that were oriented in the in-line (X) and cross-line (Y) directions, in order to obtain the tipper functions Z/X and Z/Y. The In-Phase and Quadrature components ZTEM field ratio data ere obtained, using Fourier-based, digital signal processing analyses, at 5 frequencies, between 30Hz and 360Hz. The magnetometer was a Geometrics optically pumped caesium vapour magnetic field sensor, towed at approx 120m above ground level.

Figure 1: ZTEM Hz Receiver Coil (foreground) and Hx-Hy Reference Coils (background).

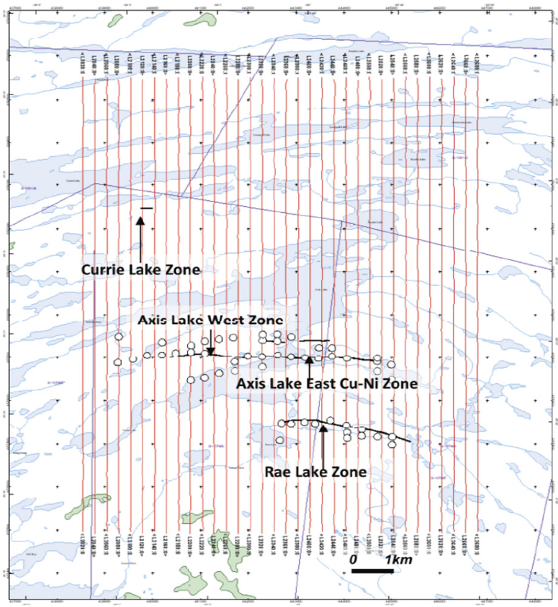


Figure 2: Axis Lake Mineralized Occurrences, Ground UTEM Anomalies and ZTEM Flight Lines.

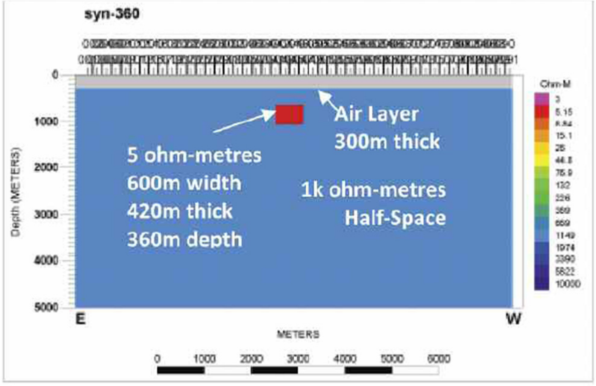
## GENERAL THEORY

The ZTEM system uses naturally occurring Afmag magnetotelluric fields as the source of the primary fields, and therefore requires no transmitter (Ward, 1959). The fields resemble those from VLF except that they are lower frequency (tens & hundreds of Hz versus tens of kHz) and are not strongly directionally polarized (Labson et al., 1985). These AFMAG EM fields, derived from worldwide atmospheric thunderstorm activity, have the unique characteristic of being uniform, planar and horizontal, and also propagate vertically into the earth – to great depth, up to several km, as determined by the magnetotelluric (MT) skin depth, which is directly proportional to the ratio of the bedrock resistivity to the frequency. At the frequencies used for ZTEM, the MT skin depths likely range between approx. 600m to 2km in this region, according to the following equation for skin depth (Vozoff,1972):

$$\delta_s = 356 * \sqrt{(\rho_A / f)} \text{ metres}$$

$$\text{If } \rho_A = 1\text{k ohm-m}, \ \delta_s \approx 600\text{m at 360Hz and} \sim 2.0\text{km at 30Hz}$$

The other unique aspect of AFMAG fields is that they react to relative contrasts in the resistivity, and therefore do not depend on the absolute conductance, as measured using inductive EM systems, such as VTEM – hence poorly conductive targets, such as alteration zones and fault zones, can be mapped, as well as higher conductance features, like graphitic units. Conversely, resistive targets can also be mapped using AFMAG–provided they are of a sufficient size and contrast to produce a vertical field anomaly. Indeed resistors produce reversed anomalies relative to conductive features. Examples of ZTEM 2D forward model Tipper profile responses, at the earth's surface & 300m over a conductive body are given in Figure 3.



Above: Conductive brick used in test inversion for ZTEM data using ZVERT2D. The gray region is a 300m thick air layer. Below: Synthetic data and inversion model responses at five frequencies for Z/X response profile along the ground (solid curves) and 300m in the air (dashed curves). Small open squares are the inversion fits.

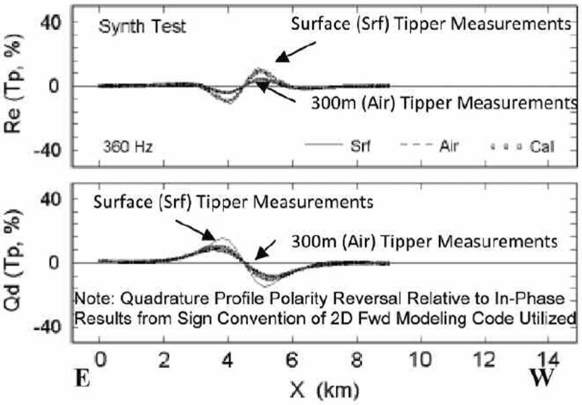


Figure 3: Calculated 2D Forward Model Response for In-Line (Z/X) IP and QP Components over Buried Conductor in Resistive Half Space at 0m & 200m Elevations (Ref.Wannamaker, 2008).

## GENERAL GEOLOGY

The Axis Lake property is located in the Tantato domain, Stony Rapids area, north-northeast of Lake Athabasca. The Tantato domain is defined as a triangular area underlain by granulite to upper amphibolite facies metamorphosed sediments, volcanics, and granitoids (Figure 4). Mineralization on the Axis Lake property is associated with magmatic nickel-copper sulphides. Mineralization has been transported along a prominent fault conduit formed in an extensional rift environment (Figure 5). Norite magmas containing sulphide droplets settle out of the magma in areas where differentiation of the magma occurs. (Vivian and Lo, 2007).

The rocks at Axis Lake consist mainly of diatexite, which is a highly metamorphosed sediment, and mafic granulites, which are metamorphic plutonic rocks. The diatexite is a white to tan, banded, leucocratic, quartzofeldspathic rock, containing garnet, orthopyroxene, graphite, and minor sillimanite.

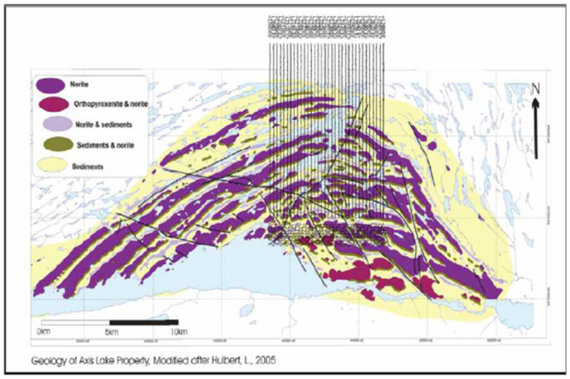


Figure 4: Axis Lake General Geology and ZTEM Flight Lines (after Vivian and Lo, 2007).

This unit also contains 1-10 metre thick orthopyroxene ± garnet granite sheets. Meter-scale to kilometer-scale sheets of metanorite ± garnet, clinopyroxene ± garnet noritic granulite predominate at Axis Lake. These rocks show coarse gabbroic to microgabbroic textures and indicate a plutonic origin. A pyroxenite also cuts the gabbroic rocks south of Rea Lake (Vivian and Lo, 2007).

Geologic mapping has been assisted with the aid of property-scale Total Field Magnetic surveys and further delineated the diatexite and mafic granulite units as shown in Figure 4. Diatexite sediments occupy areas of low magnetic response while the metanorite is coincident with high magnetic response.

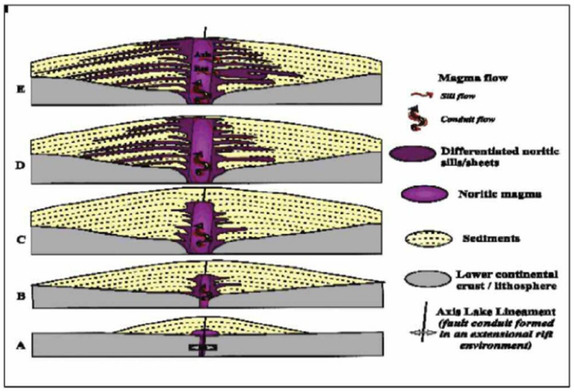


Figure 5: Geologic Model for Magmatic Mineralization at Axis Lake (Vivian and Lo, 2007).

The geologic units on the Axis Lake property are folded into a steeply south-plunging syncline with an axial plane trending 040 degrees. At Curie Lake, northeast of Axis Lake, units strike 065° to 085° (RHR); at Axis Lake in the hinge zone, units strike 085° to 110° and dip 65° to subvertically to the south; west of Axis Lake in the Clut Lakes area units are oriented 110° to 170°.

Property-scale faults are identified by breaks in the magnetic and topographic data, with a dominant northwest trend (Figure 4). However, a prominent northeast-trending fault bisects the property and is coincident with the axial trace of the regional fold. This feature is also coincident with a significant topographical break and a significant linear gravity low. This fault is interpreted to be a key component in the emplacement of the norite sills.

Pyrrhotite dominates the sulphide mineralogy at the Axis, Rae and Currie Lake Zones (Figure 2). There are three styles of mineralization: 1) fine to coarsely disseminated, from 1-5% and up to 10% sulphides; 2) network to net-textured mineralization of up to 15% sulphide, trending to 30%; and 3) massive sulphide horizons comprising up to 50% mineralization but occurring only locally in zones less than 0.5 m thick. Sulphide mineralogy is dominated by pyrrhotite (up to 90%) with accessory compositions of chalcopyrite (up to 5%) and pyrite (usually less than 5%). The nickel-bearing sulphide is pentlandite and it is also common to see the nickel to copper ratios approximately 2:1 to 3:1 (Vivian and Lo, 2007).

Seven diamond drill holes, totaling 2260 metres were completed in Spring 2006 that were designed based on the 2005 VTEM and 2006 UTEM results and to infill Cu-Ni mineralization intersected previously (Figure 6). The results showed that the sulphide mineralization in the East and West zones ranges from fine to coarsely disseminated, to semi-massive network textures to massive, with nickel and copper values in the range of 1-2% and 0.4-0.6% respectively. Rae Lake remains untested. The reported mineral resource for the property is 3,400,000 tons of 0.66% Nickel, 0.60% Copper and 0.15% Cobalt (Vivian and Lo, 2007).

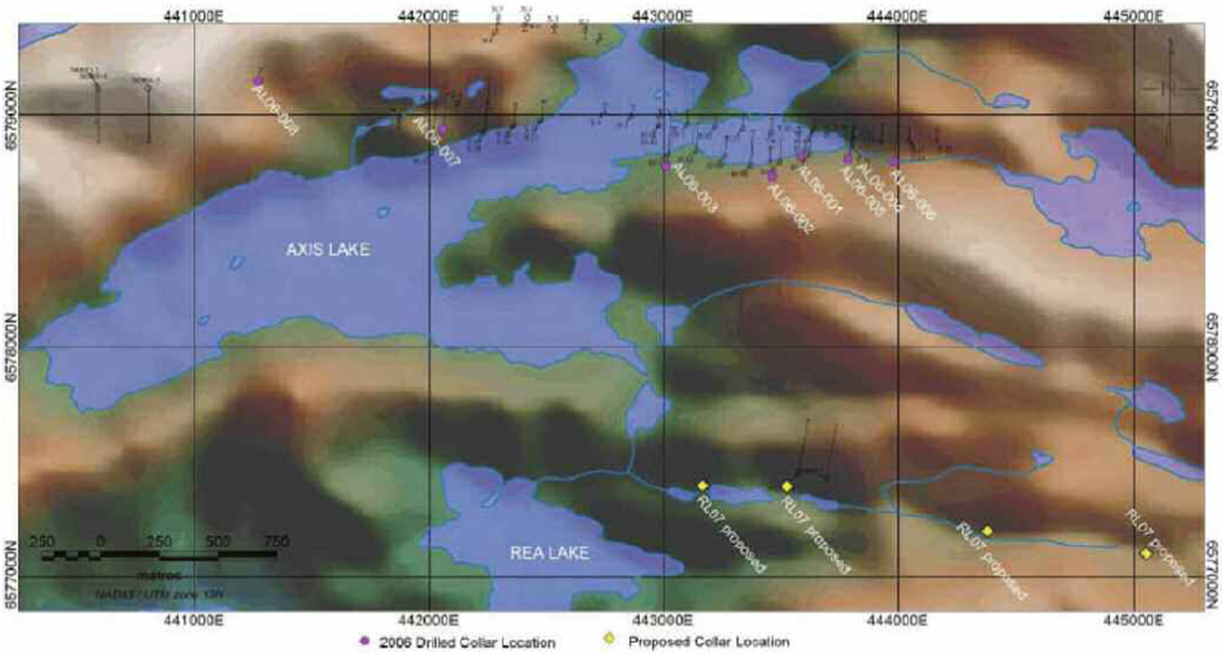


Figure 6: Existing Diamond Drill-holes, 2006 Holes and Proposed ddh's over DEM model (Vivian and Lo, 2007).

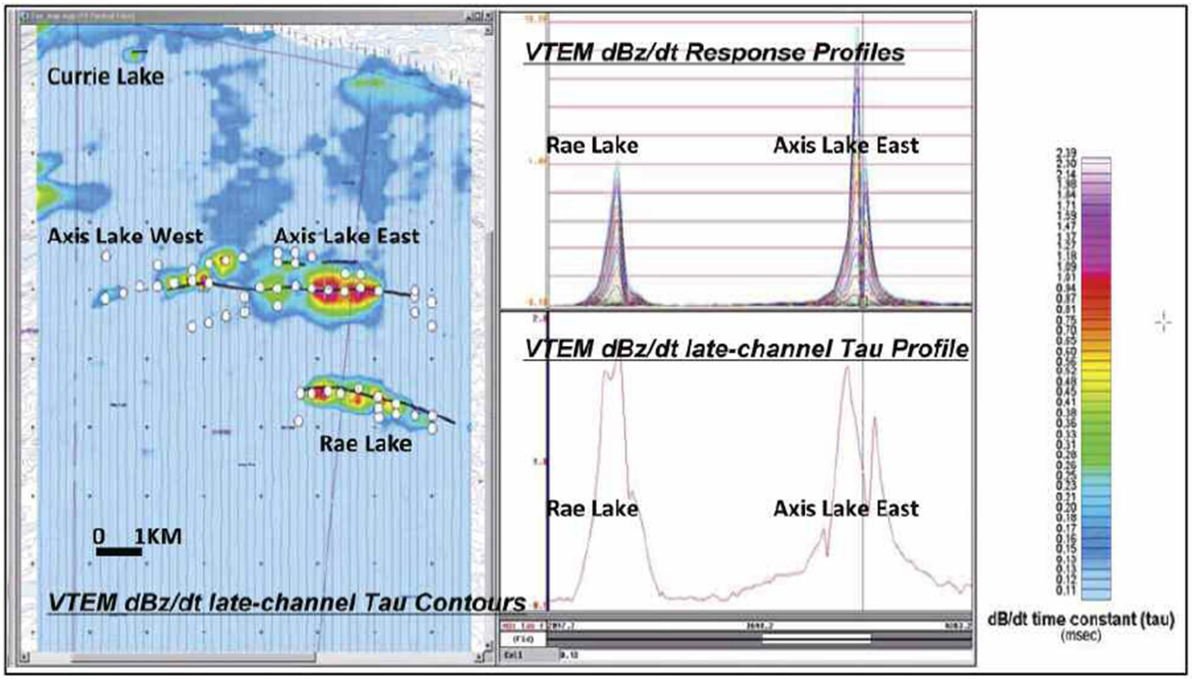


Figure 7: VTEM EM Time-Constant and UTEM anomalies (modified after Vivian and Lo, 2007).

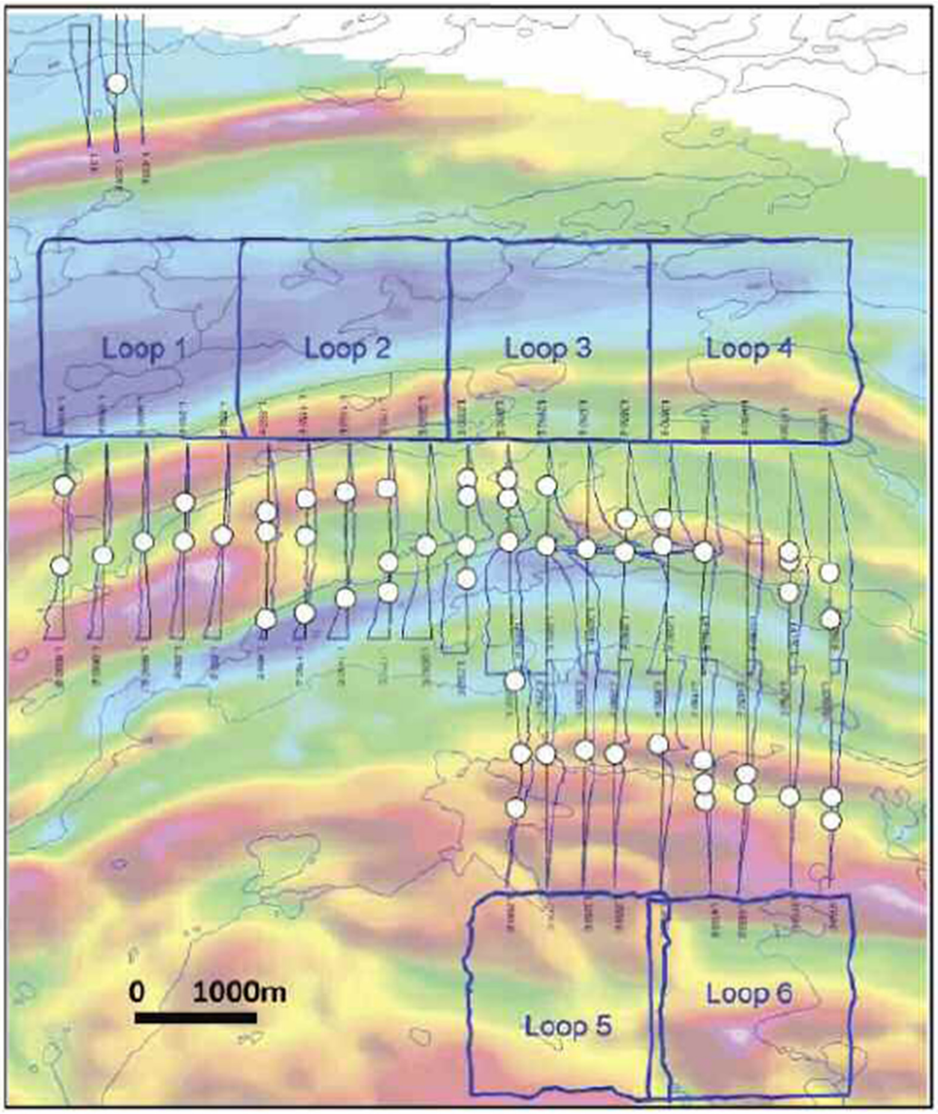


Figure 8: UTEM Anomalies (white dots) on Pole-Reduced Magnetics (Vivian and Lo, 2007).

## PREVIOUS GEOPHYSICS

Exploration on the Axis Lake area has been sporadic since the initial discovery of a gossan in 1929, until 1991and the ground geophysics has reportedly included IP and magnetics. More recently, geophysics on the property has included heliborne VTEM electromagnetics in 2005 and ground UTEM electromagnetic surveys in 2006.

VTEM and aeromagnetic surveys were undertaken in March, 2005 at 150-250m line-spacings and totaling 1503 line-km (Orta et al., 2005). Over 40 conductive responses were identified in the VTEM and the results show that the Axis Lake zone EM response is quite varied and less extensive than the known mineralization. The East Zone dips south and reveals better amplitudes due to better connectivity than the West Zone. The Rae Lake zone also dips south, is more continuous but is slightly less conductive than Axis Lake. The Currie Lake zone dips north but has very limited size. Additional areas for ground follow-up were defined elsewhere on the property (Vivian and Lo, 2007). Figure 7 presents VTEM profile results and newly calculated EM time-constant (Tau) grid contours and compares them to the known mineralized zones and UTEM anomalies.

UTEM ground surveys were undertaken in February-March, 2006, and targeted the main VTEM responses and favourable geochemical anomalies. The surveys were undertaken at 25-50min station intervals, along 300m spaced lines and in the fixed, outside-loop configuration, from 6 1.5x1.5km loops (Figure 8), totaling approx. 70 line-km (Vivian and Lo, 2007).

The UTEM survey outlined numerous conductive responses on the Axis Lake property, including 4 significant areas at Axis Lake East & West, Rae Lake and Currie Lake. In particular, modeling suggests that mineralization at Axis and Rae Lakes extends to 400+ metres. South dips are indicated at Axis and Rae Lakes, and steep dips at Currie Lake. The 5-10 siemens conductivities obtained suggest that the Cu-Ni sulphide mineralization is weak, likely semi-massive, particularly at Currie Lake (Vivian and Lo, 2007). Figure 8 presents the Z-component channel 6 profiles and location of UTEM anomalies as white-dots, superposed on the calculated pole- reduced total magnetic intensity (TMI) from the VTEM airborne survey. These UTEM anomalies are also compared to the VTEM results and known mineralized horizons in Figure 7.

## DATA PRESENTATION

The nature of the AFMAG fields is such that, as with VLF (Pederson, et al., 1994), buried, tabular conductors and resistors produce cross-over responses (see Fig. 3). As such, although the field results are shown as cross-over profiles, additional post-processing is applied to convert these cross-over's into peak responses, to make them more useful as mapping tools. These include 2 types: the 90-degree Phase Rotation (Lo, et. Al, 2008) which is a horizontal; derivative process method (Kuzmin, et al., 2005) – both are used interchangeably in this study.

a) The ZTEM field results are presented as plan-view profiles of:
b) In-Phase Z/X component, multi-frequency (30-360 Hz) profiles over the mid-frequency (90 Hz) Phase Rotated (PR) In-Phase Z/X component grid (see Fig. 9a)
c) In-Phase Z/Y component, multi-frequency (30-360 Hz) profiles over the mid-frequency (90 Hz) Phase Rotated In-Phase Z/Y component grid (see Fig. 9b).
d) Quadrature Z/X component, multi-frequency (30-360 Hz) profiles over the mid-frequency (90 Hz) Phase Rotated Quadrature Z/X component grid
e) Quadrature Z/Y component, multi-frequency (30-360 Hz) profiles over the mid-frequency (90 Hz) Phase Rotated Quadrature Z/Y component grid

The ZTEM processed results are presented as plan-view grids of:

a) In-Phase Total Divergence (DT) grids (Fig. 11) and Quadrature DT grid contours, from 30-360 Hz
b) In-Phase Resulting Phase-Rotated (RPR) grids (Fig. 10) and Quadrature RPR contours from 30-360 Hz
c) 3D View of the multi-frequency In-Phase DT (30-45-90-280-360 Hz) grid contours, plotted at equivalent skin depth (600 to 2000m depth – assuming 1k ohm-m half-space) with DEM model at surface
d) 3D View of the multi-frequency In-Phase Resulting Phase-Rotated (RPR) Grid (30-45-90-180-360 Hz) grid contours, plotted at equivalent skin depth (~600 to ~2000m depth – assuming 1k ohm-m half-space) with DEM model at surface (Fig. 13).

In addition to the ZTEM results, the following Magnetic maps are presented as plan-view grids:

e) Total Magnetic Intensity (TMI) grid contour (Fig. 12b).

And the following VTEM results are presented as plan-view grids of:

f) Late-channel EM Time-Constant (Tay) grid contour (Fig. 7a).

## DATA ANALYSIS

The Axis Lake ZTEM results, in particular, showcase the generally high level of data quality, in terms of signal/noise and well defined anomaly resolution. Particularly given the fact that a) the data were obtained in early-mid May, and therefore not at the peak season of sferic activity – hence at best moderate natural field levels expected; and b) the data were obtained using aircraft flying at ~ 100km/hr, approximately 100m above ground level – hence without significant stacking or additional processing applied.

## PLAN VIEW RESULTS

Both orthogonal sets of In-Phase Tipper profile data (Z/X = In-line – Z/Y = Cross-line) with corresponding 90-degree Phase-Rotated (PR) grids are presented for the 30 to 360 Hz frequencies, in Figure 9, for comparison purposes. The axis traces of the known Axis Lake East and West zones, Currie Lake and Rae Lake zones are also shown.

There are distinctive differences observed between the Z/X (In-Line) component profile results (Figure 9a), which are most sensitive to structures orientated perpendicular to the In-Line direction- notably the 2 prominent, thin EW lineaments that are centered directly over the known Axis Lake East & West and Rae Lake mineralized zones; as well as 2 major EW conductive zones located south and north of Currie Lake – the latter of which appears correspond to the Tantato Domain contact, and might represent a major regional fault structure. A fifth unexplained EW conductive lineament, representing a new target, is also defined south of Currie Lake. This image contrasts the Z/Y (Cross-line) component profiles (Figure9b), which are sensitive to structures oriented oblique/parallel to the In-Line flight direction. Indeed the Z/Y images are less well defined except for a SW-NE lineament extending across Axis Lake zone, potentially relating to a fault structure; and the Tantato Domain boundary to the north which is equally as prominent as in the Z/X results, presumably because it is NE-SW oriented. When the 2 Tippers are combined, using either the Resulting PR or the DT grid methods, as shown in Figures 10 and 11, the imaging of geoelectric structures becomes omni-directional, with all orientations being highlighted.

The Resulting PR and the DT images at 360Hz and 90Hz shown in Figures 10 and 11 each also demonstrate the notable differences in the frequency-dependence of the responses, that imply resolved differences in the vertical depth of the defined structures– including a) the main Axis Lake and the Rae Lake Zone responses, that rapidly weaken from high to low frequency, and b) similarly for the new target and the Currie Lake zone, barely visible. This suggests that they relate more to the near-surface geology and may not extend to significant depths. These behaviours contrast the main Tantato Domain contact zone response, which is equally strong from 45 Hz to 360Hz in both the Resulting PR and DT images. This suggests that it represents a major crustal feature, with great depth extent.

Figure 12 shows the 360 Hz In-Phase DT results (Fig 12a), as well as the corresponding Total Magnetic Intensity (TMI) results (Fig. 12b) along with the known mineralized zones as overlays. Clearly, both the DT and the TMI results both map similar mineralized, lithologic and fault-fracture structures, including: a) the Axis Lake East & West and Rae Lake zones, which are weakly magnetic and also weakly conductive, and b) the main ENE-WSW Tantato Domain contact, which is magnetic and a resistivity contact. However, the locus of the ZTEM resistivity lows appears to provide stronger evidence of NE trending fault structures relative to the magnetic results in Figure 12b. The results showcase the complementary nature of the ZTEM and Magnetic results. They also highlight the geologic mapping capability using resistivity contrasts that ZTEM provides.

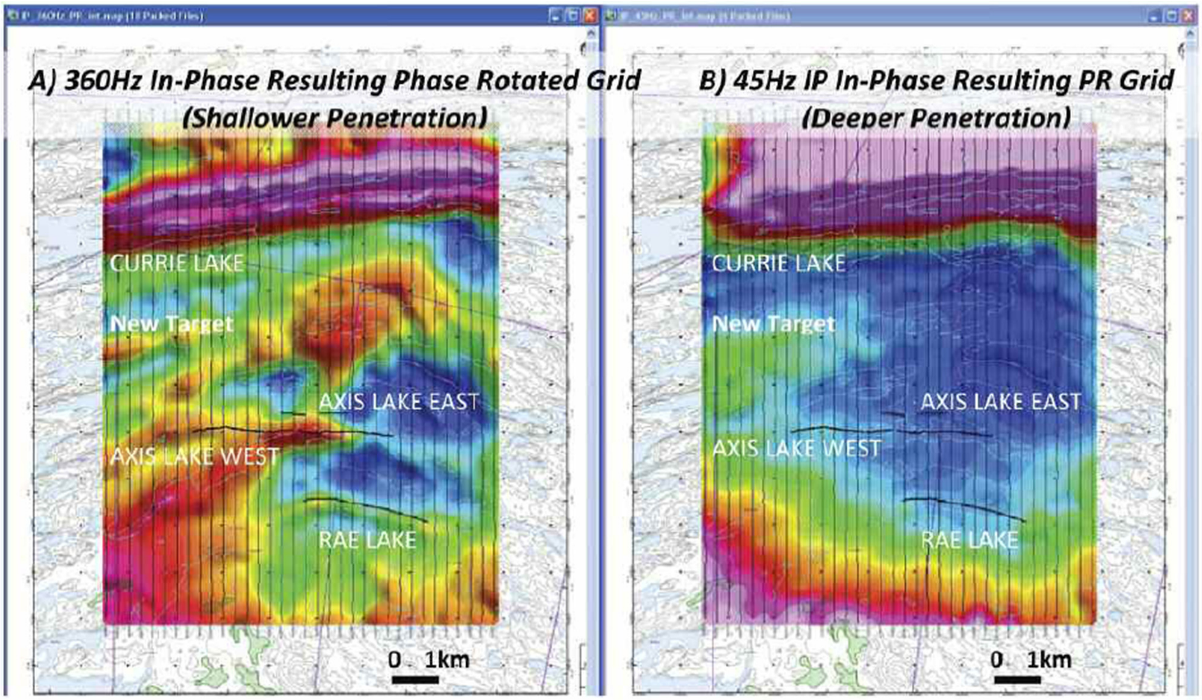


Figure 10: Axis Lake ZTEM Test Block: 360 Hz In-Phase Resulting Phase Rotated Grid (left) versus Corresponding 45 Hz In-Phase Resulting PR Grid (right) and mineralized Zones.

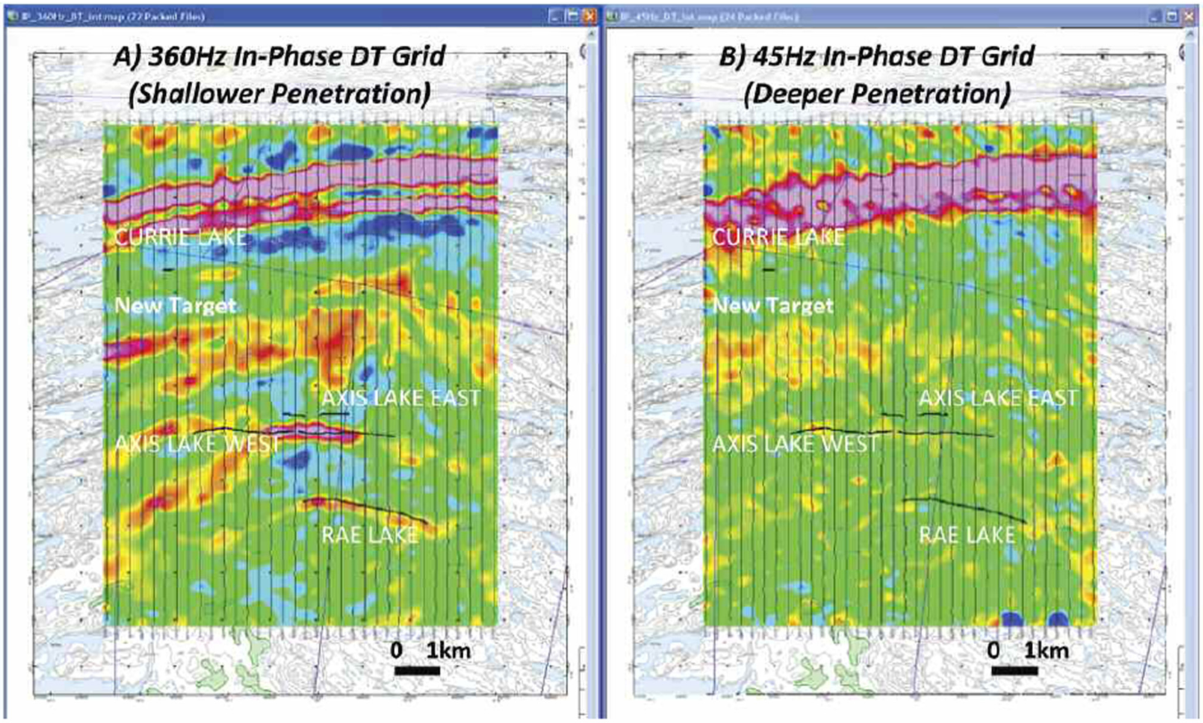


Figure 11: Axis Lake Test Block: 360 Hz In-Phase DT Grid (left) versus Corresponding 45 Hz In-Phase DT Grid (right) and Mineralized Zones.

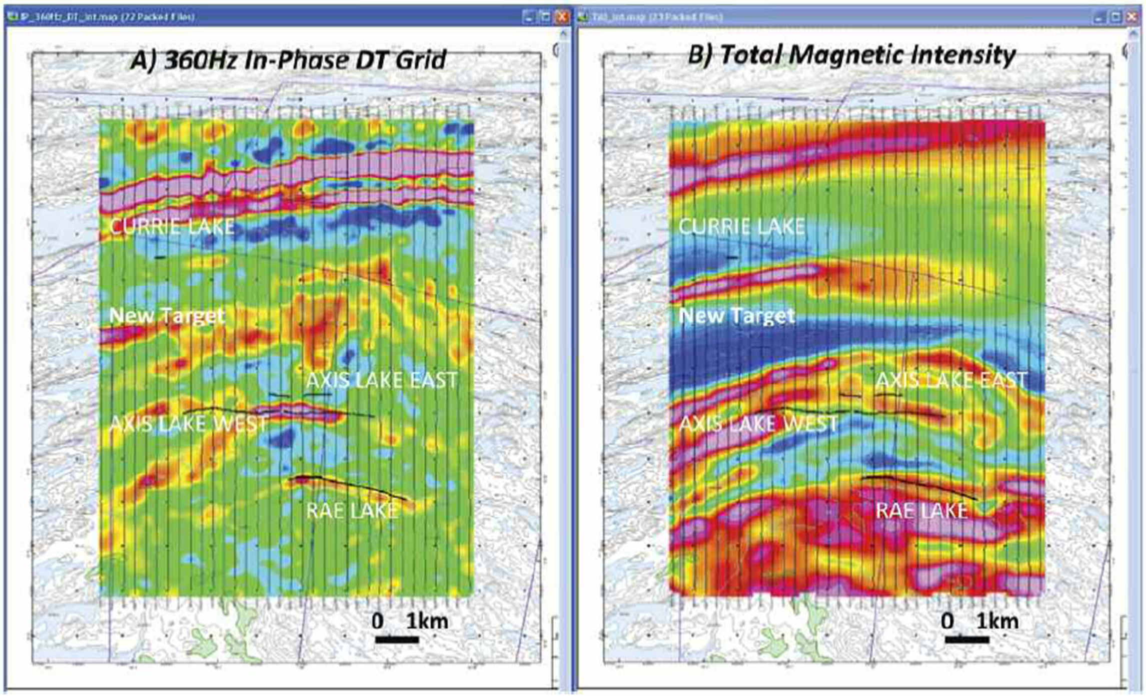


Figure 12: Axis Lake Test Block: 360 Hz In-Phase DT Grid (left) versus Corresponding Total Magnetic Intensity (TMI) Grid (right) and Mineralized Zones.

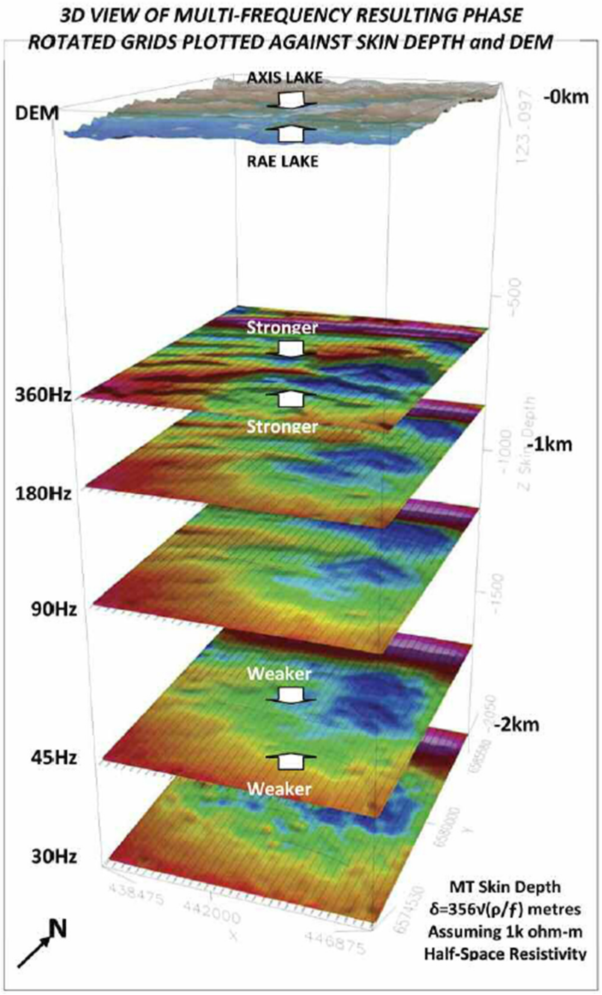


Figure 13: 3D Perspective view of Multi-frequency In-Phase Resulting PR Grids plotted according to MT skin depth (using 1k ohm-m half-space Earth) and DEM model at surface.

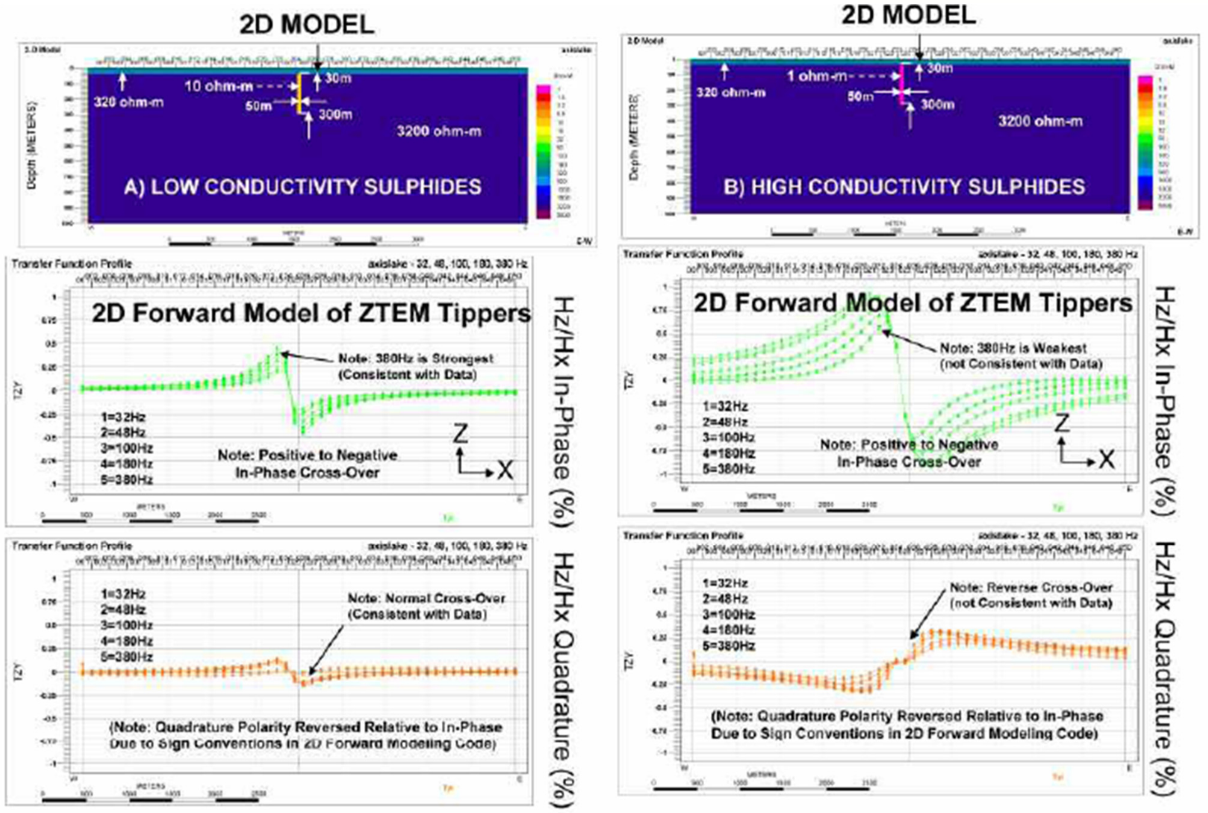


Figure 14: Axis Lake 2D Resistivity Models and 2D Forward Model Z/X profiles for low conductivity model (left) and high conductivity model (right), extending to 300 m depths.

Figure 13, presents a 3D composite image of the Resulting Phase Rotated Grids at Axis Lakes, plotted at the equivalent MT skin depth for each frequency assuming a 1,000 ohm-m average resistivity. As shown, the depth of the Resulting PR slice increases with decreasing frequency (360Hz-30Hz) from ~600m to ~2000m. Also highlighted is the fact that the responses associated with the Axis Lake and Rae Lake showings rapidly diminish with increasing skin depth, implying that they are primarily near-surface features and do not strengthen significantly with depth.

## 2D FORWARD MODEL RESULTS

Although cross-sectional images of the ZTEM frequency domain results can be obtained using 2D inversion algorithms, in the manner proposed by Perrson et al. (2008) for airborne VLF data, using the Zvert2dTM code developed for Geotech Ltd. by Prof. Phil Wannamaker at University of Utah (Wannamaker, 2008), 2D inversions were not performed on the Axis Lake data. Instead, 2D synthetic data were obtained that simulate and compare the expected Tipper responses for the Axis Lake geologic model using the 2D forward MT modeling code inside the GeotoolsTM modeling platform (AOA Geophysics Inc., Austin, TX). The PW2d forward code is based on the Gauss-Newton algorithm of deLugao and Wannamaker (1996). Unlike the Zvert2D code mentioned earlier, the PW2D code assumes that Hz-Hx-Hy readings are obtained at the earth's surface and does not take into account the "air" layer between the ZTEM aircoil sensor and the ground level. It is designed to run on a desktop Pentium with 3GHz processor, requiring approximately <5 seconds to compute for a typical Tipper model profile.

Figure 14 presents the In-line (Z/X) In-Phase and Quadrature profiles for 2 similar geologic models, whose only dissimilarity is the target conductivity, which is 10x less for the low conductivity model (10 ohm-m=5 siemens), shown on the left, versus the high conductivity model (1 ohm-m = 50 siemens), shown on the right. The notable similarities that the low conductivity model have with the measured data are: a) In-Phase (IP) responses that diminish in amplitude at lower frequencies, and b) Quadrature phase (QP) responses that follow the same polarity as the In-phase (note the reversed sign for QP relative to our measured results is due to polarity convention in MT 2d code utilized), and c) model amplitudes for the IP and QP for the low conductivity model closely match the observed data (i.e., +/- 40% IP and +/- 10% QP) and are significantly weaker than for the high conductivity model (see Figures 14 vs. 15). Hence the 2D forward modeling results suggest that the Axis Lake mineralized zones are only moderately conductive (~5 siemens) and do not extend to significant depth (~300-500m) – both of which agree with the VTEM and UTEM survey results and the known geology.

## CONCLUSION AND RECOMMENDATIONS

The ZTEM test results performed over known magmatic copper-nickel deposits in northern Saskatchewan have highlighted the high quality and high resolution resistivity mapping capability, and deep penetration of the Tipper AFMAG data obtained using the ZTEM system. The ZTEM results appear to correlate very well with the known geology, in particular the presence of a Cu-Ni mineralized conductive horizons, at Axis Lake and Rae Lake, which are known to occur at surface and are followed along several kilometers along strike. In particular, the ZTEM results provide indications of the longer strike continuity of the known mineralized horizons, as compared to the VTEM results, that likely relate to more weakly mineralized, lower conductivity extensions of the zones. This also agrees with the ground UTEM anomaly trends that extend beyond the known mineralized zones (Fig.15). In fact, an unexplained ZTEM anomaly northwest of the known Cu-Ni showings and south of Currie Lake correlate well with the east-extension of VTEM conductor and therefore represents a new target for follow-up(Figure 15).

Other ZTEM lineaments also correlate well with similar aeromagnetic trends and structures, which highlight its ability to provide complementary information. In addition to mapping lithology and structure, the ZTEM results appear corroborate the moderate conductance (~5 siemens) and the relatively limited vertical depth-extent (~300-500m) of the defined mineralized zones and therefore agree with the previous geophysical and drill-tested geologic findings (Figure 15). 2D forward model results appear to corroborate the observed data and are consistent with the known geology and geophysical property distributions. The Zvert2d algorithm appears to have been able to compute accurate ZTEM responses in the air and to indicates that reasonable earth resistivity cross section could be obtained using 2D inversions at Axis Lake. Although they are dependant on the value of the uniform 1D half space resistivity starting model utilized, provided approximate constraints on the host resistivity are available, inversion anomaly depth estimates are also likely to be more accurate. With poor constraints, trials with a variety of host resistivities are required to judge their dependency (Wannamaker, 2008). We recommend that these ZTEM results be compared with the available geoscientific data, in order to better explain the observed correlations with the known geology. This might include more direct comparisons with any geophysical survey data, in particular, ground EM and airborne EM. We also recommend that additional interpretation of the ZTEM data be attempted, using 2D inversions, possibly with geologically-referenced starting models, in order to further validate the inferred depth-extents indicated in the 2D forward modeling.

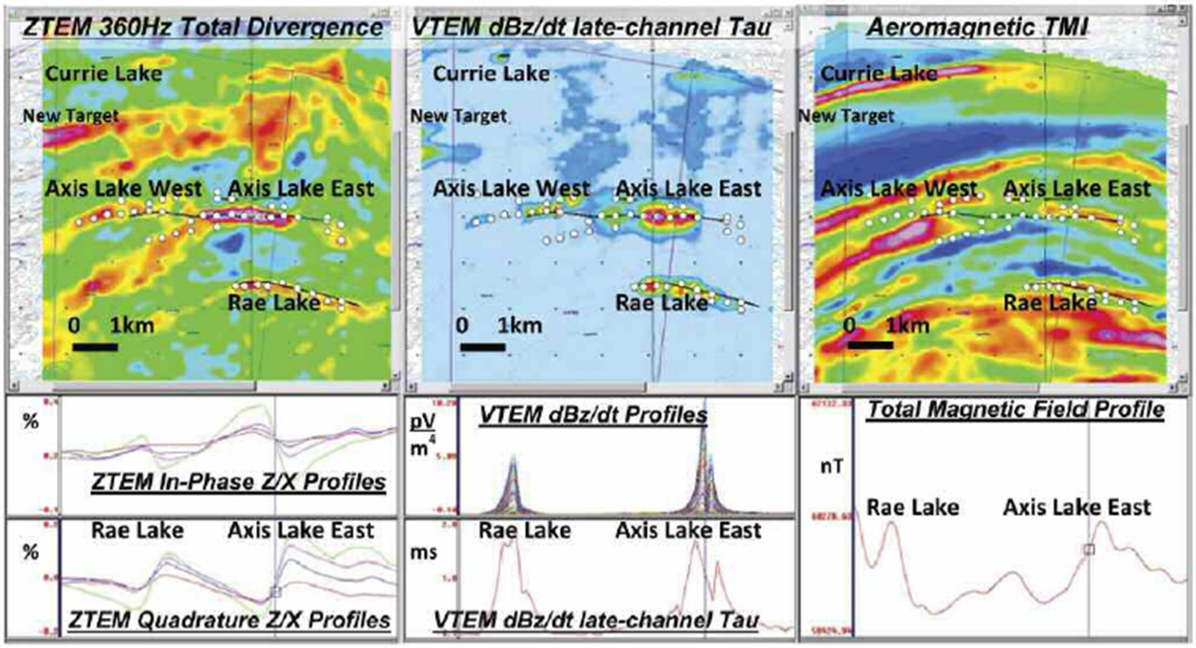


Figure 15: Axis Lake ZTEM 360 Hz DT (left), VTEM Late-Channel Tau (center), Aeromagnetic TMI (right) Results, Mineralized Zones and Ground UTEM Anomalies.

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