INVERSION OF AIRBORNE DATA FOR THREE-DIMENSIONAL CONDUCTIVITY, CHARGEABILITY, AND MAGNETIC PROPERTIES MODELS IN WAWA, ONTARIO, CANADA.

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Summary

Modern airborne surveys simultaneously collect electromagnetic (EM) and total magnetic intensity (TMI) data. Three-dimensional inversion of all collected data provides important information about the geology in the survey area. In this paper, we present the results of the inversion of VTEM and TMI data collected over the Echum Project Area, 54 km ENE of Wawa in Northwestern Ontario, Canada.
We have inverted the VTEM dB/dt data into 3D conductivity and chargeability models and the TMI data into both 3D magnetic susceptibility and 3D magnetization vector (remanent magnetization) models. Obtaining multiple 3D physical properties models from a single airborne geophysical survey maximizes the data value and provides more intuitive interpretation than using data maps and other transformed products. Several drilling targets were developed based on the results of this 3D interpretation.

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Introduction

Modern airborne surveys simultaneously collect electromagnetic (EM) and total magnetic intensity (TMI) data. Three-dimensional inversion of all collected data provides important information about the geology in the survey area. In this paper, we present the results of the inversion of VTEM and TMI data collected over the Echum Project Area, 54 km ENE of Wawa in Northwestern Ontario, Canada.

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Airborne Data Collection and Geological Background of the Survey Area

The survey area is located in the southeastern part of the Wawa Greenstone Belt, which consists of early 2.89- to 2.70-billion-year-old, Precambrian rock extending inland from the northeastern margin of Lake Superior and terminating along the western contact of the Kapuskasing Horst structural zone of migmatized rock. In the area of study, this metavolcanic – metasedimentary belt is intruded by stocks of mafic to ultramafic bodies of different ages. Gold, silver, zinc, copper and iron mineralization are the common associated metallic occurrences found in the belt. Recently diamondiferous kimberlite and lamprophyre rocks have been recognized in the southeastern part of the Wawa Greenstone belt (Cullen and Clark, 2017).

The airborne survey was flown February of 2021. The survey employed the Geotech Time Domain EM (VTEM™ Plus) full receiver-waveform streamed data recorded system. The transmitter-receiver loop had an average terrain clearance of 64 meters and the magnetic sensor at 74 meters. The full waveform VTEM system uses the streamed half-cycle recording of transmitter and receiver waveforms to obtain a complete system response calibration throughout the entire survey flight. A horizontal loop transmitter produced an approximate vertical magnetic dipole for the source fields. The measured fields were vertical and inline dB/dt fields. Forty-three time measurement gates were archived by Geotech in the database in the range from 0.021 to 8.083 msec.

Modeling and Inversion of VTEM Data: Conductivity and Chargeability

We have developed a variety of one-dimensional (1D) and three-dimensional (3D) techniques to process the data and construct the best final conductivity model. In our standard workflow, 1D inversion is used to QC the data and create an approximate background model, plate modeling is used to further QC and understand the data with appropriate targets, and then full 3D inversion is used for final, higher accuracy inversion runs. One-dimensional inversion is typically faster than 3D inversion and can create accurate models where horizontally layered formation can well approximate the earth. The 1D approximation is used to speed up calculations under the assumption that the earth layers extend to infinity horizontally under every position of the airborne system. Each transmitter-receiver position, or sounding location, has a 1D earth under it which is recovered during inversion. The 1D pseudo sections are then gridded into a 3D model to create a more realistic earth image, but the modeling and physics do not accurately represent the real 3D geology. In this case, only the Z (vertical) component can be used because a 1D earth does not create an electromagnetic field in the X (inline) direction with a coincident system like VTEM. Hence, with 1D inversion, half the data must be ignored. This is the half portion of the data that responds best to lateral variations in conductivity and could produce high-resolution images.

In contrast, 3D inversion considers all the subsurface geometry and can use both X and Z components of the data. The recovered 3D models are thus much more accurate, especially in areas that have complex geometry and geology. However, this requires the development and application of much more complex algorithms. A detailed description of the advanced 3D modeling and inversion methods for interpretation of AEM data can be found in several publications (e.g., Cox and Zhdanov, 2007, 2008; Cox et al., 2015; Zhdanov, 2018).

In addition, the developed inversion algorithms consider both the EM induction and induced polarization (IP) effects within the unified inversion process. The IP modeling is based on the generalized effective-medium theory of the IP effect (GEMTIP) introduced in Zhdanov (2008, 2018). As a result, the airborne EM survey provided conductivity, chargeability, and time constant recovered during inversion using the GEMTIP model.

TMI Inversion: Susceptibility and Remanence

In mineral exploration, magnetic data have traditionally been inverted to produce magnetic susceptibility models, representing magnetization induced by the current magnetic field. This does not take into account the remanent magnetization of the rocks produced by the ancient magnetic field. More information about rock formations and geological processes can be obtained by inverting magnetic data for magnetization vector instead of magnetic susceptibility only. Please refer to Jorgensen and Zhdanov (2021) for more technical details.

A second-degree polynomial was used to filter the data quickly and remove regional trends. No other processing was required. The 3D inversion was run using a homogeneous half-space as the reference and initial model. The stabilizing constraint (stabilizer) used to ensure a robust inversion was the minimum norm of the departure of the model parameters from the reference model and the first derivative in the horizontal and vertical directions (Zhdanov, 2015).

VTEM Conductivity Results

Figure 1 presents a slice of the recovered 3D conductivity model at a depth of 100 m below the surface. The image shows conductive and resistive lineaments running roughly northwest to southeast. Some mild line stripping is also apparent in the figures, especially in the northwest. The most obvious feature in the data is the MPD Zinc Copper showing (strong conductor in the western 1/3). This target is shown in detail in Figure 2.

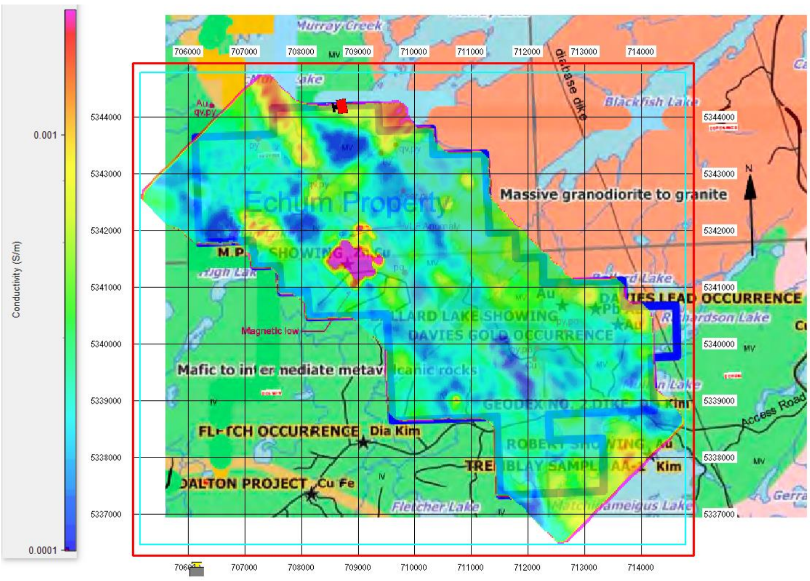

Figure 1. Conductivity inversion results on a compressed color scale to bring out details at a depth of 100 m below the surface. Trends in the conductivity can be clearly seen, which relate to geology.

Chargeability Inversion Results

The airborne EM data were also inverted for chargeability distribution based on GEMTIP model. Figure 3 shows a horizontal slice from the 3D airborne derived chargeability at a depth of 150 m below the surface. As is common with AEM chargeability measurements, much of the chargeability corresponds to lake bottom sediments, but areas such as around 711500 mE and 5341000 mN show chargeability that is not associated with a lake and is at the intersection of major structures, which makes it a good exploration target.

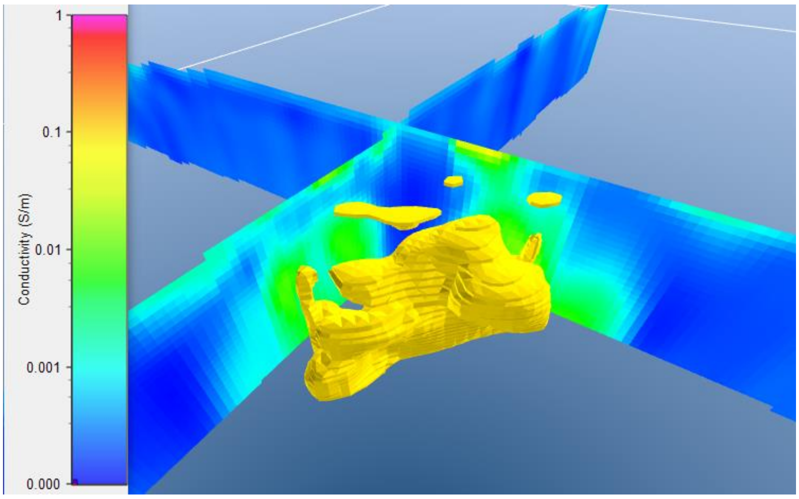

Figure 2. Detail of conductor at MPD Zinc-Copper mineralization looking northeast. The isosurface (in yellow) is shown at 0.1 S/m. The body is about 600 m in length and 100 m below the surface. The full section depth extent is about 500 m. There is no vertical exaggeration. Running the final 3D inversion with a high contrast FE solution enables maximum value to be extracted from the data.

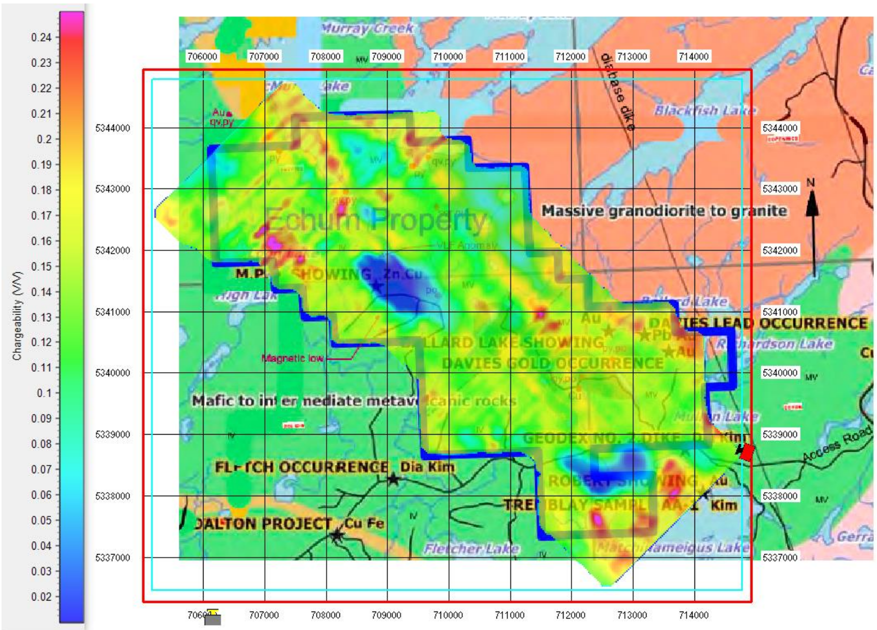

Figure 3. Chargeability inversion results at a depth of 150 m below the surface.

TMI Inversion Results

The TMI data were inverted to both susceptibility and magnetic vector models using the Gramian method (Jorgensen and Zhdanov, 2021). The susceptibility model is a standard product but cannot consider remanent magnetization. The magnetic vector model considers both susceptibility and remanent magnetization and is the preferred product to study. Figure 4 shows an isosurface view of the Z component of the magnetic vector looking southeast. The red body is the MPD body showing conductivities greater than 0.1 S/m. The yellow bodies are magnetic showing values greater than 0.004 A/m. The yellow body in the foreground is a possible kimberlite.

Conclusions

Full 3D inversion of the airborne EM and TMI data increases the effectiveness of airborne geophysical methods in mineral exploration. We have demonstrated that the results of these inversions correlate well with the known geology in the area. Several examples of potential targets have been suggested based on our understanding of the area, and an abbreviated summary is listed below:

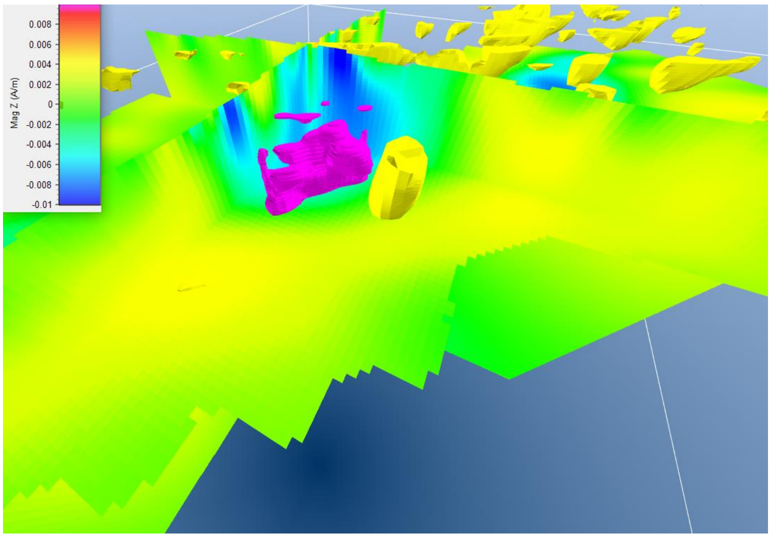

Figure 4. An isosurface view of the Z component of the magnetic vector looking southeast.

- Detailed 3D conductivity model of the VTEM data covering the MPD Zinc-Copper mineralization outlining a zone of the order of 600 m in length and 100m below surface. At least one other weaker and smaller but very similar conductor was defined to the southeast.
- We have identified chargeability anomalies from airborne EM data that warrant further investigation for gold and disseminated sulfide mineralization.
- There is an excellent correlation of the vertical component of the magnetization vector with copper, pyrite and pyrrhotite mineralization and similar responses in a favorable geological setting.

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