Finding Geology Structures in Depth Sections from Airborne Geophysics: Automatic workflows

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SUMMARY

The explosion in new airborne electro-magnetic surveys is creating the need for less cutting of corners, better honouring of the known physics in the algorithms, proper use of all the system monitors.

The importance of a “good” starting model in a deterministic, iterative, non-linear inversion, such as that provided by the 2.5D Moksha code, has been recognised for many years.

This study touch bases on two project scale examples that collected by the same aircraft. Clearly in the context of an emerging continent wide AEM campaign to acquire prospective surveys the implications fort these developments are critical, in that these tools can also manage complete surveys, no matter what line length are involved. This concentration of predicting geology structures in depth sections has demonstrated the ability to identify possible exploration targets and map steeply dipping and folded geology in a deformed terrane. Equally important is then to create workflows and visualization toolkits to help interpreters, no matter what scale, or which aspect of geology or rock properties they wish to interrogate.

The lase-fare situation of accepting sub-optimal methods for estimating potential field gradients has plagued, and held back, the successful use of potential field geophysics for too many years now. Almost all interpretation methods are based upon estimating these gradients.

Key words: airborne electromagnetic, inversion, targeting, prospective survey.

INTRODUCTION

Significant breakthroughs are made by not cutting corners. 2.5D Inversion (FWI, 2D-geology, 3D-sources) formulations of Maxwell’s equations leads to inversion of airborne electromagnetic (AEM) data.

Our approach with the Moksha application:

1. Links solving Maxwell’s equations numerically.
2. Takes into account all of the measured secondary components (X, Y & Z)
3. Uses an adaptive noise estimation.
4. Considers topography.
5. Allows prior geology models, as well as a resistive half space as a starting model.
6. Automatically optimises the formation of the system of global equations, formulated in the complex frequency domain.
7. Is based upon a forward model algorithm for the above, that also can include both Induced Polarization and SPM.

Unlike 1D inversion methods, there is no need for applying a late time smoothing filter or using a sample-to-sample averaging process. The vertical plane approximation used in Moksha, is the canvas on which an adaptive 2D finite element mesh, is created.

All of this is hosted in a common earth 3D geology workbench environment. The setup for any survey, involves creating a system file, and a Wizard multi-panel visualization set of tools, to examine all aspects of the survey data, including decay curves, and aides for leading the operators to what part of the signal is consistent, and what part drops into the noise floor.

This has evolved (hundreds of surveys) into an established practice on any/all AEM datasets This is, hosted in the GeoModeller workbench to collate and create direct interpretation sections in their 3D context. This also includes an evolving API, based upon the GOOGLE protobuf messaging technology, that leads to optimization, audit trails, re-usable workflows, partitioning parts of the process across a set of complimentary tools, that can be deployed, via the Docker packaging, on any modern hardware (Except Fujitsu).

A second breakthrough applies to aeromagnetic datasets. Well known, but ignored till now, Cauchy derivative by integration theory stabilises the field measurements. In the last 12 months, extensive R&D and calibration work has been undertaken to verify the application of this theory to exploration geophysics datasets. This allows for higher order gradients to be computed that remain coherent, up to order 7 or better. Downwards continuation follows, allowing the creation of depth sections. Given a second high resolution depth section, the established ideas about joint inversion involving magnetics and AEM are being questioned.

The Dugald River case study, (North Queensland) demonstrates the ability of 2.5D AEM Inversion to image steeply dipping and folded geology. Simultaneously Aeromagnetic data collected in the same survey, is used to show the magnetic field projected far below the surface, also imaging some of the same, but also other aspects of the geology.

METHOD AND RESULTS

Merging the disciplines of AEM, TMI geophysics and 3D structural geology continues to challenge software engineering. Full geophysical survey data, structural geology field data and processed and inverted depth sections are to be rapidly linked, created model space and rendered in a 3D context. The support of the implicit volume, potential field-based calculation engine used in GeoModeller, gives added influence on any gradients derived from the geophysics (Guillen et.al., 2008)

The new demonstrated workflow automatically takes any airborne observed dataset and creates a 3D project and then best fit vertical sections on a line-by-line basis. Not only AEM but TMI, Falcon, gravity, all make use of this automation.

- TMI downward continued
- EM_X & EM_Z, FWI processed,

Case Study: Dugald River VTEM Survey

In 2017 Geoscience Australia contracted Geotech to acquire approximately 15,000 line-km of VTEM Airborne EM data in Mt Isa district, Queensland. The subset of these regional survey flight lines, covering the Dugald River geological syncline are shown in Figure 1.

It is a historic and present-day mining district and also includes the Lady Loretta strata bound Zn Pb Ag deposit, and the Mount Oxide and Capricorn (Mount Gordon) fault-bound breccia and replacement copper deposits (Hutton and Wilson, 1985).

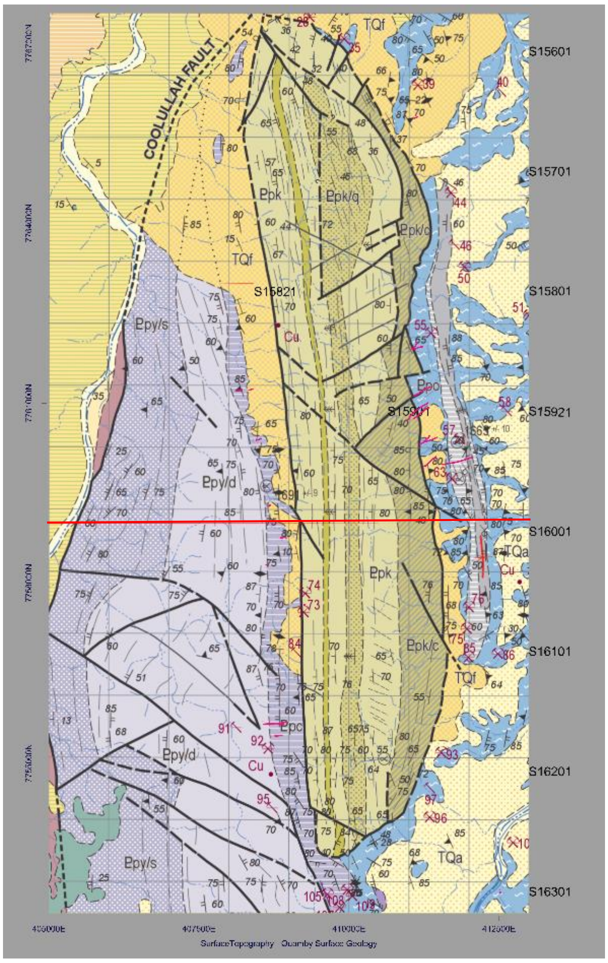

Figure 1. Dugald River area showing the Airborne EM VTEM Plus survey lines overlain. Data acquired by Geoscience Australia in 2017

Inversion result is presented for line number 16101 in Figure 1. The Moksha FWI take account of variable receiver-transmitter geometry and make use of the recorded receiver pitch channel as well as the vertical, along line and across line transmitter-receiver separation. (Silic et al, 2018, Paterson, 2020, FitzGerald et al, 2018)

Once completed, a process of presentation of the inversion results as sections in the 3D common earth geology model for the prospect are shown in Figure 2. A section is created for each survey line and then used to show each AEM geoelectric prediction, as well as the new style TMI downwards continued sections.

In this part of Australia, there is a conductive regolith, which hampers the ability to penetrate much below 400m. Compare this with areas in Canada and Europe, where depths greater than 1000m are more routinely achieved.

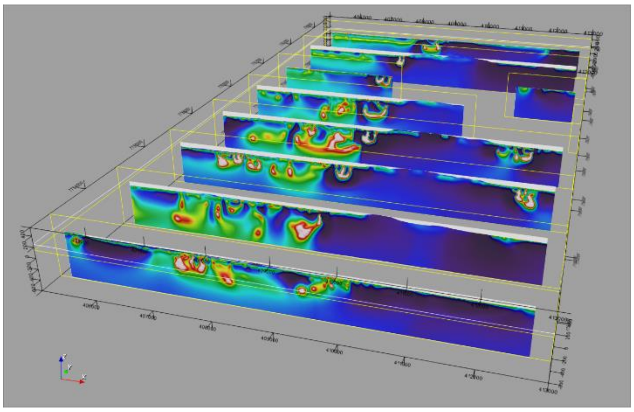

Figure 2. Dugald River Full Waveform inversion for the Log Conductivity property (units: mS/m) shown in a 3D Perspective.

For comparison, a 1D inversion was also performed on the same line. The results for Line 16101 are shown on Figure 3 along with the near-coincident geological cross section.

The FWI, using all the measured components of the B field decays, improves the definition of steep conductors, and produces a much cleaner section geometry at greater depths through the higher sensitivity of a joint inversion using both X and Z components. The adaptive noise model strategy also allows for final fine details to be teased out at depth.

Downward Continuation Method applied to Dugald River Case Study

Figure 4 shows the TMI DC responses for the same airborne survey line. The results are showing some detail that AEM does not see, some thin deeper dipoles to the west. In the location of the known synclines, the black shales may well be remnant, as positive/negative responses can be brought out via image enhancements on the limbs.

Relatively shallow positive susceptibility contrast with a polarity flip at depth (~250m asl). The plane on which the change from positive (red) to negative (blue) may be interpreted as the lower extent of the source, so we suggest this is a relatively high susceptibility body, compact in the lateral and vertical dimensions. The bottom of the source is roughly coincident with the conductive body imaged on the EM inversion.

Interpreted as sub-vertical positive susceptibility source with considerable depth extent (i.e. no change in polarity at depth). This feature aligns with the dipping eastern edge of the highly conductive EM response.

Similar in character to Feature 1, except the shallow low suggests a negative susceptibility contrast with a polarity flip to positive at depth (~250m asl). The plane on which the change from negative (blue) to positive (red) may be interpreted as the lower extent of the source. We interpret this as a relatively low susceptibility body, compact in the lateral and vertical dimensions. The bottom of is slightly offset from the eastern edge of the conductive body imaged on the EM inversion.

Figure 5 shows both the TMI and Log Conductivity sections properly co-registered. It indicates the synclines, and the more resistive quartz rocks. The TMI downward continued results show similar, and also different aspects of the geology. The dipole anomaly responses in the magnetics, are not just reflecting the inducing field, but also responding to the geometry and remanence of the black shales.

Signal enhancements are a critical enabler for the non-specialist to grasp the implied geological context. For AEM, the property shown is the electrical conductivity rock property, so units of microSeimens, while then taking its log. The dynamic range is usually 0 to 3. For the TMI work, the signal remains magnetic intensity, so the units are nano-Teslas. What is shown, derives from histogram stretching and a pseudo-colour lookup. However, a cube root is also an appropriate enhancement, as both positive and negative numbers are involved.

CONCLUSIONS

While this case study is at a relatively small scale, it still effectively shows the contrasts between the AEM/**FWI** results compared to the TMI/Cauchy Downward Continuation results. The depth sections that directly reflect structures that show Hot-Spots, folds, faults, in a way that a geologist can directly appreciate, and also test by drilling, is a major improvement and cost saver.

In the near surface conductive terrain of North Queensland, FWI still manages to see through cover and estimate both depth, geology gradients and geometry.
This collection of predicting geology structures in depth sections has demonstrated the ability to identify possible exploration targets and map steeply-dipping and folded geology in a deformed terrane. Equally important is then to create workflows and visualization toolkits to help interpreters, no matter what scale, or which aspect of geology or rock properties you wish to interrogate.

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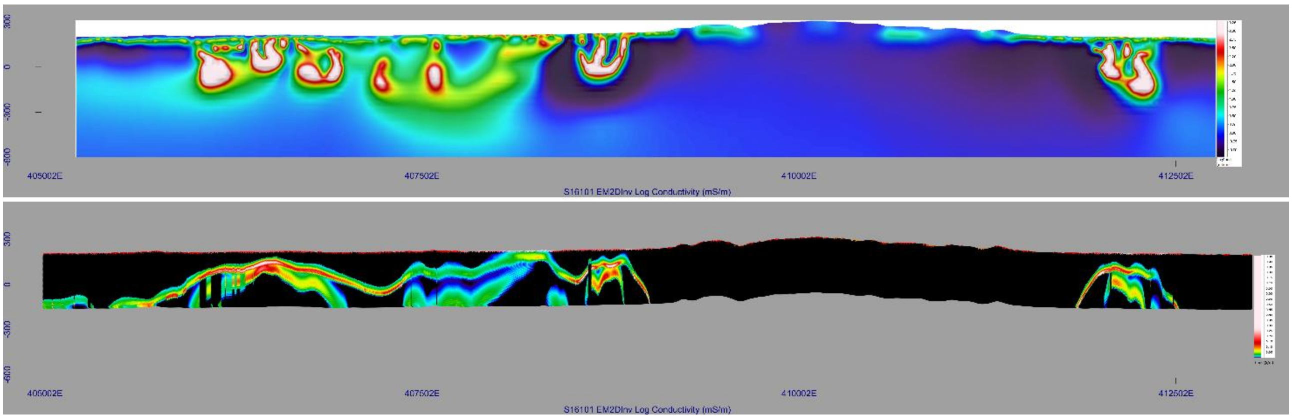

Figure 3. Dugald River Full Waveform inversion and CDI results for Line 16101 in 900m depth level.

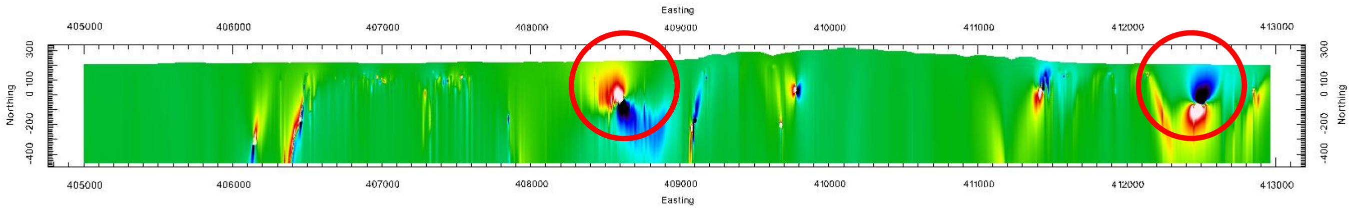

Figure 4. Dugald River Downward Continuation Dipoles, line 16101

a

b

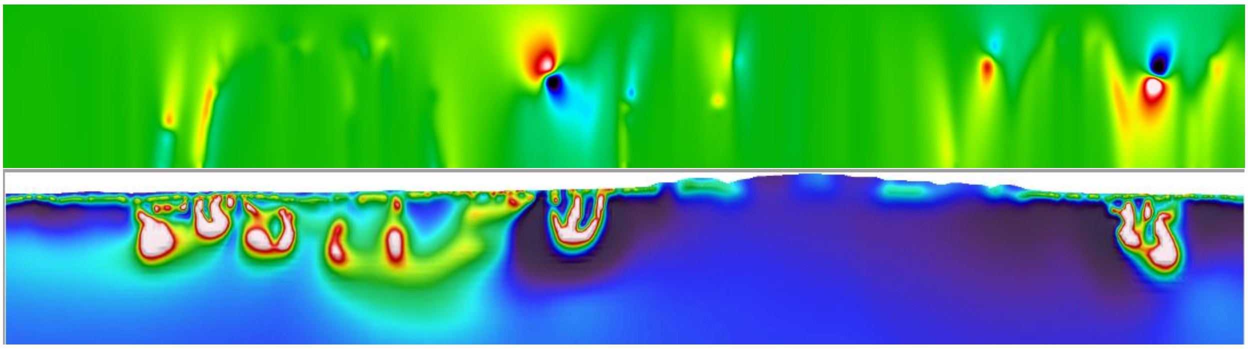

Figure 5. Dugald River a) Downward Continuation and b) Airborne VTEM 2.5D Inversion results