AFMAG Evolution - Expanding Limits

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BIOGRAPHY

Andrei Bagrianski Ph.D., P.Geo., has over 35 years of professional experience in the acquisition, processing, and interpretation of airborne and ground geophysical data for a wide range of applications.
Petr Kuzmin, Ph.D., has over 40 years of experience in the development of ground and airborne TDEM, MT, and IP methods, equipment, and software.
Alexander Prikhodko, Ph.D., EMBA, P.Geo, an exploration geophysicist with decades of experience in airborne and ground geophysics over the World. The focus during the last 15 years is on airborne electromagnetic methods and the data interpretation.

SUMMARY

Nowadays mineral exploration industry requires extended abilities of technologies and processes used for new deposits discovery. To address these requirements the new airborne EM system "MobileMT" was developed which is in the field of Airborne Natural Source Audio Frequency Magnetotellurics, known as AFMAG. The new system is being designed with the goal to expand abilities and overcome limitations of previous technical solutions.

Significantly expanded bandwidth, increased number of extracted frequency windows, measurements of two components of electrical field and three components of magnetic field (total field data) resulted in the next achievements:

- inferring geo-electric structures in an absolute sense (apparent conductivity);
- expanded depth of investigation from near-surface to >1km with high resolution description;
- resolving resistivity contrasts between geological units in any direction including layered geology.

Key words: airborne geophysics, EM methods..

INTRODUCTION

The mineral and hydrocarbon exploration industry continually is extending demands for identification potential resources. The MobileMT technology pushes the limits of existing airborne EM geophysics in sensitivity, resolution, and investigation depth range. Existing electromagnetic "active" systems, such as time-domain, have known limits in sensitivity in high resistivity range differences (in thousands and tens of thousands Ohm-m). In case of comparatively conductive environment, depth of investigation of "active" systems very often fails to satisfy exploration requirements. A commercially used airborne EM system in the "passive" field domain (Legault, 2012) is limited by one vertical component of magnetic field measured in flight ("tipper" data) in 4-5 windows in two orders of frequency.

At the beginning 2018, the latest generation of passive airborne AFMAG EM technology, MobileMT (Mobile MagnetoTellurics), was introduced and generally described during SEG Natural Source EM workshop (Sattel, 2018). The system acquires data from synchronized a towed three component inductive magnetic sensor and grounded two orthogonal electric lines, one of them plays role of reference signal. The natural electromagnetic primary field sources for MobileMT are considered with frequencies ranging from 30 Hz to 20 kHz (ELF+VLF) and the secondary inductive field signal is divided on up to 30 extracted windows with the next standard but able to be customized windows centres: 26.6 33.5 42.2 53.2 67.0 84.4 106.4 134.1 168.9 212.8 268.1 337.8 425.6 536.2 675.6 851.2 1072.4 1351.2 1702.4 2144.9 2702.4 3404.8 4289.8 5404.8 6809.6 8579.6 10809.6 13619.2 17159.1 21619.1 Hz.

In order to continue evolution of the airborne electromagnetic passive fields technology and in comparison with the last AFMAG development (Bob Lo, 2009) the current development enriched by the next key characteristics:

- Expanding measured frequencies range into high end to complement deep exploration with near surface and medium depth of investigation;
- Increasing sensitivity and reducing system noise level to provide with data at low natural electromagnetic fields signal conditions especially in the range of the last hundred – first thousands Hz frequencies band where the field spectral density is lowest (dead-band);
- Providing ability to recover electrical properties differences between geological boundaries of any direction, including and between horizontal and vertical boundaries;
- Increasing spatial and frequency data resolution;
- Measuring of elements of admittance-type transfer functions of the magnetotelluric field.

METHOD AND RESULTS

Technical solution and theory

In order to improve data quality and increase its informative content we measure telluric currents induced by the natural electromagnetic fields on the ground synchronised with measuring the magnetic components of the natural audio frequency electromagnetic fields in the air and process mutually both, magnetic airborne and electric ground data (**Error! Reference source not found.**1). To obtain accurate signal of the natural field spectrum and eliminate noise spectra of sensors we use electrical field measurements at the base station. One of the reasons of choosing electrical components for reference is capacity to control the natural signal strength in the wire lines. Each electrical field component on the base station is registered independently from two sensors, signal and reference, which is utilized to eliminate the data bias distortions (Labson et al., 1985). This technical solution is critically helpful in periods of weak natural field signals in some frequency bands.

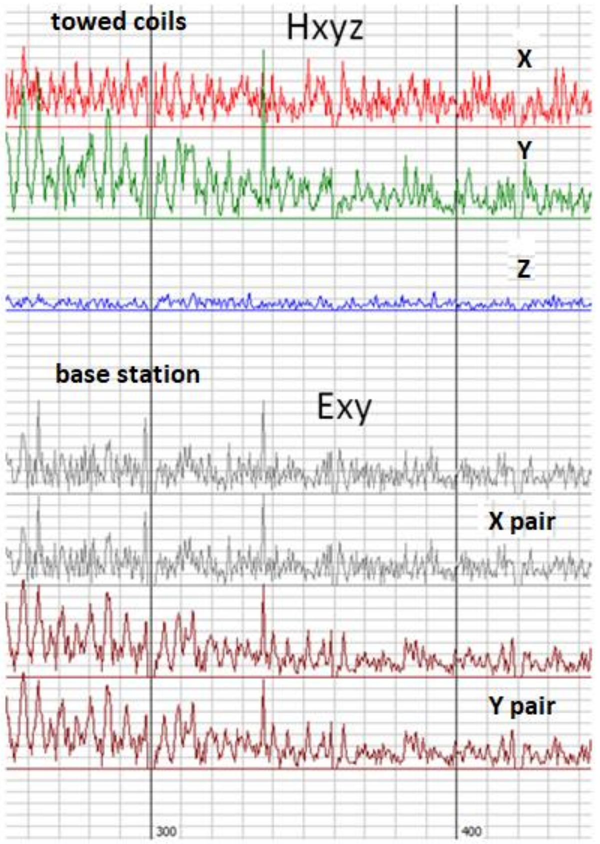

Figure 1. MobileMT data time series of Hxyz and Exy data

In general, processing of the field data is based on the Larsen and Chave robust remote-reference method (Chave et al., 1987; Larsen, 1989). The data processing program merges the stationary measured electrical two horizontal components and the moving orientation irrelevant receiver of three magnetic field components into one file. Then, FFT technique is applied to the recordings with calculation matrixes describing relations between the electric and magnetic signals (six admittances) on the different time bases and in different frequency bands. In the result of modular computation of the matrixes determinants, as rotation invariant parameters, we calculate apparent conductivity in mS/m as a parameter of MobileMT mapping. The rotation invariant parameters are free from the receiver motion distortions. The admittances (Y) are represented as the electric field horizontal vectors projection into the space of the magnetic field three components. In other words, the H+E system measures combination of tensor and scalar (rotational invariant) components. The components combination is expressed as the transfer function (in-phase and quadrature) of a total magnetic field, through the three orthogonal directions measurements of the airborne receiver, to the two orthogonal horizontal directions of electric field measured at a ground base location. Generalizing the Weiss-Parkinson relationship (Berdichevsky and Zhdanov, 1984), such as that measured three orthogonal magnetic field components (***Hxyz***) are linearly related to the horizontal electric fields measured on the ground (***Exy***, reference), with adoption it to the admittances domain (***Y***):

$$\begin{bmatrix} Hx \\ Hy \\ Hz \end{bmatrix} = \begin{bmatrix} Yxx & Yxy \\ Yyx & Yyy \\ Yzx & Yzy \end{bmatrix} \begin{bmatrix} Ex \\ Ey \end{bmatrix} \qquad (1)$$

Solutions of the equations are obtained by averaging over a number of closely spaced frequencies. The complex data spectrums are expressed in apparent conductivity (**σ**):

$$\boldsymbol{\sigma} = \mu\omega|Y^2| \qquad (2)$$

where $\boldsymbol{Y}$ is the determinant of the corresponded matrix in Equation (1); $\boldsymbol{Y^2} = \mathrm{im}(\boldsymbol{Y^2})/\mathrm{re}(\boldsymbol{Y^2})$; $\boldsymbol{\mu}$ is the magnetic permeability of free air and $\boldsymbol{\omega}$ is the angular frequency.

Field examples

The next two MobileMT field examples illustrate the technology effectiveness equally in deep and shallow investigations, and in revealing differentiation in resistive range.

Example 1. The Thomas Creek (Tasmania, Australia), high-grade copper and gold mineralization was identified in the result of follow-up soil sampling. The sulfide mineralization occurs above the 400x600m IP anomaly identified before the discovery (Figure 2), and

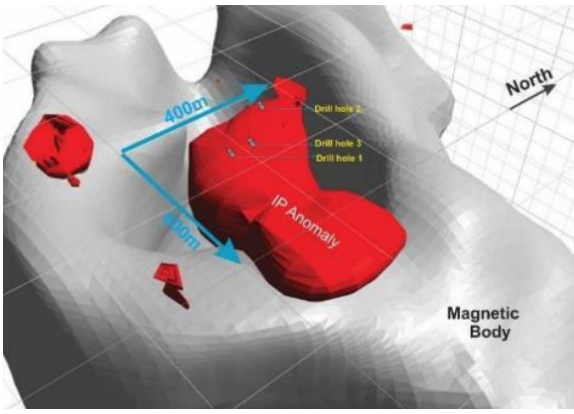

Figure 2. MobileMT data Thomas Creek – 3D Chargeable IP Anomalies with Drill Holes (Accelerate Resources, 2018).

and depth to the anomaly source is estimated 100 m below the surface (Accelerate Resources, 2018).
Figure 3 represents 3D inversion of Mobile MT data in 3D view of conductivity depth-slices (high conductivity corresponds to-warm colors).

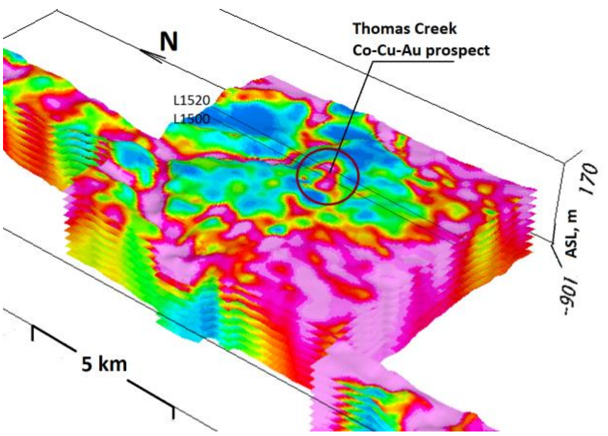

Figure 3. Conductivity-Depth slices from -50m up to -1000 m depth (MobileMT data 3D inversion, Computational Geosciences Inc.)

The conductivity sections along two of lines crossing the Thomas Creek prospect zone and the IP anomaly are presented in Figure 4**.**

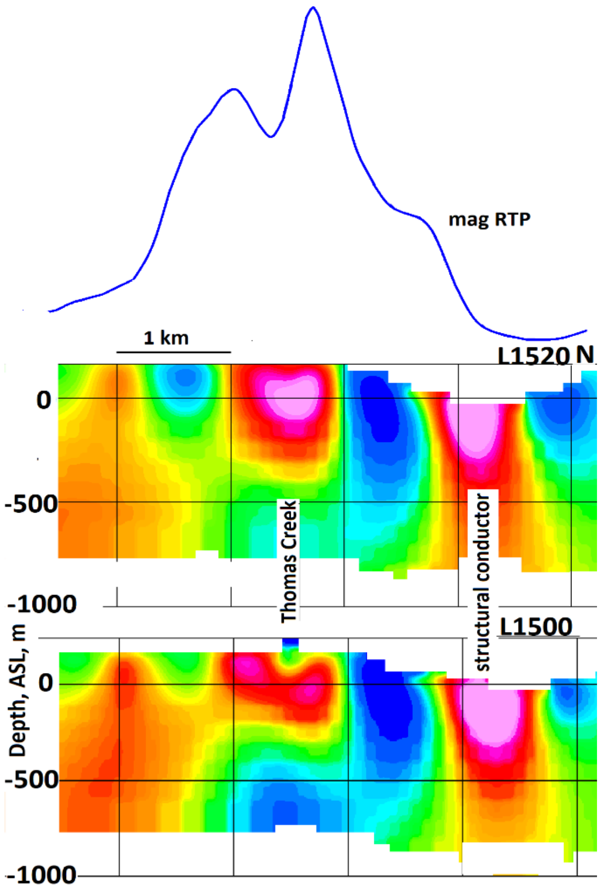

Figure 4. Conductivity sections along parts of two lines crossing the Thomas Creek prospect (from 3D inversion).

The descrete conductive zone in the survey block center with two extremums corresponds to the prospect site and correlates with a magnetic anomaly interpreted as an oval shaped dioritic intrusive complex. Simirarly to the IP anomaly, MobileMT conductive zone position is in the magnetic field depression (see magnetic field profile in Figure 4 and the "Magnetic body" in Figure 2**)**.

The Example 1 illustrates MobileMT ability to recover near surface descrete conductor with limited extension to depth.

Example 2. In August, 2018, Expert Geophysics Limited flew a MobileMT test line over the Shea Creek uranium deposits area in the western Athabasca basin, just south of the former Cluff Lake mine site.

Shea Creek deposits display full range of mineralization styles in the Athabasca basin (Rhys et.al., 2010, Figure 5):
- unconformity mineralization along the Saskatoon Lake conductor (UC);
- basement mineralization (UB) localized mainly in footwall of conductor;
- alteration plume developed above and surrounded by clay-chlorite alteration in sandstone (UP).

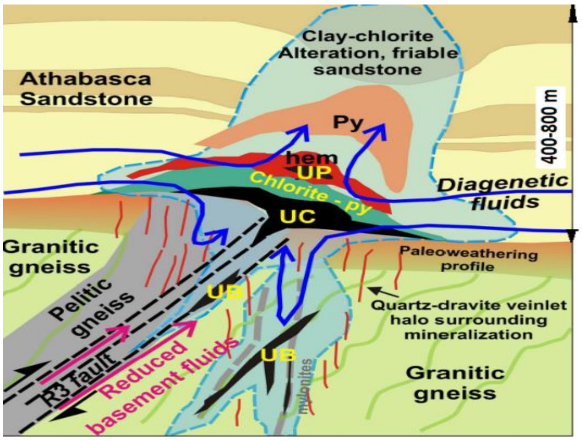

Figure 5. Typical schematic Shea Creek geological cross-section (after Rhys, 2010)

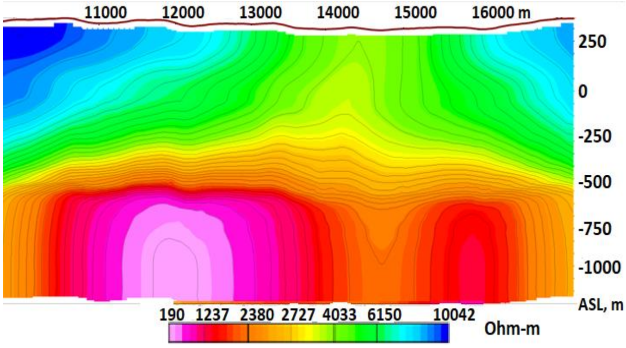

Figure 6. MobileMT resistivity section over the Shea Creek area (2D inversion).

The test line (Figure 6) is crossing the Kianna unconformity style mineralized zone in the Shea Creek area. The zone is positioned at the unconformity between the sandstone underlying crystalline basement (the pink conductive zone around ~12000 m mark along the line and at >750 m depth). The line of the unconformity geologically is marked by a paleoweathering profile (Figure 5) most likely corresponded to the horizontal high gradient of resistivity at depth 700-750 m (Figure 6). The resistivity distribution shows that MobileMT data is sensitive not only to highly conductive targets but to variations in the sandstone unit. The shape of the anomaly at the 14000-15000m marks similar to clay-chlorite alteration shown on Figure 5.

The Example 2 illustrates MobileMT ability to detect deep conductors along with comparatively weak resistivity variations in highly resistive environment in thousands Ohm-m. As our experience shows, MobileMT signal-to-noise ratio alows to detect contrasts even in the resistivity range of tens of thousand Ohm-m.

CONCLUSIONS

This paper describes further development of the airborne electromagnetic technology based on passive fields. A crucial element of the MobileMT technology is the capability of aerial acquisition magnetotelluric data in four decades frequency band with high resolution. Field data are acquired using stationary orthogonal pairs of electrical field sensors (grounded wire dipoles) and towed magnetic field detectors (three orthogonal induction coils).

The technology solutions implemented in the MobileMT system have resulted in the next main abilities:

- recovering resistivity contrast in geologic structures of any shape due to total field measurements;
- resistivity discrimination for both deep and shallow geology due to frequency broadband.

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REFERENCES

Accelerate Resources Limited Annual Report for 2018. From: http://www.ax8.com.au/site/PDF/1223_1/AnnualReporttoshareholders

Chave, A. D., Thomson, D. J., and Ander, M. E., 1987, On the Robust Estimation of Power Spectra, Coherences, and Transfer Functions: Journal of Geophysical Research, 92, 633-648.

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

Larsen, J. C., 1989, Transfer functions: smooth robust estimates by least-squares and remote reference methods: Geophysical Journal International, 99, 645-663.

Legault J.M., 2012, Ten Years Of Passive Airborne AFMAG EM Development For Mineral Exploration: presented at SEG 2012.

Lo, B., Legault J., Kuzmin P., 2009, Z-TEM (airborne AFMAG) tests over unconformity uranium deposits. Extended Abstract 20th International Geophysical Conference and Exhibition, Adelaide, South Australia.

Sattel D., 2018, A brief analysis of MobileMT data: presented at SEG 2018.

Rhys D., Sierd E., Luke van der Meer, 2010, Geology of the Shea Creek uranium deposits: an expanding uranium district in the Western Athabasca Basin: Saskatchewan Geological Survey Open House, Nov. 29, 2010.