Comparison of Fixed-Wing Airborne Electromagnetic 1D Inversion Methods

FUGRO AIRBORNE SURVEYS

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ABSTRACT

One-dimensional transformation and inversion techniques have been applied to GEOTEM airborne electromagnetic data collected over the Reid-Mahaffy test site. Results from a conductivity-depth transform (CDT), Zohdy's method, and a layered-earth inversion (AIRBEO) are compared. Different results are obtained and can be only validated using geological information. Experimentation with the AIRBEO program showed that the results varied depending on the initial guess. The section with the best mathematical fit was inconsistent with the known geology.

INTRODUCTION

Different methods are available to invert Time-Domain Airborne Electromagnetic (TDAEM) data to a layered earth (1D) model. Generally these methods are best suited for quasi-layered structures in a conductive environment. It is common practice to apply 1D methods to synthesize TDAEM data even when the geology is not 1D, although this approach has limitations (Ellis, 1998). Furthermore, the 1D results can be incorporated in a 2D inversion scheme as shown by Christensen and Wolfgram (2006).

In order to analyse the strengths and limitations of three different methods, we applied the inversion techniques to TDAEM data collected over the Reid Mahaffy test site. The TDAEM data are 90 Hz GEOTEM data collected in 2006 as part of a test survey over the Reid Mahaffy test site, which has been used regularly since 1999 to calibrate and compare geophysical instruments (Witherly et al., 2004). The geology at this site consists of a conductive overburden of variable thickness between 17 m and 60 m (ascertained from drill information). The bedrock is comprised of resistive volcanic rock and a number of generally vertical conductive structures.

1D INVERSION

In this study, we compared the following techniques for inverting TDAEM data: conductivity-depth transform (CDT) (Wolfgram and Karlik, 1995) and Zohdy's method (Sattel, 2005) using Fugro proprietary programs and layered-earth inversion using the AIRBEO program from CSIRO.

CDT

The Conductivity-depth transform (CDT) is a technique developed by Wolfgram and Karlik (1995) to image GEOTEM time-domain data using a 1D model. Figure 1 shows the application of the technique on the B-field data of line 15. The technique images a conductive superficial layer over a resistive basement. The thickness of this layer is consistent with the drill information. A local conductor is imaged at Northing 5403300 at a depth greater than 200m. This conductor has been intersected by a drill hole at 120 m depth below 50 m of overburden and interpreted to be a vertical plate-like structure (Smith and Lee, 2002).

Zohdy's method

The Zohdy's method has been modified by Sattel (2005) to image the subsurface based on an apparent conductivity derived from the step response decay curve. We transformed the GEOTEM data into step response in order to apply this method. The results for line 15 are presented in Figure 2. Like the CDT, this method images a conductive superficial layer of approximately constant thickness. The thickness is deeper than estimated from the CDT and slightly greater than might be inferred from the drill information. The deep vertical bedrock conductor at 5403300N is not imaged well. There is a deep and extensive conductive layer of depth varying between 150 and 400 m depth. There is no geological evidence for such a feature.

One of the weaknesses of the CDT and Zohdy methods is that the results cannot be constrained to lie within a specific range or to consist of a specified number of layers.

Layered-earth inversion with AIRBEO

The AIRBEO program from CSIRO (Raiche, 1998; Chen and Raiche, 1998) allows the inversion of GEOTEM data based on a layered-earth model in which various constraints can be included. The simplest model is a half-space, the results for which are displayed in Figure 3 for line 15. This model is not consistent with the known geology at Reid Mahaffy. A two-layer model is a more plausible model, and for this reason, the inversion for a two-layer was explored and the results are presented on Figure 4. Based on the expected resistive volcanic rocks, we simplify the two-layer inversion by fixing the conductivity of the basement at 1 mS/m. The results are shown in Figure 5. Both cases show a conductive overburden with a thickness consistent with the drill information. There is no strong or obvious indication of a bedrock conductor. In Figure 6, we compare the percent symmetric error (PSE), that is a measure of goodness-of-fit of the inversion, for the different models presented in Figures 3 to 5. PSE is smaller for the two-layer models than for the half-space. It is similar for both two-layer models, but sometimes better for the model with a fixed basement conductivity.

We also investigated the possibility of a three-layer model to explain the observed data. As we discovered in a number of different attempts, the three-layer inversion is very sensitive to the initial model. We illustrate the problem by showing the results from two inversions with different initial models. In the two cases, the initial guess for the two top-layers are the same: a 50 m layer of 10 mS/m over a 50 m layer of 1 mS/m. In the first case shown in Figure 7, the basement is 0.1 mS/m. In the second case presented in Figure 8, the basement is 1.0 S/m. The results are very different. The mathematical fit to the data (PSE), shown in Figure 9, indicates that the model with the initial conductive basement has the best fits. However; for this model the overburden thickness is inconsistent with the drill information. Also there is no geological indication of a conductive basement. In none of the results from any of the three-layer models we attempted was there a strong indication of the bedrock conductor.

CONCLUSIONS

The results obtained using the different techniques explored in this study showed some similarities and some differences. Except for the half-space model, all techniques image a conductive layer at surface. The thickness of this layer varies with each method, being very thin on the CDT section and thicker on the AIRBEO and Zohdy sections. Its thickness is approximately constant along the profile on the Zohdy and CDT sections. The Zohdy images a second conductive layer at depth. A three-layer inversion can also recover a conductive layer at depth, for a specific initial guess.

The CDT method provides a section that shows a relatively uniform overburden layer consistent with the drilling (which indicates an overburden of 50 m at 5403300N) and a reasonable indication of the bedrock conductor (at too great a depth, attributed to the fact that the CDT is based on an horizontal model and the conductor is a vertical feature). The Zohdy also shows the overburden as a relatively uniform layer, albeit a little thick. There is no indication of the bedrock conductor. Neither the CDT nor Zohdy algorithms allow us to constrain the number of model layers or their properties.

The AIRBEO inversion technique does allow the model to be constrained. However, the results obtained depend strongly on the number of layers and the initial guess. The best section for imaging the variability of the overburden thickness is the two layer case with the bedrock conductivity fixed. None of the AIRBEO inversions were able to image the bedrock conductor; however, this is consistent with Ellis' (1998) observation that stitched 1D inversions do not image more complicated structure well.

Our experience is that good results can be obtained with layered earth inversions, but that good knowledge of the geology is required to guide or constrain the inversion. A good mathematical fit is not necessarily a good indication of the correct geology.

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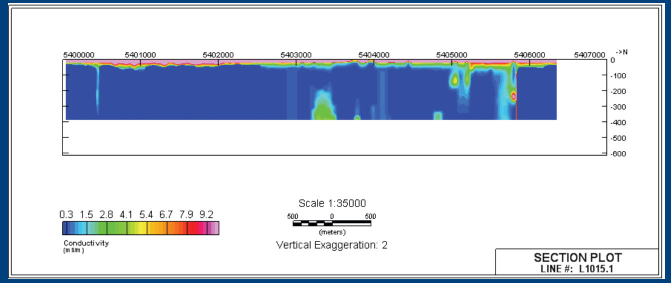

Figure 1: Conductivity-depth transform of B-field GEOTEM data for Reid-Mahaffy line 15.

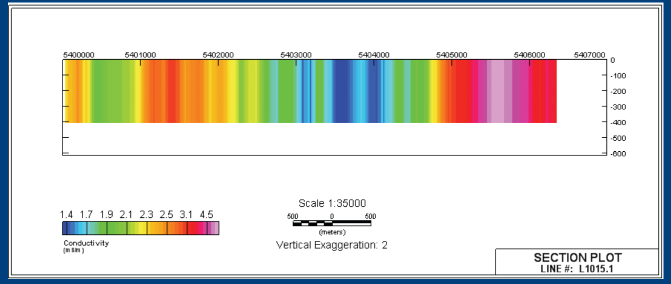

Figure 3: Half-space inversion with AIRBEO over line 15 at Reid-Mahaffy.

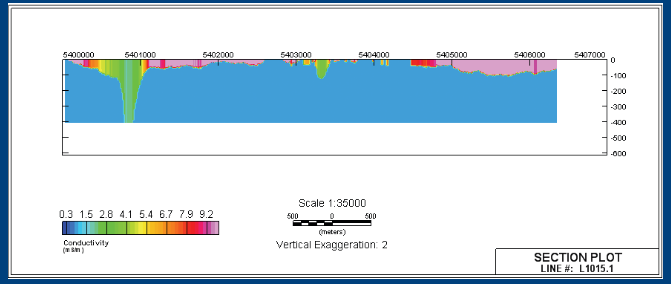

Figure 5: Two-layer inversion with a fixed basement of 1 mS/m on line 15 at Reid Mahaffy with AIRBEO.

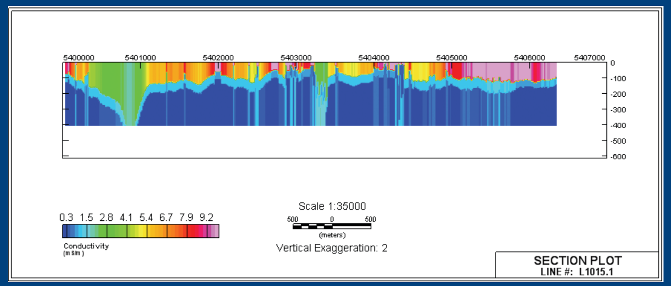

Figure 7: Three-layer inversion of line 15 with an initial model of 10 mS/m, 50 m, over 1 mS/m, 50 m, and a half-space of 0.1 mS/m

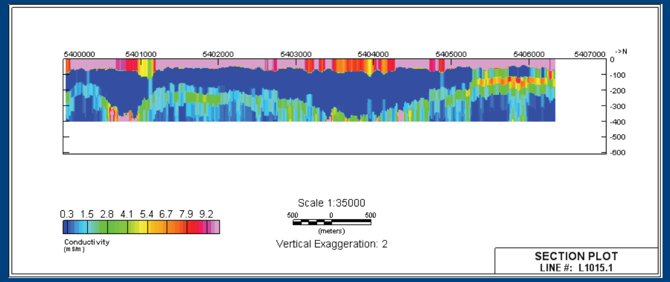

Figure 2: Conductivity image along Reid-Mahaffy line 15 using Zohdy's method.

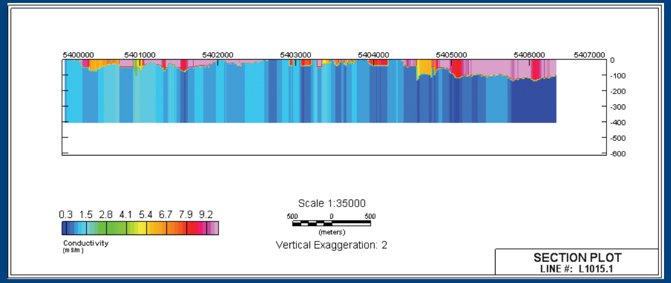

Figure 4: Two-layer inversion over line 15 at Reid Mahaffy with AIRBEO.

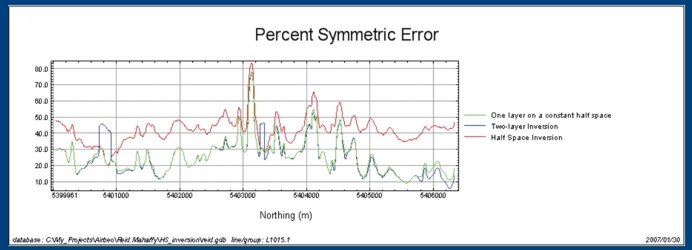

Figure 6: Plot of the percent symmetric error for one-layer and two-layer inversions on line 15 with AIRBEO.

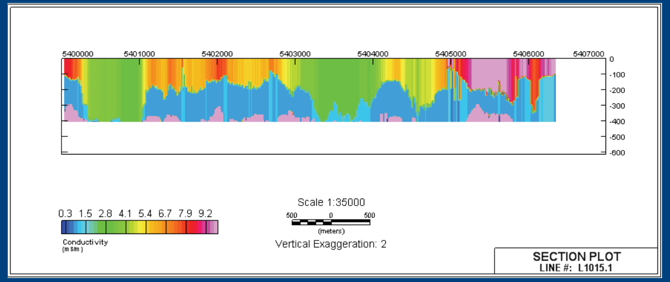

Figure 8: Three-layer inversion of line 15 with an initial model of 10 mS/m, 50 m, over 1 mS/m, 50 m, and a half-space of 1 S/m.

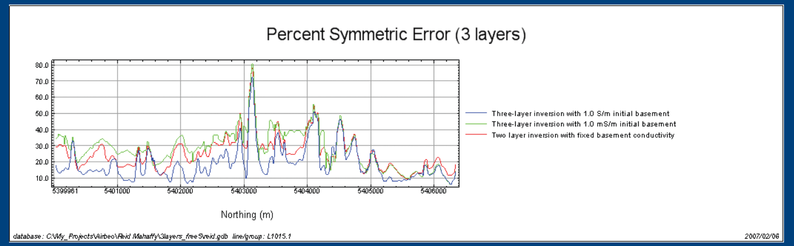

Figure 9: Percent symmetric error for the inversions displayed in Figures 5, 7, and 8.

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