The application of ZTEM to porphyry copper-gold exploration

Ken Witherly*
Condor Consulting, Inc., USA
ken@condorconsult.com

Daniel Sattel
EM Solutions, USA
dsattel@earthlink.net

SUMMARY

The ZTEM airborne EM system was introduced into commercial service by Geotech Ltd. in late 2007. ZTEM is unlike any other commercial EM system in that it relies on the measurement of natural occurring EM fields in the Afmag frequency range of 25-720 Hz.

As a result of using natural EM fields that pass through the earth as plane waves, the ZTEM system response shares similarities and important differences to traditional inductive source EM systems such as VTEM or MegaTEM, used extensively by the minerals industry to explore for targets of high conductance. While ZTEM can detect discrete conductors like inductive systems, it also responds to bulk changes in resistivity and conductivity gradients that often characterize geological contacts or structures.

One important deposit style that typically lacks a discrete conductivity response are porphyry copper-gold deposits, such as commonly found in many locations around the circum Pacific region. The present study will examine the ZTEM responses for several porphyry deposits in light of other exploration data including drilling, mapped geology and other forms of airborne and ground geophysics.

Key words: Afmag, airborne EM, ZTEM, porphyry copper.

INTRODUCTION

The ZTEM system (built and operated by Geotech Ltd.) measures the Afmag responses of naturally occurring subsurface currents, induced by distant lightning discharges. The vertical component is measured from a helicopter platform, while the horizontal components are recorded on the ground at a base station; data are typically acquired over a frequency range of 30-720 Hz. Various methods are used for the modeling and interpretation of ZTEM data, including 2D inversion, Karous-Hjelt filters and the derivation of apparent conductivity; these are discussed in Sattel et al. (2010).

The 2D algorithm used for the forward modeling and inverting ZTEM data is based on a 2D MT algorithm developed by Constable and Wannamaker. The algorithm derives the in-line (Tzx) tipper profiles from the computed transverse electric (TE) response. The finite-element algorithm models the effect of topography and takes into account the terrain clearance of the airborne platform along the flight line. An example of the model mesh is illustrated in Figure 1. This application is discussed further in Sattel and Witherly (2012). For the interpretation of survey data, the Tzx. Geotech provides a suite of grids from the primary Tzx and Tzy outcomes along with filtered versions of the primary results intended to facilitate the interpretation of outcomes. Table 1 summaries the products typically delivered by Geotech and Condor.

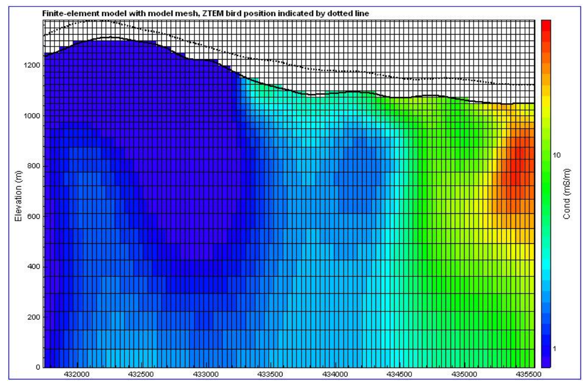

Figure 1: Illustration of model mesh for 2D inversion. Since the algorithm takes into account the topography and ZTEM bird terrain clearance along each line, air cells are an integral part of the finite-element model.

FIELD RESULTS

Pebble, Alaska: The Pebble deposit is a major copper-gold porphyry system in southern Alaska. ZTEM results over the deposit have been presented earlier by Paré and Legault (2010). The geology (plan and section) are shown in Figure 2. In addition to the ZTEM, Spectrem was flown over the deposit and surrounding area. These results have proven useful to compare with the ZTEM results. Figure 3 shows the ZTEM DT results for the three lower frequencies along with the TMI-Tilt, Spectrem tau and conductivity depth slice at 100 m. The ZTEM results show a resistive core to the shallower Pebble West deposit, with an irregular distribution of conductive trends surrounding the Pebble West. One roughly N-S linear along the eastern side of Pebble West correlates very closely to the Tertiary contact (marked as yellow line). The other ZTEM features to the north and west of the deposit are of unknown geological origin. The TMI-tilt was produced to see if the magnetic results correlated with the ZTEM trends in and around the deposit. There appeared to be no significant correlation between the magnetic and ZTEM outcomes. The Spectrem tau and a conductivity depth slice at 100 m show conductivity along the eastern side of Pebble West and across the northern edge of the deposit. The 100 m depth slice shows a strong N-S trending linear high that correlates with the mapped Tertiary contact and which is also picked up in the ZTEM results. Both the 100 m depth slice and ZTEM DT show an isolated high just off the western edge of Pebble

Table 1

Product D = primary data G = grid f(l) frequency low f(h) frequency high	Source	Comments
X-In-phase & Quad f(l)- f(h) D	Geotech	Primary data provided for all obtained frequencies
Y In-phase & Quad f(l) - f(h) D	Geotech	Primary data provided for all obtained frequencies
DT (Total derivative) f(l) - f(h) G	Geotech	DT is calculated from the horizontal derivatives of the Tzx and Tzy tippers; it is analogous to the "Peaker" parameter in VLF(Sattel and Witherly 2010). Long wave length information can be lost.
TPR (Total phase rotated) f(l) - f(h) G	Geotech	Transforms bipolar (cross over) anomalies into single pole anomalies with a maximum over conductors, while preserving long wavelength information
AppCon f(l) - f(h) D	Condor	Provides a better measure of conductivity changes within the data set.

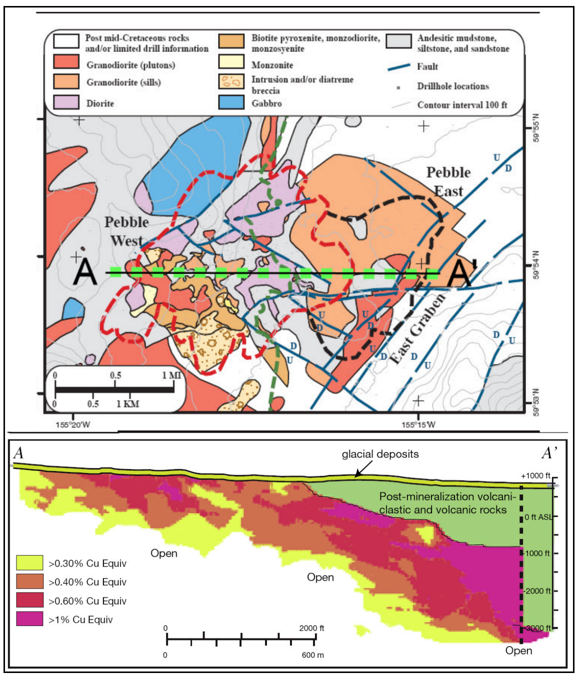

Figure 2: Geological map and section over Pebble deposit.

West; this feature is circled as a white dash on both images. Other aspects of the Spectrem and ZTEM results as well show a general agreement, while differing in detail. Figure 4 shows depth conductivity sections for the Spectrem and ZTEM results. The Spectrem data were processed with an Occam style layered earth inversion code whereas the ZTEM were processed with a 2D Occam inversion code discussed earlier in this abstract. The location of the two lines is shown in the upper left panel of Figure 3. Note, the lines were not flown using the same flight bearing but do cross over the deposit. These results show there is an extensive zone of shallow conductivity associated with Pebble West (defined by 0.3% Cu equ. zone). On both surveys however, the conductive zone extends well west of the actual deposit.

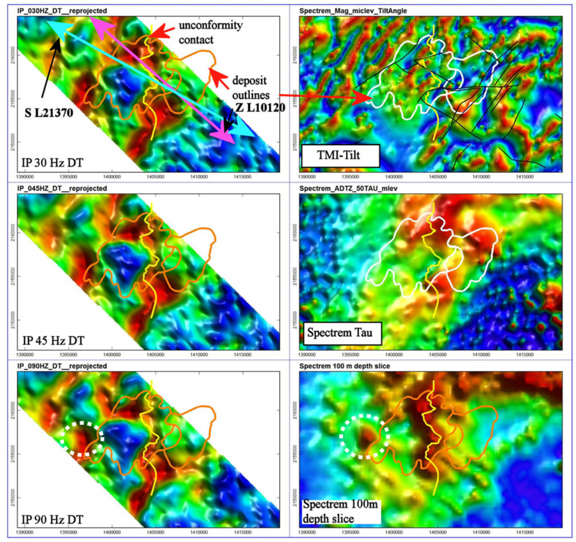

Figure 3: Pebble DT grids for 30, 45 and 90 Hz (left side); TMI-tilt (upper right), Spectrem tau and 100 m conductivity depth slice.

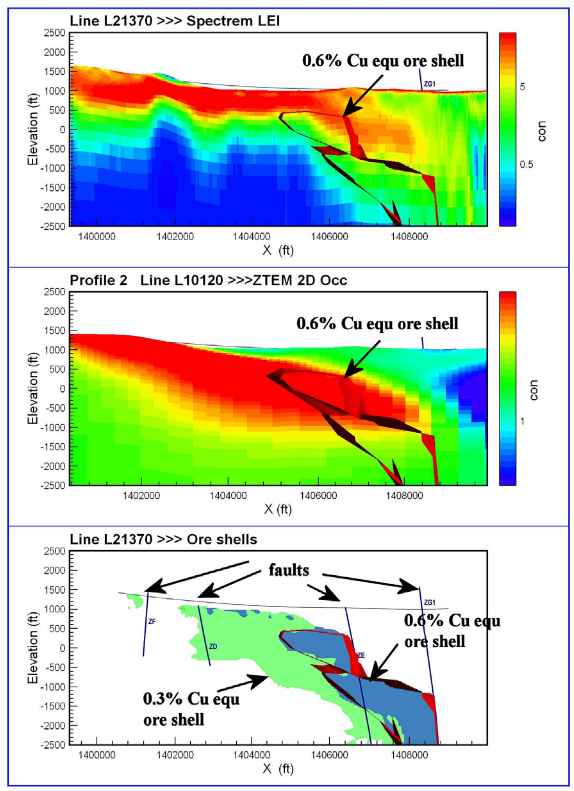

Figure 4: Conductivity depth sections from Spectrem and ZTEM along with 0.3% and 0.6% Cu equ. ore shells.

Both results as well appear to capture the faulted (down-dropped) aspect of the mineralized zone going to the east with the ZTEM appearing to capture this slightly better than the Spectrem results. The extent of the conductivity is considered unusual for this style of deposit and there is currently no petrophysical or borehole data to define a specific source. Based on geological descriptions however, a late stage alteration termed the quartz-sericite-pyrite event could be the causing much of the conductivity response not attributed to other sources such as the Tertiary contact discussed earlier.

Planned borehole physical property logging should help to establish with greater certainty what geological sources are causing the observed conductivity.

Babine Lake, British Colombia: The Babine property consists of two intrusive systems; the Nak and the Dorothy. These are shown in Figure 5. Prior to the ZTEM survey, an IP-resistivity survey and extensive drilling were carried out on the property. While the IP-resistivity survey covered both the Nak and Dorothy, the drilling was localized around the Nak.

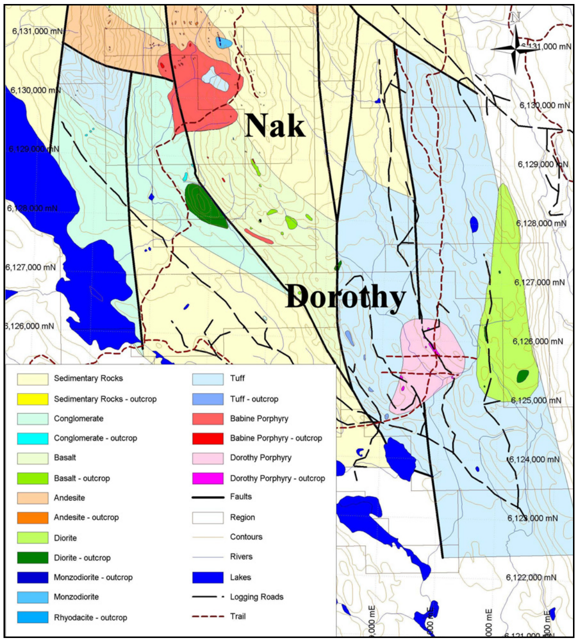

Figure 5: Geology over the Nak and Dorothy intrusives.

Figure 6 shows the TMI and ZTEM 30 Hz In-Phase TPR. The Nak and Dorothy intrusive systems are outlined. The Nak porphyry shows a direct magnetic high with dimensions similar to the mapped porphyry system. As well, the Nak outline overlaps with a discrete 30 Hz In-Phase TPR low. The Dorothy intrusive lies on the flank of the elongate magnetic high. A discrete 30 Hz In-Phase TPR low is noted just west of the intrusive. Figure 7 shows a depth slice at 100 m from the resistivity survey and the 30 Hz In-Phase TPR data. A strong linear low resistivity (colored blue) is apparent in the data and this has been traced out on both figures. In the 30 Hz In-Phase TPR response, this line corresponds very closely to a ridge of high. In Figure 8, this linear is traced over the geology map with the TMI result repeated as well.

Morrison, British Colombia: The Morrison property lies SW of the Babine Lake property discussed above. Morrison is a large tonnage, low copper-gold grade resource defined by extensive drilling. A second intrusive center called the Hearne Hill that is not significantly mineralized is also covered by the ZTEM survey. Geology and the results of an AeroTEM EM (Rudd and Sterritt 2010) and magnetic survey covering part of the property are available to help assess the ZTEM results. Figure 9 shows the outline of the ZTEM and AeroTEM surveys and the local geology with the Morrison and Hearne Hill intrusives as well as highlighting the major faults. The magnetic results show the two intrusives to be situated in different settings; Morrison is located along a narrow arcuate

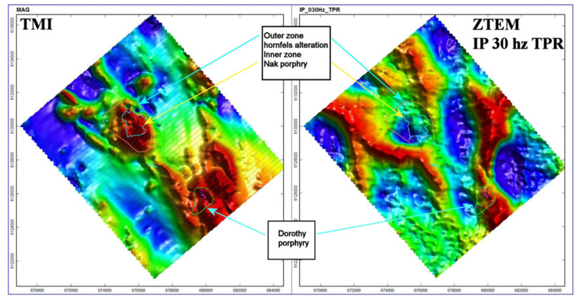

Figure 6: TMI (left) and 30 Hz In-Phase TPR (right) over Babine property.

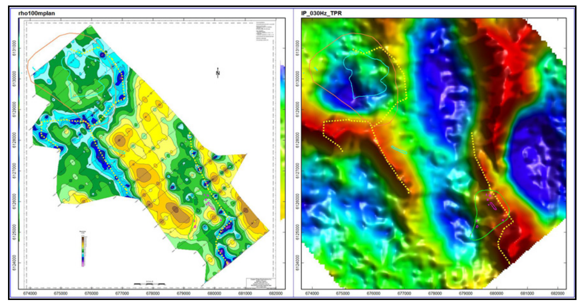

Figure 7: Resistivity 100 m depth slice (left) and 30 Hz In-Phase TPR; axis of resistivity low is highlighted in both images. Note, for the resistivity results, low resistivity values are assigned cooler colors.

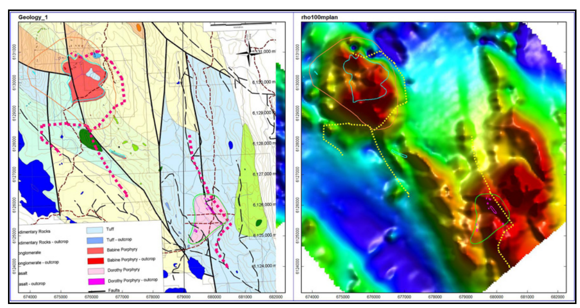

Figure 8: Geology with resistivity linear (left) and TMI showing the resistivity linear.

moderate high whereas Hearne Hill is situated within a much larger magnetic high. The mapped faults are not well expressed in the magnetic results. Figure 10 shows a zoom-in on the area with the intrusives, showing the ZTEM 90 Hz In-Phase TPR result. This result shows that the Morrison intrusive lies centered over a zone of high resistivity (blue area). The Hearne Hill intrusive however, lies over a zone of elevated ZTEM response. This zone also corresponds to a mapped NE-SW trending fault so the ZTEM response is interpreted to be that of a fault system. The geology shows a second shorter fault orientated orthogonally to the NE trending feature directly over the intrusive. The ZTEM does not appear to reflect this structure. The two major structures that trend NW and enclose the Morrison intrusive are not well represented in the ZTEM results. Figure 11 shows the zoomed-in view for 90 Hz for both the TPR and DT results. Figure 12 shows the same components at 360 Hz. This shows that the DT results at both frequencies provides more detail than observed in the TPR outcomes. Some of the DT response looks somewhat ‘noisy’ but the two linear highs that enclose

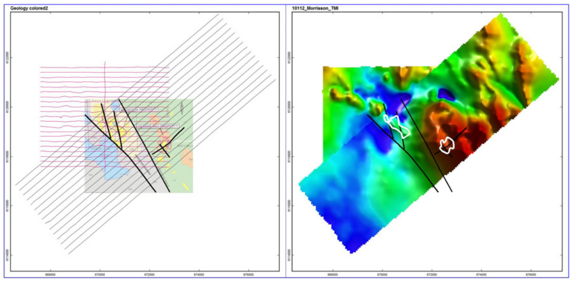

Figure 9: Geology map of Morrison and Hearne Hill intrusives with ZTEM and AeroTEM flight path (left) and merged magnetic image of two airborne surveys (right).

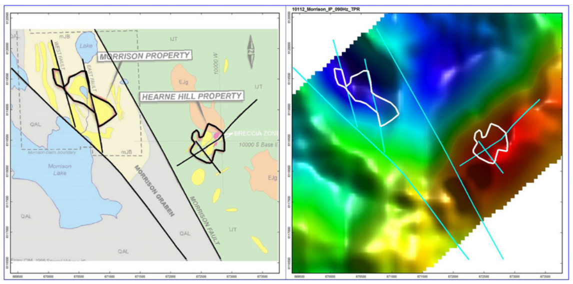

Figure 10: Geology map showing the Morrison and Hearne Hill intrusives (left) with ZTEM 90 Hz In-Phase TPR result (right).

the Morrison intrusive are better defined in the DT results and the feature that the Hearne Hill intrusive is associated with shows the Hearne to be situated within an apparent 'notch' or hole in a circular shaped DT response, whereas the TPR response lacks such detail. Figure 13 shows the AeroTEM Zoff Ch. 1 response and the ZTEM 360 Hz DT. The results show a strong degree of similarity. As with the ZTEM, the AeroTEM results show the Morrison intrusive to be of low response, bracketed by the two NW trending faults. The response of the faults is also similar but the southern-most fault in the AeroTEM appears to define a geological edge as there is an elevated response to the south of the fault whereas the ZTEM seems to show more of the edge itself. The Hearne Hill intrusive appears as being located within a ring-like high in both surveys that also appears to be open on the north side in both cases as well.

CONCLUSIONS

ZTEM results over three known porphyry copper-gold systems have been examined. In each case, the ZTEM results were showing areas of low and high conductivity as well as contacts that were identified independently via geological mapping, drilling or other geophysical surveys. At Pebble, the ZTEM showed good agreement with an overlapping Spectrem survey. While the Spectrem appeared to resolve the shallow conductivity better than ZTEM, the ZTEM appeared to show better correlation with the mineralization at depth. At Babine Lake, the main zone of mineralization termed the Nak intrusive, appears in the ZTEM as discrete resistivity high with similar dimensions to the known intrusive body. A series of linear resistivity lows defined by a resistivity survey correlate with mapped faults and show as well as clear linear highs in the ZTEM outcomes. At the Morrison property, the ZTEM showed the main Morrison intrusive as a resistivity high bounded by two faults. The near-by Herne Hill mineralization showed a quite different character with the

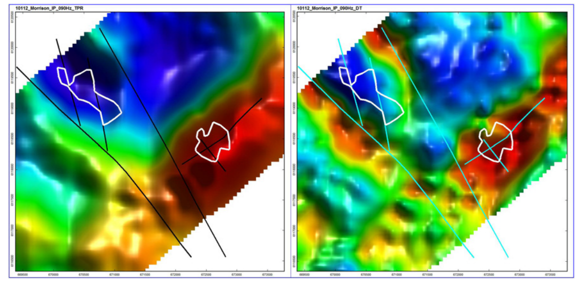

Figure 11: Zoom-in showing 90 Hz TRP (left) and DT (left) outcomes.

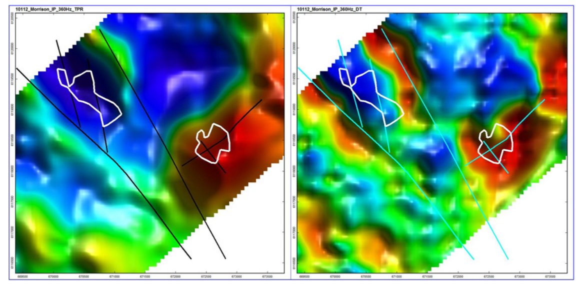

Figure 12: Zoom-in showing 360 Hz TRP (left) and DT (right) outcomes.

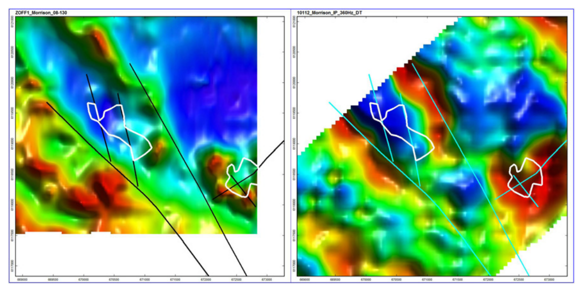

Figure 13: AeroTEM Zoff Ch. 1 (left) and ZTEM 360 Hz DT (right).

intrusive core being encircled by a ring of elevated ZTEM response. The results of an AeroTEM survey were available for part of the ZTEM block and showed quite similar character to the ZTEM outcomes.

ACKNOWLEDGMENTS

We thank Anglo American Exploration Canada, Pebble Limited Partnership, Red Tail Metals and Geotech Ltd. for providing data shown in this study.

REFERENCES

Paré, P., and J. M. Legault, 2010, Ground IP-resistivity, airborne spectrum and helicopter ZTEM survey results over Pebble copper-moly-gold porphyry deposit, Alaska: 80th Annual International Meeting, SEG, Expanded Abstracts, 1734-1738.

Rudd, J and Sterritt, V. Report on a Helicopter-Borne Magnetic and Electromagnetic Survey, Quest West, BC, by Aeroquest Surveys, January 2009 produced for Geoscience BC. Quest-West Project 2009.

Sattel, D., Witherly, K., and Becken M., 2010, A brief analysis of ZTEM data from the Forrestania test site, WA: 21st International Geophysical Conference and Exhibition, ASEG, Extended Abstracts.

Sattel, D. and Witherly, K., 2012 Extracting information from ZTEM data with 2D inversions; submitted for inclusion in 22st International Geophysical Conference and Exhibition, ASEG, Extended Abstracts.