Numerical modeling of Z-TEM (airborne AFMAG) responses to guide exploration strategies

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Summary

Mineral exploration using the Z-TEM or Z-Axis Tipper Electromagnetics, an airborne AFMAG system, has been guided by numerical modeling of the target types. Numerical modeling is used to plan the survey in terms of survey line spacing, survey height, and expected signatures of the targets. Knowing the Z-TEM response of a deposit of the type that is being explored for, aids in the interpretation of the results. Numerical modeling has demonstrated that the Z-TEM system is ideally suited for large, deep deposits of low to high resistivity contrasts such as porphyry copper and SEDEX deposits.

Introduction

Z-TEM, has been flown commercially since mid-2007. Exploration Syndicate and Geotech. have flown a number of demonstration and large commercial surveys following an exploration strategy of selecting the best area to explore based on geological models and an assessment of the suitability of the Z-TEM for the particular target type.

Z-TEM uses the natural or passive fields of the Earth as the source of transmitted energy. These natural fields are planar and due to the manner in which they propagate, are horizontal. Any vertical EM field is caused by conductivity contrasts in the Earth. The Z-TEM system measures the vertical EM field in the air along the survey lines and makes use of a base station to measure the horizontal fields. The assumption is that the horizontal fields are relatively homogenous over the survey area and the base station location. The vertical EM field is remotely referenced to the horizontal EM fields.

Numerical modeling of the Z-TEM response over deposits or representative deposits is done to gain an understanding of the expected signature from these deposits to aid in the interpretation of the data. The data is also used to help determine the acquisition parameters such as line spacing, extracted frequencies, surveying height, etc. To this end, a number of world classs deposits such as the Spence porphyry copper deposit, and the Red Dog SEDEX massive sulphide deposit were selected for numerical simulation.

Z-TEM Background

<u>Instrumentation</u>
As the Z-TEM instrumentation is relatively new, a brief description of the system and its data processing stream will be given.

Z-TEM instrumentation consists of a 7.4 metre diameter single axis air-cored airborne coil measuring the vertical component of the EM field. The airborne coil is deployed from a helicopter using a 90 metre long cable to separate the coil as much as possible from the helicopter EM noise, while still maintaining a structure that can be controlled by a skilled pilot.

The horizontal reference field is measured by a base station consisting of two, four metre square air-core coils placed orthogonal to each other. The horizontal field can be decomposed into the two orientations of the survey flight.

Figure 1 - picture of the airborne coil with the base station in the background.

The airborne coil is designed to fly horizontally at a constant speed. A minor amount of tilt is introduced when the aircraft speeds up or slows down. We assume that the vertical field measurements are not unduly affected. However, the cross coupling between the horizontal and vertical EM field caused by the coil tilt must be removed. Three GPS receivers are placed on the Z-TEM airborne coil to measure the attitude. From the attitude information, the amount of horizontal field detected by the airborne is removed.

<u>Data Processing and Presentation</u>
The raw data are recorded as time series, digitized at 2,000 Hz using a 24 bit ADC. Time synchronization between the airborne data and the base stations uses the 1 pps pulse from the GPS receiver. Figure 2 shows an example of the merged datasets and of the filtering that is performed. The top two traces are the base station coils. The third trace is of the airborne coil. Note that the motion noise is evident as a low frequency variation in the airborne coil. This is filtered away prior to the calculation of the two tippers. The direction of the event is shown in the circle.

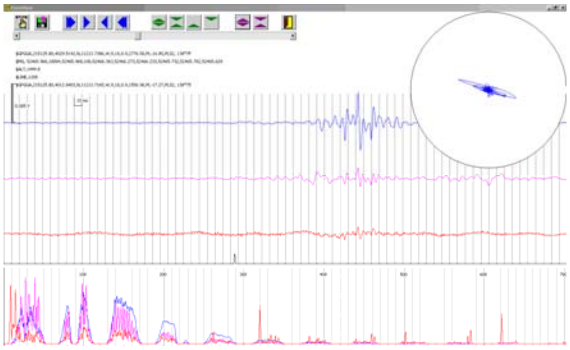

Figure 2 – an example of the merged dataset. The bottom panel show the power spectrum after digital filtering of powerline and other cultural noise.

The relationship between the vertical fields and the two horizontal fields is the tipper. The tipper is a cross-over type of anomaly over a steeply dipping body. We wish to combine the two components into one single one which is centred over the conductive anomaly – i.e. not a cross-over anomaly. In order to combine the two components and to transform the cross-overs into peaks, the data is presented in terms of the DT. The DT is defined as the divergence of tipper relations DT = div (Z/X, Z/Y) = d(Z/X)/dx+d(Z/X)/dy. The DT has a local minima over a conductive body, so we use an inverted colour bar when presenting the DT.

The divergence being a derivative, does not preserve some of the long wavelength, and thus might not convey all information about the conductor's depth and extent. Phase rotated grids (by 90 degrees) exhibit maxima over conductors and are sometimes used. They preserve longer wavelength, but have the disadvantage of favouring one direction (X or Y) only.

Numerical Simulation

Z-TEM should be suited for large deposits at depth, with or without a large resistivity contrast. Porphyries and SEDEX are the obvious target types.

Numerical modeling of simple shapes representing, say, the conductive alteration surrounding the intrusive core of a porphyry were conducted. Porphyry copper deposits are a well recognized type of large, low grade copper-gold mineral deposit. Porphyry copper deposits originate with the intrusion of porphyritic rock. The hydrothermal fluid circulation caused by the hot magma modifies the minerals in the rocks they pass through in a process called hydrothermal alteration. The metallic minerals that the intrusion and the host rocks contain can be concentrated and precipitated at various zones. The hydrothermal alteration accompanying these deposits causes changes in the physical property of the rocks. Hydrothermal alteration and sulphide deposition causes change in the resistivity of the rock. Pervasive clay minerals associated with argillic-propylitic alteration zones generate low resistivities in the 10 to 30 ohm-metre range. (Allis, 1990). The low grade core, with lower sulphide content, would have a higher resistivity as should the host rock.

Initially, the higher resistivity low grade core was not modeled. A cylinder, 2,000 m in diameter and 1,000 km tall, capped with a dome of 500 metres height of 50 ohm-m is used to represent the conductive alteration package. There is 10 metres of 10 ohm-m overburden over a conductive host of 200 ohm-m. The results from the Emigma software package are shown below.

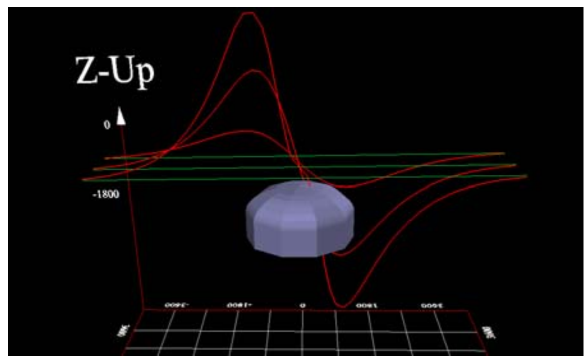

Figure 3 – perspective view of the inphase Tx Tippers over a "porphyry" feature.

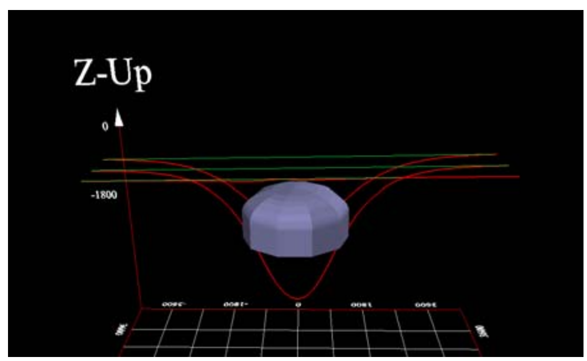

Figure 4 – perspective view of the inphase Ty Tippers over a "porphyry" feature.

The top of the dome is 100 metres below the surface. The source polarization for the model is from 0^{o} azimuth and the peak-to-peak value of the Tx ratio is 0.16 (0.08 for Ty) which above the noise floor of the instrumentation.

The results of the modeling showed that Z-TEM responded sufficiently well to relatively poorly conductive targets.

This is thought to be due to the uniform excitation of the large geological structures by the natural fields.

Demonstration Survey

Encouraged by the results of the simulation results, a demonstration survey was conducted over two know porphyries in southwestern USA. The flight lines over simplified geology is shown in Figure 5.

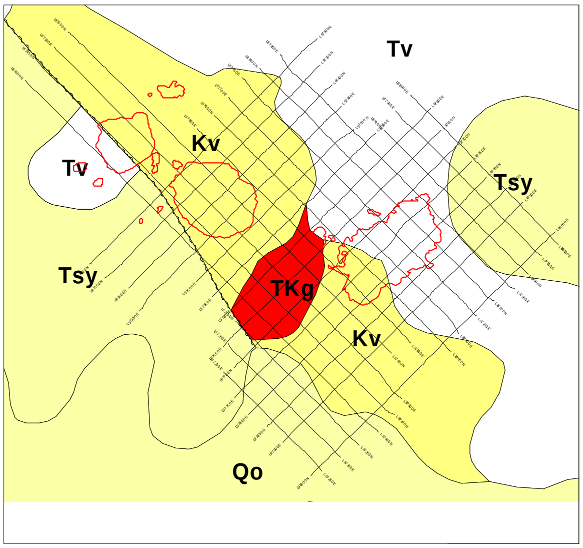

Figure 5 – simplified geology over the demonstration survey. Qo = Surficial Deposits (Holocene to mid Pleistocene), Tsy = Sedimentary Rocks (Pliocene to mid Miocene), Tv=Volcanic Rocks (Mid Miocene to Oligocene), TKg = Granitoid Rocks (Early Tertiary to Late Cretaceous), Kv = Volcanic Rocks (Late Cretaceous to early Tertiary).

Also shown in Figure 5 is the outline of the two porphyries covered by the survey.

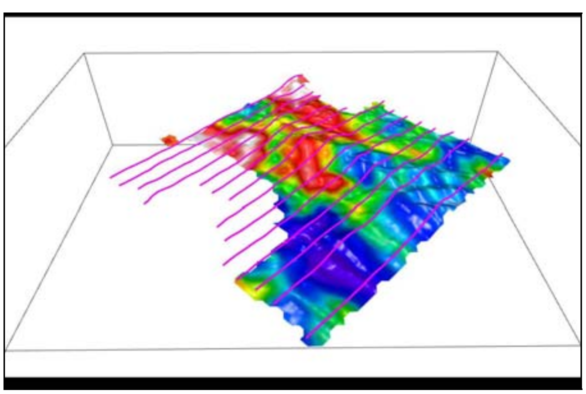

Figure 6 – perspective view of the phase rotated inphase in-line Tippers.

Figure 6 shows a perpective view of the phase rotated, in-line, 109 Hz real component of the tipper. Note that the data from the area to the southwest was contaminated by powerlines and was not useable. Only the northeast line data is presented. Note the half circular feature in the southwestern portion of the survey and the almost circular feature in the approximate middle of the survey.

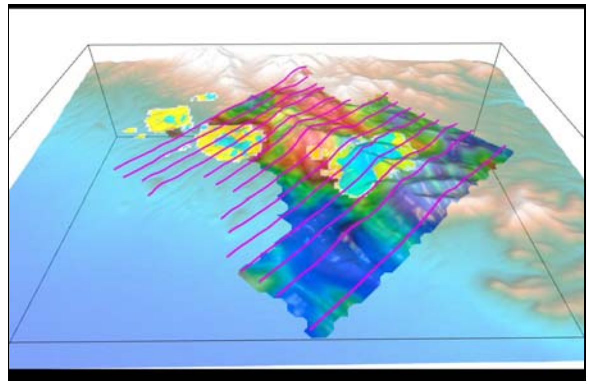

Figure 7 – perspective view of the phase rotated inphase in-line Tippers superimposed on topography and with the outlines of the porphyry mineralization and alteration (yellow) and intrusion (blue) superimposed.

Figure 7 has the outline of the alteration and mineralization of the porphyries shown in yellow, superimposed on the data. The visual correlation between the phase rotated Z-TEM highs, due to conductive features, and the outline of the alteration and mineralization is very compelling. Note that the survey results did not readily match with model results presented early. This is perhaps due to a lower erosional level of the porphyry system. Depending on the level of erosion, different alteration packages are exposed. A level or plan cut to the level below the low grade core will yield an alteration pattern in plan, that consists of annuli of different alteration. The resistivity response in this case would be an annulus of low resistivity surrounding a core of higher resistivity as more or less seen in the data.

Additional Numerical Simulation

Building on the knowledge gained, models were generated of various known world class deposits to determine the signature of these deposits so that similar targets can be recognized, to guide the exploration efforts, and to reduce the risk in exploration. Results from the Spence Deposit are shown.

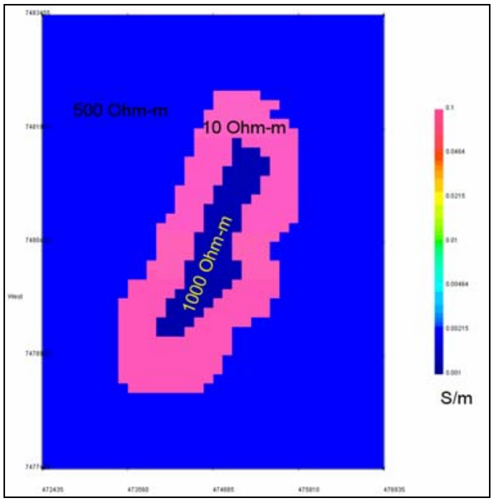

Figure 8 – plan view of the block model used for the Spence deposit.

Figure 8 shows the plan view of the block model and the resistivities used for the forward modeling. Initially, the topography was assumed to be flat and the barren core was at the surface.

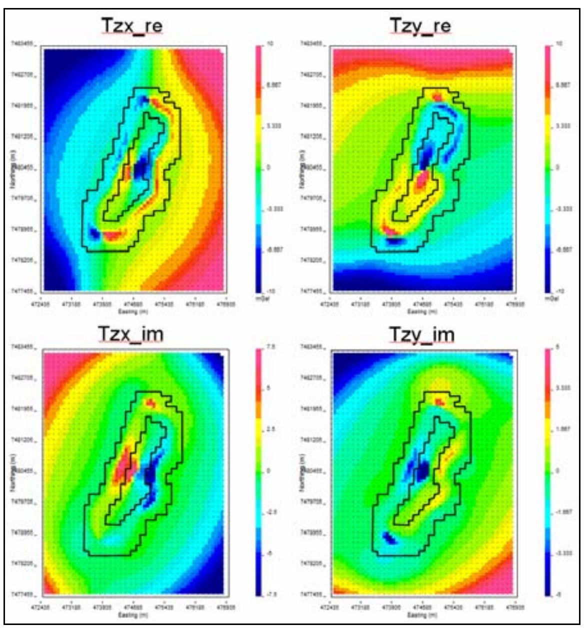

Figure 9 – plan view of the responses from the Spence deposit at 32 Hz.

The Spence model can be made more complex with the addition of topography and burying the intrusive core. A conductive response surrounding the intrusive core is seen in the model results, as expected.

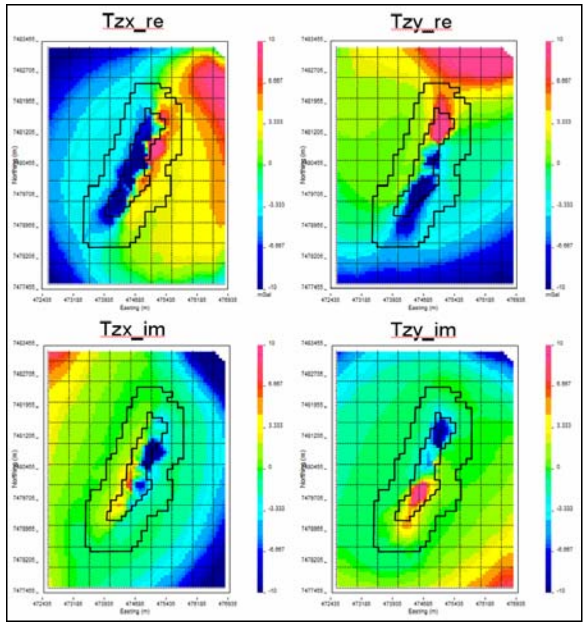

Figure 10 – plan view of the response from the Spence model incorporating topography, overburden and burying the intrusive core.

Conclusions

The ZTEM system has unambiguously detected a robust anomaly coincident with part of the large blind porphyry Cu deposit. By inference big deposits should produce big anomalies.

The optimal presentation of the data is dependant upon the interpretation purpose with geological input being critical.

Numerical modeling of Z-TEM results greatly aids the exploration process and reduces risk in geophysical exploration.

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EDITED REFERENCES

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REFERENCES

Allis, R. G., 1990, Geophysical anomalies over epithermal systems: Journal of Geochemistry Exploration, 36.

Anav, A., S. Cantarano, P. Cerruli-Irelli, and G. V. Pallotino, 1976, A correlation method for measurement of variable magnetic fields: Geoscience of Electricity, GE14, 106–114.

Kuzmin, P., B. Lo, and E. Morrison, 2005, Final report on modeling, interpretation methods and field trials of an existing prototype AFMAG system: Miscellaneous Data Release, 167, Ontario Geological Survey.

Labson, V. F., A. Becker, H. F. Morrison, and U. Conti, 1985, Geophysical exploration with audio-frequency natural magnetic fields: Geophysics, **50**, 656–664.

Strangway, D. W., C. M. Swift Jr., and R. C. Holmer, 1973, The application of audio-frequency magnetotellurics (AMT) to mineral exploration: Geophysics, **38**, 1159–1175.

Vozoff, K., 1972, The magnetotelluric method in the exploration of sedimentary basins: Geophysics, **37**, 98–141.

———1991. The magnetotelluric method: SEG.

Ward, S. H., 1959, AFMAG—Airborne and ground: Geophysics, **24**, 761–787.