MobileMT for porphyry exploration – model studies and field examples

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SUMMARY

Resistivity methods are an important part of the arsenal of geophysical techniques for the exploration of porphyry-style mineralization. One of the geophysical techniques that could be used to detect the porphyry targets, or its attributes is MobileMT, an airborne, electromagnetic system utilizing natural electromagnetic fields. We are examining and presenting capabilities of the airborne EM technology in detecting the porphyry mineralization using synthetic models and field data examples from different regions with different resistivity distribution scenarios.

Key words: airborne geophysics, porphyry mineralization, MobileMT, electromagnetics.

INTRODUCTION

Porphyry ore deposits developed in conditions of active subduction have a wide variety of types and patterns which can be shown by a geoelectrical image. There is no unifying or common geophysical model for porphyry systems since there are many factors which affect the resistivity pattern. The factors include the different host rock lithologies and compositions, the extent and degree of following specific alteration processes and fracture/faulting system development, possible superimposed infiltrations, post-ore tectonic events, depth positioning, and a current erosion level.

Regardless of the complexity of porphyry systems and related possible exploration challenges, resistivity methods are considered to be one of effective geophysical tools in exploration of porphyry prospective areas (Mitchinson et al., 2013). In particular, the airborne electromagnetic survey method is able to cover large and hard-to-rich areas in a relatively short period of time. However, an applied airborne EM system should have specific capabilities for porphyry exploration: sufficient depth of investigation, especially in conductive environment and at the presence of conductive overburden; sensitivity not only to clear conductors but also to subtle variations in broader resistivity range; detectability of geoelectrical boundaries in an arbitrary direction; reliable data over areas of rough terrains. Jansen and Cristall (2017) state that natural EM field methods achieve depth of investigation exceeding controlled-source airborne electromagnetic systems, sensitive to a wider range of resistivities, and these characteristics of natural electromagnetic field methods "change the geophysical paradigm" from an orientation towards anomalous field component to a way of visualizing entire mineral systems.

The airborne MobileMT technology, based on natural electromagnetic fields (Bagrianski et al., 2019), utilizes a three-component magnetic field sensor towed by a helicopter and a stationary electric field measurement system with two orthogonal pairs of grounded reference and signal lines. The synchronized magnetic and electric components time series data (***ExEyHxHyHz***) are processed to determine a magnetotelluric admittance tensor response, and ultimately, apparent conductivity for up to 30 frequency windows in the range 26-21,000 Hz. To evaluate the system capabilities regarding its resolution and accuracy in recovering patterns of the porphyry mineralization, we carried out multifrequency forward modeling of several known porphyry models with different geoelectrical scenarios. The test procedures included calculating the natural electromagnetic field response from the models followed by the model's non-constrained recovery from the noise-added data, and the inversion sensitivity estimation with depth. In support of the theoretical study, we present field cases of MobileMT application to porphyry targeting. Both, the modelling, and the field surveys results demonstrate the effectiveness of the MobileMT technology in detecting and discriminating porphyry mineralization systems, even in challenging geoelectric conditions.

METHOD AND RESULTS

MARE2DEM adaptive finite-element code developed at the University of California (Key and Ovall, 2011) was used for the forward and inverse modelling exercises. In addition to it, a 1D electromagnetic model implemented into the process for the depth of investigation (DOI) estimation through a sensitivity (Jacobian) matrix recalculation as described by Christiansen and Auken (2012). The nonlinear least-squares iterative 1D code, developed by N.Golubev, specifically for MobileMT data, is based on the conjugate gradient method with adaptive regularization described by Zhdanov (2002).

The forward-inverse modeling workflow included the following procedures:
- development of a simplified or fully identical geoelectrical model-section;
- response (apparent conductivity) calculation for different inherent MobileMT frequencies along a model;
- adding gaussian noise into the calculated data (~2-3%);
- non-constraint 2D inversion of the calculated+noise field based on the half-space initial model;
- non-constraint 1D inversion of the synthetic data with sensitivity-depth calculation results output;
- combining the 2D inverse and DOI estimation results.

The synthetic data of particular frequencies is recognized as sufficient if the inverted data with DOI estimations is recovering the initial model or detecting a given target, even partially.

Forward-inverse modelling results

We investigated around ten geoelectric scenarios of porphyry systems and its variations including different styles of porphyry deposits in coastal Cordillera, in Chile and Arizona, and a typical porphyry-copper system for the south-western U.S. Two of the most challenging, for airborne EM methods, geoelectrical models are presented below.

Atlántida deposit style (Chile)

The model generalized from the work of Hope and Andersson (2016), and apparent conductivity profiles with added noise, calculated from the model, are presented in Figure 1.

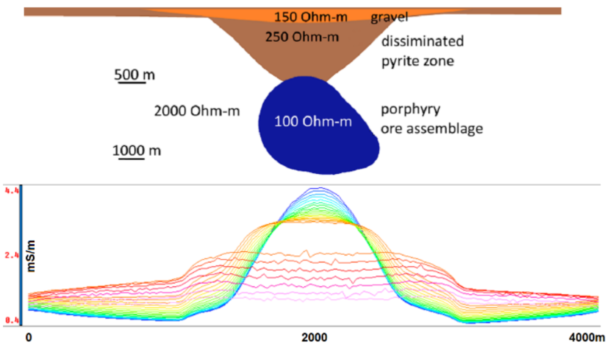

Figure 1. Geoelectrical model of the Atlántida deposit style (upper part) and apparent conductivity profiles for MobileMT frequencies (lower part) in the range of 27 Hz (blue) – 17 kHz (pink).

Figure 2 represents a resistivity-depth image from 2D inversion and Figure 3 – from 1D inversion with the line of estimated depth of investigation.

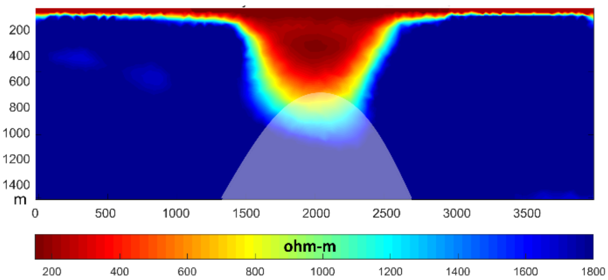

Figure 2. Resistivity-depth image from 2D inversion along the line from Figure 1. Blurred area is DOI estimation.

Estimation depth of investigation is based on the actual model output from the 1D inversion process with calculation of sensitivity (Jacobian) matrix of the final model on each measurement station, as described in the Christiansen and Auken work (2012). The 'logarithm of sensitivity-depth' section along the line in Figure 4 built up to 4000 m depth for all frequencies in relation to the nominal sensitivity = 1 on the surface. From our practical experience, depth of investigation of MobileMT data corresponds to at least -2 value of the logarithm of sensitivity. For the current estimation (blurred areas on the resistivity sections) we even used lower threshold value to be sure the DOI is not overestimated.

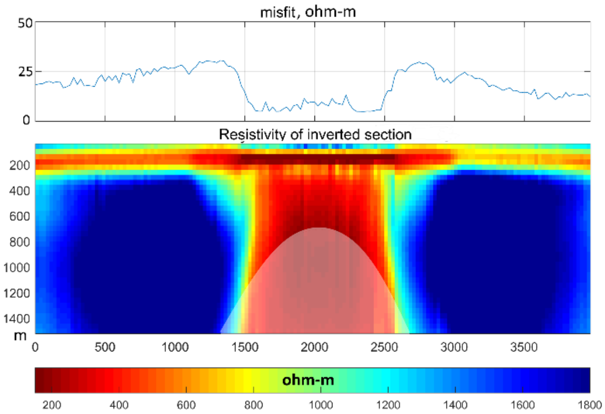

Figure 3. Resistivity-depth image from 1D inversion along the line from Figure 1. Blurred area is DOI estimation.

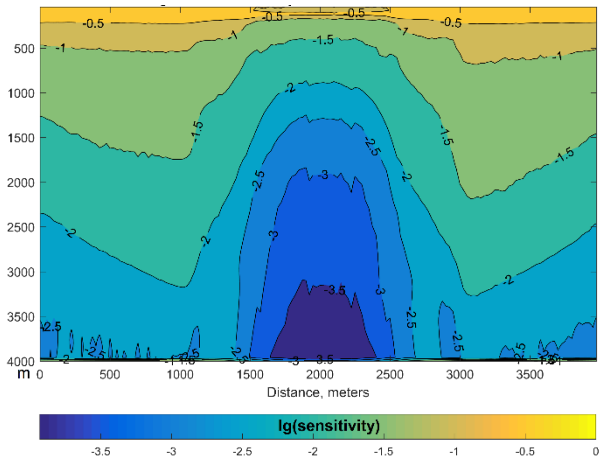

Figure 4. Sensitivity (Jacobian)-depth image from 1D inverted model along the line from Figure 1.

The forward-inverse modeling results of the Atlántida deposit shows good discrimination capabilities of the applied frequency windows in the complex assemblage of conductors.

Typical porphyry system in the SW U.S.

Another model-example is extremely challenging for most of airborne EM systems due to the thick (~150 m), conductive (20 ohm-m) overburden layer (Figure 5).

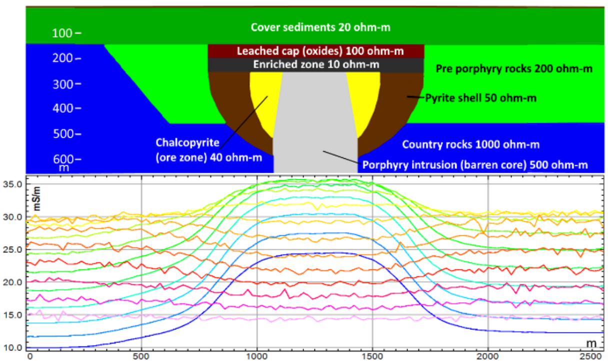

Figure 5. Geoelectrical model of the typical porphyry-copper system in the SW U.S. (from Emond et al., 2006) – upper part; and apparent conductivity profiles for MobileMT frequencies (lower part) in the range of 33 Hz (blue) – 13.6 kHz (pink).

The synthetic data is inverted in the same way as in the previous example, with a DOI estimation based on a sensitivity matrix (Figure 6). Even in the most conductive, central part of the model, specific patterns of the porphyry system are recovered under the thick conductive layer, up to 500 m depth.

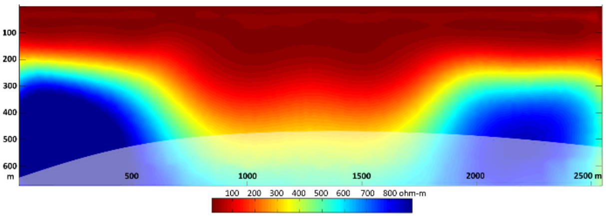

Figure 6. Resistivity-depth image from 2D inversion along the line from Figure 5. Blurred area is DOI estimation.

Field MobileMT porphyry cases

Santiago project in Ecuador

The Santiago project (the MobileMT survey was flown in 2019) is located in south-central Ecuador in the prospective district for large copper-gold porphyry targets. The MobileMT conductive anomaly (3x2 km), presented on the map in Figure 7, coincides with prospective geology, a wide-spread hydrothermal alteration footprint, and an extensive Au and Cu surficial geochemistry anomaly (Adventus, 2020).

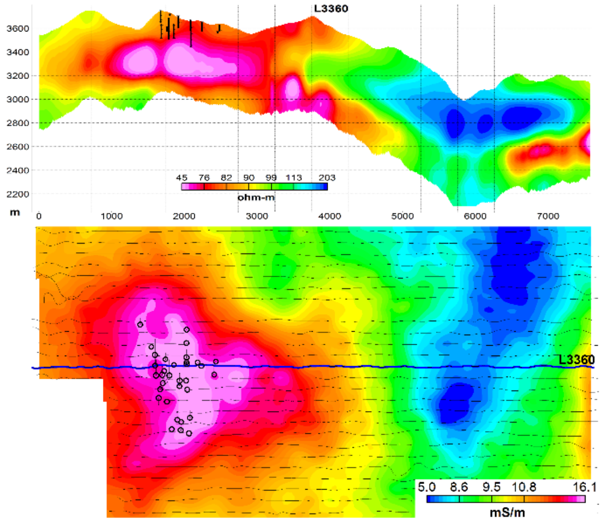

Figure 7. Upper part – Resistivity-depth image with DOI cut from the inverted MobileMT data along L3360 line; Lower – MobileMT apparent conductivity map of a part of the Santiago survey block, 106 Hz, with historical drilling positions on the map and projections on the section.

All historical drilling (in the 1970th and mid-90th) have stayed above the conductor and within more resistive rocks corresponding to the mapped quartz-alunite alteration and hydrothermal breccia. The drilling, with an average depth of 200 m (Figure 7), was targeting the coincident gold sampling anomaly and a ground IP anomaly (Adventus, 2020). A couple deep drillholes showed 0.65-0.91 % CuEq.

In general, the Santiago prospect area is a conductive environment within a narrow (approximately 40-200 ohm-m) range of resistivities. MobileMT was able to map the area within the depth of investigation from 500 m to 900 m from the surface in the rough terrain conditions.

Mt Read Cobalt project in Tasmania

Early 2019 Expert Geophysics Limited (EGL) flew a MobileMT survey for Accelerate Resources Limited over the areas of the project located on the Sorrell Peninsular in western Tasmania. Inside of the flown area there is a known Co-Cu-Au occurrence/prospect under the name of Thomas Creek previously investigated by ground dipole-dipole IP and Downhole EM. Depth to the top of the IP anomaly source was estimated 100 m below the surface. The MobileMT system also idefined the comparatively near-surface sulphide target. The sulfide body, reflected in the MobileMT resistivity image in the center of the line, is within the Thomas Creek intrusive complex followed by the magnetic anomaly (Figure 9).

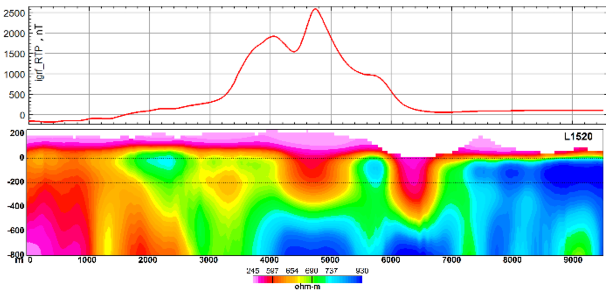

Figure 9. Resistivity-depth section from inverted MobileMT data over a line crossing the porphyry target (lower part) and magnetic field profile (upper part).

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CONCLUSIONS

Numerical methods have been used to simulate porphyry ore-systems models and their reflection in the natural electromagnetic field data. The presented forward modeling results cover two generalized porphyry systems models in a challenging spectrum of geoelectrical conditions for airborne electromagnetic methods.

Modeling results from the Atlántida deposit demonstrated the MobileMT simulated data capabilities for the discrimination of complex assemblage of conductors. The typical porphyry system in the SW U.S. showed its capability to recover patterns of the porphyry deposit given that it is under a thick conductive overburden layer.

The field MobileMT case study on the Santiago project demonstrates the technology ability to map an area in an environment with a comparatively narrow range of resistivities, and difficult mountainous conditions. The Mt Read Cobalt project shows that the airborne EM technology is capable of mapping not only deep geological structures but discrete targets in the near surface as well.

As the theoretical results and field examples show, there is high potential for the use of the natural EM field technology in porphyry mineral exploration, including those porphyry ore-systems that are deeply located or masked by challenging post-mineral cover.

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