GEOPHYSICAL REPORT ON HELICOPTER-BORNE ZTEM TIPPER CASE STUDY RESULTS

over
RIOU LAKE TEST BLOCK, May 2008
Northern Athabasca Basin, Saskatchewan

Introduction

ZTEM (Z-Tipper Axis Electromagnetic) surveys were conducted over the Riou Lake Test Block, in the North Athabasca Basin in May, 2008. The ZTEM survey consists of airborne Tipper AFMAG (audio frequency electromagnetics) measurements, as well as aeromagnetics using a caesium magnetometer. The survey consisted of fifty-four (54) 11.5km long, NW-SE oriented flight lines, totaling 621 line-km, that were obtained at nominal 400m line spacings over an approximately 30 x 60km area. The area was chosen because it had been partially flown using VTEM, it hosted significant thicknesses of Athabasca sandstone (500-750+ metres) cover and also because the area's schematic geology was available on the web and in the public domain.

Figure 1: *ZTEM Hz Receiver Coil and Hx-Hy Reference Coils*

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 were obtained, using Fourier-based, digital signal processing analyses, at 5 frequencies, between 30Hz and 360Hz.

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 world wide 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 range between 600m to 2km in this region of the Athabasca Basin, according to the following equation for skin depth (Vozoff, 1972):

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

if ρ_A = 1k ohm-m, $\delta_s \approx$ 600m at 360Hz and ~2.0km 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.

Data Presentation

The nature of the AFMAG fields is such that, as with VLF, buried, tabular conductors and resistors produce cross-over responses. As such, although the field results are shown as cross-over profiles, additional post-processing is applied to convert these cross-overs 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 Geosoft-based FFT process applied to the grid data, and the Total Divergence (DT) which is a summative, horizontal derivative process method (Kuzmin, et al., 2005) – both of these have been used in this test case.

General Geology

High-grade uranium deposits within the Athabasca Basin are associated with the unconformity between the flat-lying Proterozoic Athabasca Group sandstones and the underlying Archean-Paleoproterozoic metamorphic and igneous basement rocks. The locations of these deposits are lithologically and structurally controlled by the sub-Athabasca unconformity and basement faults and fracture zones, which are localized in graphitic pelitic gneisses that may flank structurally competent Archean granitoid domes (Lo et al., 2008).

In general, most of the known important deposits tend to occur within a few tens to a few hundred metres of the unconformity and within 500-700 m of the current ground surface. All the deposits located so far are associated with fault structures associated with a graphitic conductive basement, as well as alteration zones of clay-silicification and enrichment around the deposits. Their sometimes resistive, sometimes weakly conductive nature makes these difficult targets for airborne TEM. However, ZTEM Afmag fields are sensitive to resistivity contrasts, thereby favouring their use as tools for mapping such sandstone alteration zones.

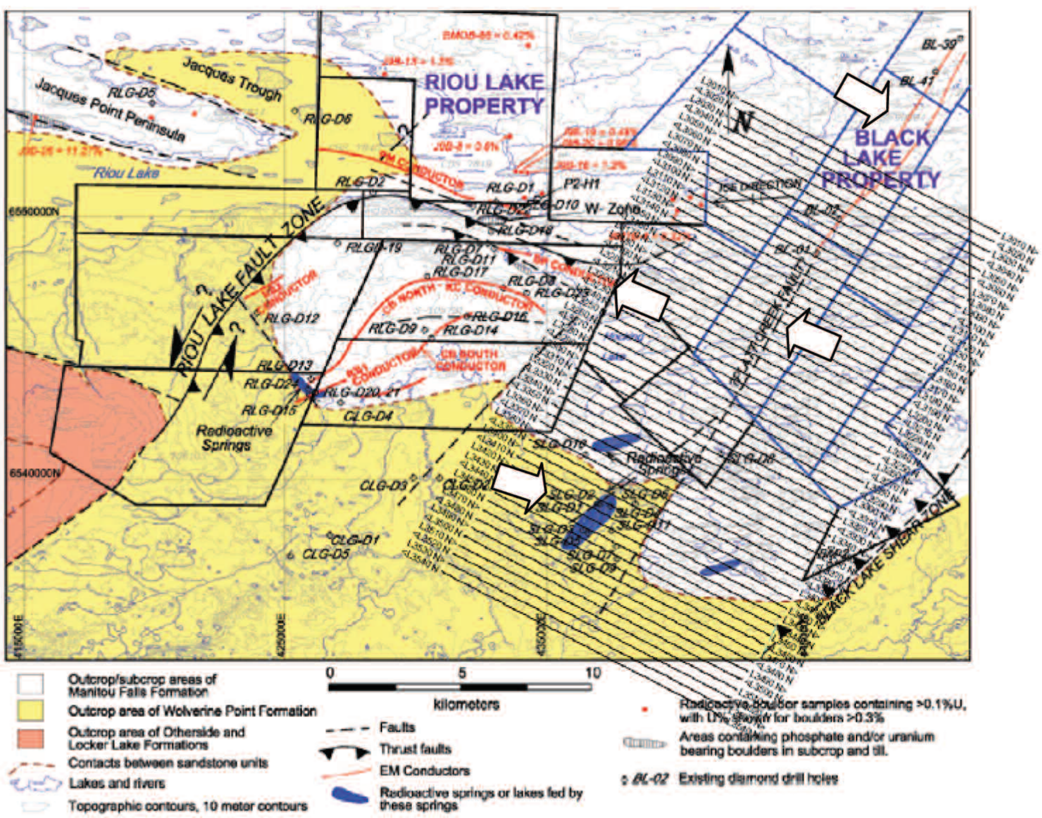


Figure 2: *Riou Lake-Black Lake General Geology (http://www.uex-corporation.com/s/RiouLake.asp)*

The general geology of the Riou Lake-Black Lake area is presented in Figure 2, along with the ZTEM flight lines. Manitou Falls sandstones occur across most of the survey area, but Wolverine Point mudstones outcrop to the south. The sandstone depth is approx. 550m to the north and >700m towards the center of the survey area. As shown, the survey area hosts a major SW-NE graphitic EM conductor that extends from the north into the Platt Creek Fault (PCF), whose presence is inferred from regional magnetics – too deep for ground or airborne EM detection.

Further south, radioactive springs, situated near the PCF, are the focus of drilling. West of the survey area, the basement geology, based on EM conductors, is more EW orientated following the Riou Lake Fault Zone – indicating complex structure locally, including a possible synformal fold structure extending into the centre of the survey area. The ZTEM survey objectives were to penetrate the thick sandstone cover to help define the deep basement geology, using the graphitic markers, as well as detecting possible alteration zones in the overlying sandstone.

Data Analysis

The North Athabasca test area ZTEM results, in particular, showcase the exceptionally high level of data quality, in terms of low signal/noise and well defined anomaly resolution. Particularly given the fact that a) the data were obtained in early May, and therefore not at the peak season of sferic activity – hence at best moderate natural field levels expected; b) the data were obtained using aircraft flying at ~100km/hr, approximately 100m above ground level – hence without significant stacking or additional processing applied, and c) the strength of response obtained from geologic targets at >500-700+ metre depths.

The In-Phase Tipper (Z/X = In-line – Z/Y = Cross-line) profile data with corresponding 90-degree Resulting Phase-Rotated (PR) grids and analogous Total Divergences (DT) grids are presented, in Figures 3-4, with the high (360Hz-left) and mid-frequency (90Hz-right) spectrum shown together, for depth-comparison purposes. The magnetic results are also compared to the ZTEM in Figure 5.

A) 360Hz Z/X IP Profiles & Resulting Phase Grid ***B) 90Hz In-Phase Resulting Phase Grid***

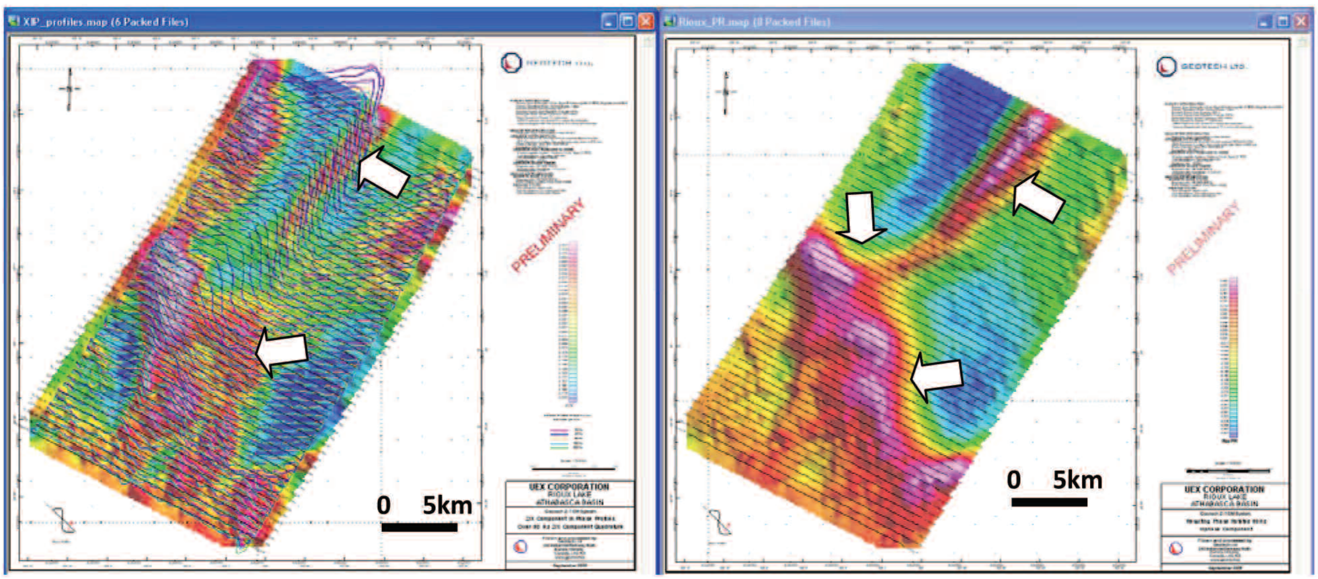


Figure 3: *Riou ZTEM Test Block: In-Phase Z/X Component Profiles over 360Hz Resulting Phase (PR) Grid (left) versus Corresponding 90Hz In-Phase PR Grid (right).*

There are distinctive differences observed between the Z/X (In-Line) component profile results (Figure 3a), which are most sensitive to structures orientated perpendicular to the In-Line direction, versus the Z/Y (Cross-line) component profiles (Figure 4a), which are sensitive to structures oriented oblique/parallel to the In-Line flight direction. When the 2 Tippers are combined, using either the PR or DT grid methods, as shown, the imaging of geoelectric structures becomes omni-directional, with all orientations being highlighted.

In this Athabasca test area, the ZTEM results detect a well-defined conductor associated with the known main NE-SW orientated graphitic conductive zone, lying to the north whose depth increases from 500 to >750m depths; whereas they also define other oblique-to-flight-line NW-SE oriented features – notably: a) the inference of a synformal fold structure, joining the Riou Lake Fault to the Platt Creek Fault zone in the central survey area, and b) a possibly NNW-SSE oblique shear zone-hosted, alteration zone, in the south-central survey area, where the numerous radioactive indicators are found and the geology is inferred to exceed 700-900m.

A) 360Hz Z/Y In-Phase Profiles + DT Grid ***B) 90Hz In-Phase DT Grid***

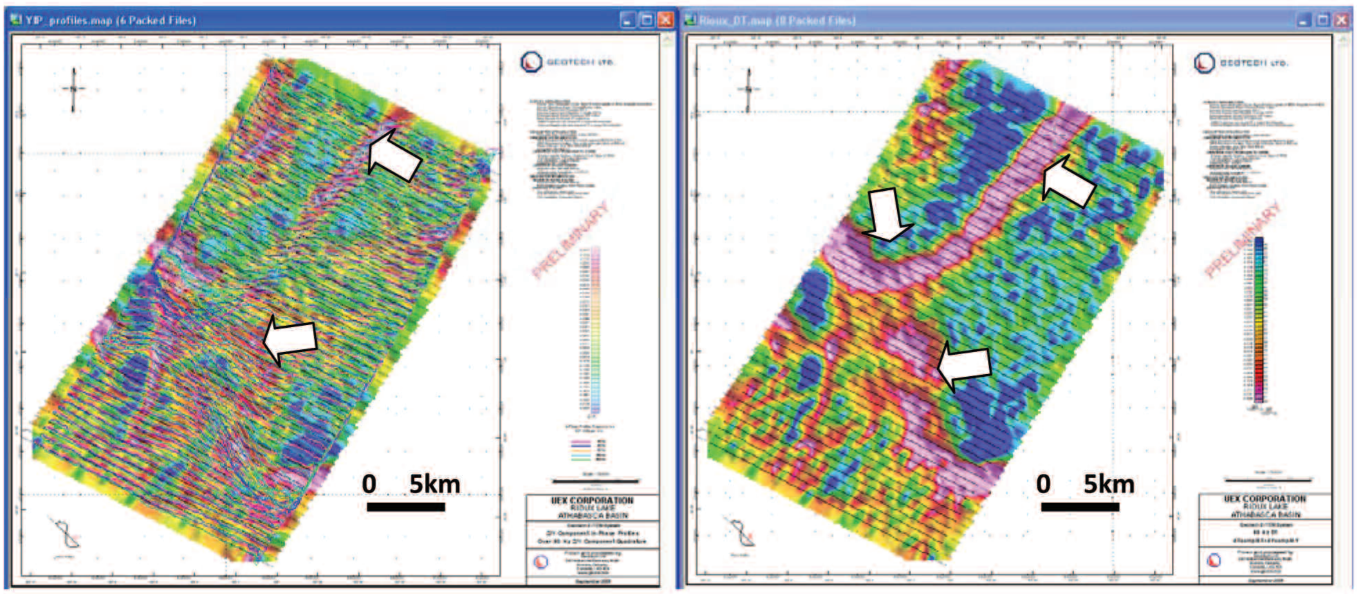


Figure 4: *Riou Test Block: In-Phase Z/Y Component Profiles over 360Hz Total Divergence (DT) Grid (left) versus Corresponding 90Hz In-Phase DT Grid (right).*

There are also 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 NE-SW Platt Creek graphitic response, occurring to the north, that progressively weakens to the south in the high frequency results (Fig. 3a & Fig 4a). This might reflect the graphitic fault that plunges deeper below the depth penetration (~600m) at 360Hz. In contrast, with decreasing frequency/increasing depth, the conductive lineament strengthens and is defined along its entire strike length (Fig. 3b & Fig. 4b) – as the Afmag fields penetrate fully below the sandstone cover and into the basement , below 180-90Hz.

Figure 5 shows the 90 Hz In-Phase DT results (Fig 5a), as well as the corresponding calculated 1ST vertical magnetic gradient (CVG) results (Fig. 5b) and compares them both directly with the schematic geology, taken from Figure 2 and shown as an overlay. Clearly, both the DT and the CVG results both map the Platt Creek Fault Zone (PCF), however there is no evidence of either A) the synform structure, or B) the inferred alteration zone in the magnetic results in Figure 4b. The results showcase the complementary nature of the ZTEM and Magnetic evidence, but also the unique and improved mapping capability that provided with resistivity parameter.

A) 90Hz In-Phase DT Grid + Geology Overlay ***B) Calculated 1^{ST} Vertical Magnetic Derivative***

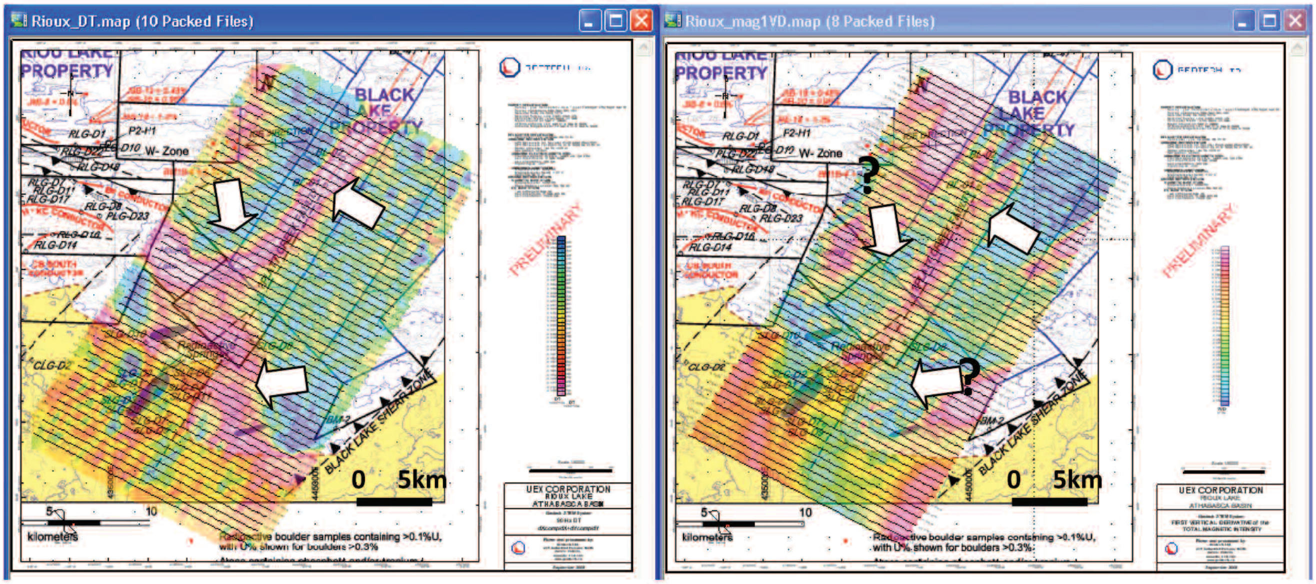


Figure 5: *Riou Test Block: 90Hz In-Phase DT Grid and Geologic Overlay (left) versus Corresponding Calculated 1ST Vertical Magnetic Grid (right).*

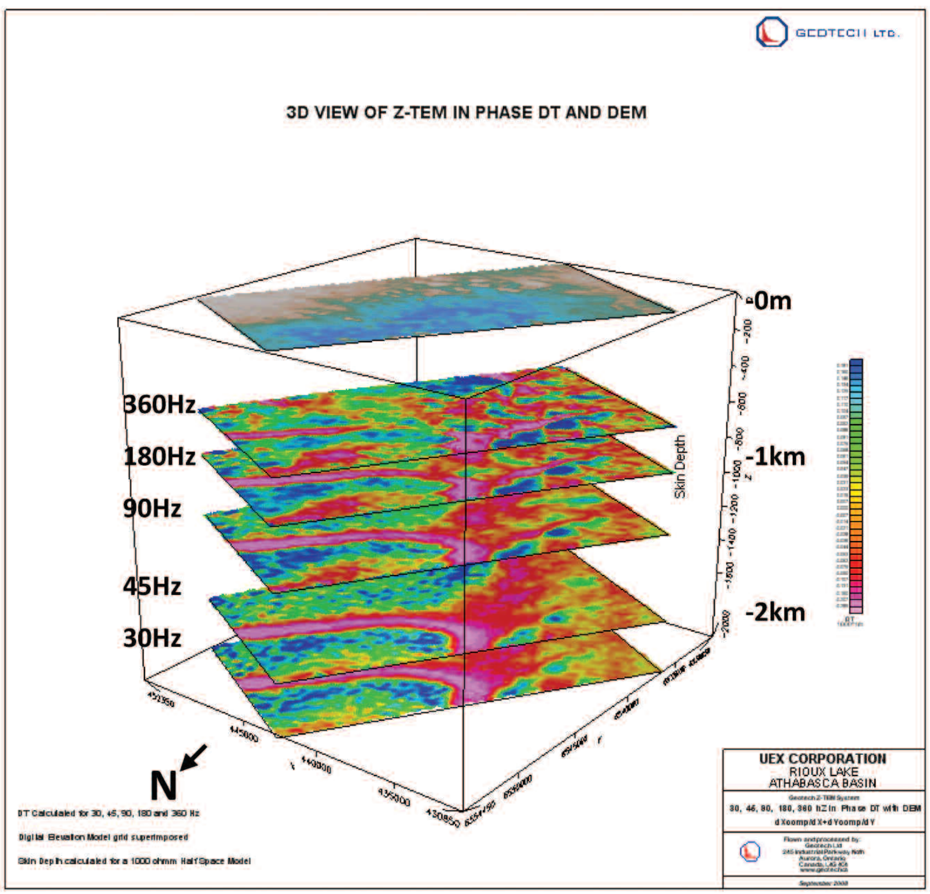


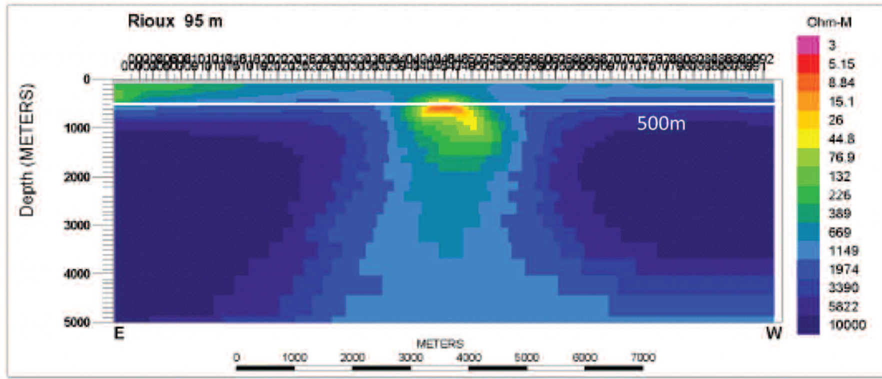
Figure 6: *3D Perspective view of Multi-frequency In-Phase DT's plotted according to MT skin depth (using 1k ohm-m half-space Earth) and DEM model at ground level.*

Figure 6, presents a 3D composite image of the DT at various frequencies plotted at the equivalent MT skin depth assuming a 1,000 ohm-m average resistivity. As shown, the depth of the DT slice increases with decreasing frequency (360Hz-30Hz) from ~600m to ~2000m.

2D Inversion Results

Cross-sectional images of the ZTEM results have been generated using 2D inversion algorithm, in the manner proposed by Pedersen et al. (1994) for airborne VLF data. The Zvert2d™ code developed for Geotech Ltd. is based on the Gauss-Newton algorithm of deLugao and Wannamaker (1996) by Prof. Phil Wannamaker at University of Utah. It was specifically modified to 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 20 minutes to execute for a typical ZTEM profile.

The In-line (Z/X) data for a single line profile, taken from the north end of the Riou Lake test block, were used to create the 2D inversion image presented in Figure 7. The input data utilized both the In-Phase and Quadrature Phase data from all five measured frequencies. Due to the impractical nature of the >1000 data points from the ZTEM profile, these were undersampled to 90 points in order to perform the calculation and proved effective. An error of 2% was assigned to the data for inversion. A host of 1000 ohm-metres was assumed for the model. Despite non-ideality of the data error, a value of nRMS of close to unity (1.0) was achieved in 4-6 iterations, with starting nRMS values of 5-6.



Figu[illegible]. Above: Inversion image for line Rioux with the flight line 95 m above the ground. Below: Observed and computed inversion model responses for line Rioux-95m.

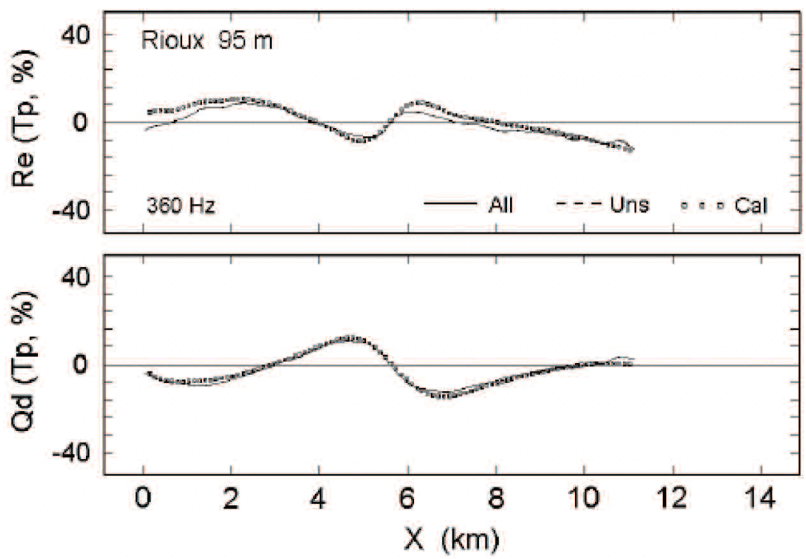


Figure 7: *2D Inversion image and Calculated vs. Observed Z/X profiles for Riou Lake flight line 95m above ground level.*

Figure 7 presents the 2D resistivity cross-section obtained from the Riou Lake line-profile and the corresponding In-Phase and Quadrature profiles showing the measured vs. 2D forward model data fits at 360Hz, for comparison (note that the Quadrature profile is reversed for convention purposes; ref. Wannamaker, 2008). As shown, although the anomaly appears at first like a simple but strong cross-over response, the inversion image is surprisingly detailed and appears accurately described the inferred geology. The host to conductive anomaly has moved during the inversion to be considerably higher than 1000 ohm-m. This is believed to have helped deepen the vertical extent of the anomaly to lower frequencies by increasing contrast. The top of the conductor occurs at 500m, which is geologically accurate. The bedrock conductor is mildly arcuate downward with some asymmetry and dips to the east. The conductive near-surface layer’s 400-500m thickness is also consistent with the known geology.

Conclusion and Recommendations

The ZTEM test results performed over an unconformity-type uranium target in the north Athabasca basin has highlighted the high quality and high accuracy of the AFMAG data obtained.

The ZTEM results appear to correlate very well with the known geology, in particular the presence of a graphitic conductor that is known to occur at depths exceeding 500-750m. In addition, the ZTEM results appear to explain/corroborate changes in the geologic strike in the deeper, more thickly sandstone-covered portions of the survey area which, up until now, are poorly explored due to lack of available geophysical and drill-hole data. In particular, the ZTEM results point to the presence of a synformal conductive structure, that relates the graphitic Riou Lake Fault zone to the Platt Creek zone, in the central survey area, as well as a weak NNW-SSE oriented low resistivity zone inferred to occur in the shallower sandstone cover rocks, which correlates with geochemical anomalies and potentially relates to a shear-hosted alteration zone.

The 2D inversion using the Zvert2d algorithm appears to have been able to compute accurate ZTEM responses in the air and to invert them for reasonable earth resistivity cross section at Riou Lake. Provided approximate constraints on the host resistivity are available, inversion anomaly positions are more accurate. With poor constraints, trials with a variety of host resistivities are required to judge their dependency,

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 comparisons with any geophysical survey data, in particular, ground EM and possibly also ground magnetotelluric and tipper MT results. We also recommend that additional interpretation of the ZTEM data be attempted, using 2D inversions with geologically-referenced starting models.

References

De Lugao, P.P., and Wannamaker (1996). Calculating the two-dimensional magnetotelluric Jacobian in finite elements using reciprocity, Geophys. J. Int., Vol. 127, pp. 806-810.

Kuzmin, P., Lo, B., and Morrison, E. (2005). Final Report on Modeling, interpretation methods and field trials of an existing prototype AFMAG system, Misc Data Release 167, Ontario Geological Survey.

Labson, V. F., Becker A., Morrison, H. F., and Conti, U. (1985). Geophysical exploration with audiofrequency natural magnetic fields, Geophysics, Vol. 50, pp. 656-664.

Lo, B., Legault, J.M., Kuzmin, P. (2008), Z-TEM (Airborne AFMAG) tests over unconformity uranium deposits, extended abstract submitted to 20^{TH} ASEG International Geophysical Conference & Exhibition, Adelaide, AU.

Pedersen, L.B, Qian, W., Dynesius, L., Zhang, P. (1994). An airborne tensor VLF system. From concept to realization, Geophysical Prospecting, Vol. 42.

Wannamaker, P.E. (2008). Two-dimensional inversion of ZTEM data: Synthetic model study and test profile images, technical report by Emblem Geophysical Inc. for Geotech Ltd.,
Dec-2008, 25 pp.

Ward, S. H. (1959). AFMAG - Airborne and Ground: Geophysics, Vol. 24, pp. 761-787.