

Deep, Accurate Structural Interpretations through Time Domain EM Techniques

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Summary

Inversion techniques are frequently used by geophysicists when interpreting airborne and ground time-domain electromagnetic data. Here, we examined critical factors for obtaining satisfactory inversion results. In particular, it was found that a precise knowledge of system parameters is essential, and that seemingly small errors in these parameters may cause misleading inversion results. However, with accurate information of the system parameters exceptionally accurate structural interpretations can be made.

Introduction

Time-domain electromagnetics (TEM) is a popular geophysical method, used in mineral exploration, groundwater, and increasingly in oil and gas exploration. With an airborne system, a large region can be surveyed quickly and with accurate reliable inversion techniques, useful geological interpretations over large regions can be developed. Ground TEM surveys can take more time to collect but we show that extremely deep and accurate structural results can be obtained through correct practices.

Ideally the inversion results should correlate with known geology, though of course there are limitations on its ability to resolve 3D structure due to the nature of the stacked one-dimensional techniques. However, sometimes inversions may yield unsatisfactory results even with a reasonable starting model. For this study we performed inversion analyses on TEM data in an area in which there was prior information on the geology. We wished to examine issues that may lead to poor inversion results, and in particular to examine the importance of accurate system settings, which were found to be critical in the modeling study by (Davis and Groom, 2009). Ground inversion results in the same area are shown for comparison correlated to known geology and drilling results.

Method

For the inversions of the airborne and ground TEM data, EMIGMA v8.1 (PetRos EiKon, 2010) was used (Groom and Jia, 2005; Jia *et al*, 2009). The response in the time domain is considered to be a convolution of the current impulse response with the current waveform and the system response (both of the transmitter and receiver).

The inversion can handle several different types of current waveforms and other parameters that may vary substantially between different TEM systems and surveys. There are a number of airborne TEM systems available, such as VTEM (Geotech Ltd), AEROTEM (Aeroquest Ltd), GEOTEM and MEGATEM (both Fugro Airborne Surveys). VTEM and AEROTEM are helicopter systems. The transmitter is towed below the helicopter and the receiver is in-loop. The altitude is typically less than for fixed wing systems, such as GEOTEM. For the GEOTEM system, the transmitter is around the airplane, and the receiver is towed behind it. There are several other

significant differences between these systems, including the type of current waveform and receiver coils. For example, the AEROTEM has a triangular pulse whereas the GEOTEM is a half-sine. Further parameters, such as the pulse width and position of time windows, depend on the base frequency and also vary between different surveys with the same system. Information on some of these parameters is typically available from the company who flew the survey, though in some cases these may not be wholly accurate (see Davis and Groom, 2009). Furthermore, information on certain parameters, such as the impulse response of the coils, is not usually provided.

The accuracy of the system parameters for a given survey is not always considered carefully by the geophysicist. In EMIGMA, we were able to invert the data through a variety of settings, including different system parameters, to study the effect of their accuracy on the results. We use waveform files to check various system parameters as needed.

Examples

Ground TEM

As an example, we consider TEM data collected north of the Grand Canyon in Arizona. The geology is a thick, flat-lying sequence of sedimentary rocks. There is limited lateral variation in subsurface structure. Drill results are available for several drill holes in the area. Several airborne surveys were performed at this site in addition to a wide-offset ground TEM survey with a PROTEM system.

For the PROTEM survey, a 400 x 400 m loop was used. Data was collected on two lines, extending 2 km south of the loop. A Marquardt-style inversion was performed on a section of the wide-offset data. The depths of the upper formations according to the inversion are in excellent agreement with the drill results (Figure 1). Although the drill results did not extend to the Supai Group, we were able to resolve this formation using the PROTEM data. The wide-offset data was critical for resolving the deep structure.

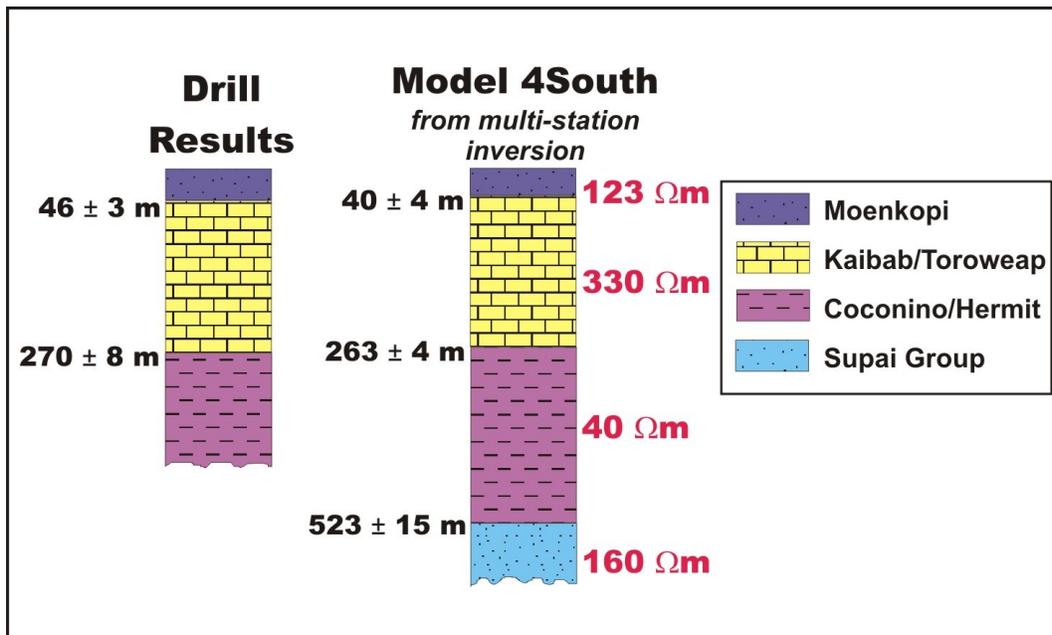


Figure 1: Comparison of the inversion result for the PROTEM data with the drill results.

Airborne TEM

Several datasets were collected at the site, but here we focus on MEGATEM data. The base frequency was 30 Hz, and while all three components were collected, we focused on Hz as it had the cleanest data. The data contains 20 off-time channels. Although 5 on-time and 15 off-time channels are standard for Fugro data, the increased off-time channels improved resolution and were important for understanding the data.

The MEGATEM system used a half-sine current waveform. The waveform file provided by Fugro contains high altitude data (essentially freespace response), and this was used to determine the pulse width.

A 4-layer 1D model from the ground TEM was used as a starting model for inversion of the MEGATEM. The resistivity and thickness of each layer were constrained. The result does not fit the response at the first three channels. Furthermore, it is inconsistent with known geology, despite the use of a reasonable starting model.

A second inversion was performed in which an additional shallow layer was added, and the resistivities of the first two layers were allowed to vary over a wide range. The result is presented in Figure 2. It is a slightly better fit to the data at Channel 1, but not at Channels 2-3, and it is still inconsistent with geology. In particular, there is an unexpected resistor at the surface.

In the first two inversions, an upper bandwidth frequency of 15 kHz was utilized, but through modeling of the data, it was determined that the upper bandwidth was actually lower. Analyses of the waveform file, including modeling of the freespace response and spectral analysis, supported this, and an upper bandwidth of 4 kHz was subsequently used.

A third inversion was performed with the same settings as the first inversion with the exception of the bandwidth, and this yielded significantly improved results (Figure 3). The inversion was both consistent with geology and fit the early-time data well.

These results show the importance of using the correct system bandwidth when inverting airborne data. If the correct settings were used, then we were able to obtain good results through the inversion. However, the airborne data does not have the sensitivity to the deep geology of the wide-offset ground TEM survey. Although the Supai Group is present in the inversion result in Figure 3, the airborne data has limited sensitivity to its exact resistivity and depth, and cannot be used to precisely determine its depth.

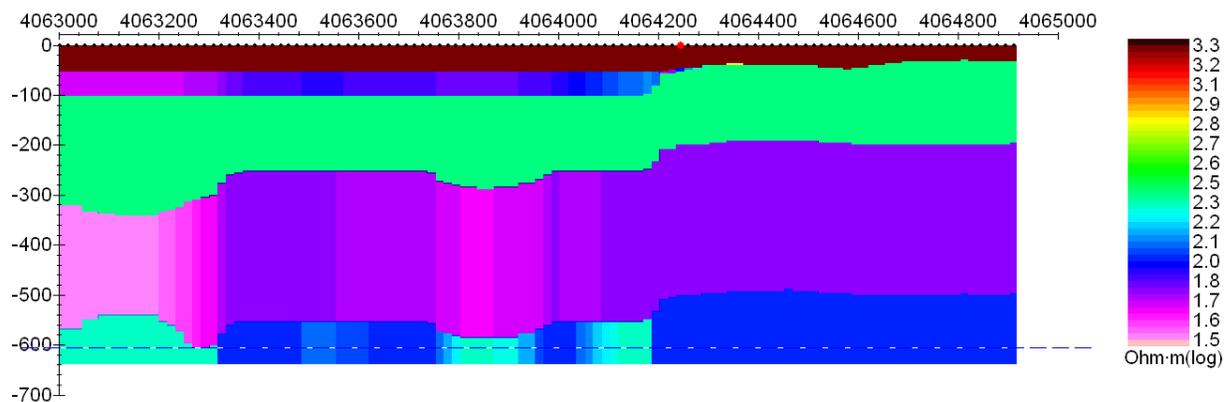


Figure 2: Second inversion result. Shallow resistor does not match geological information.

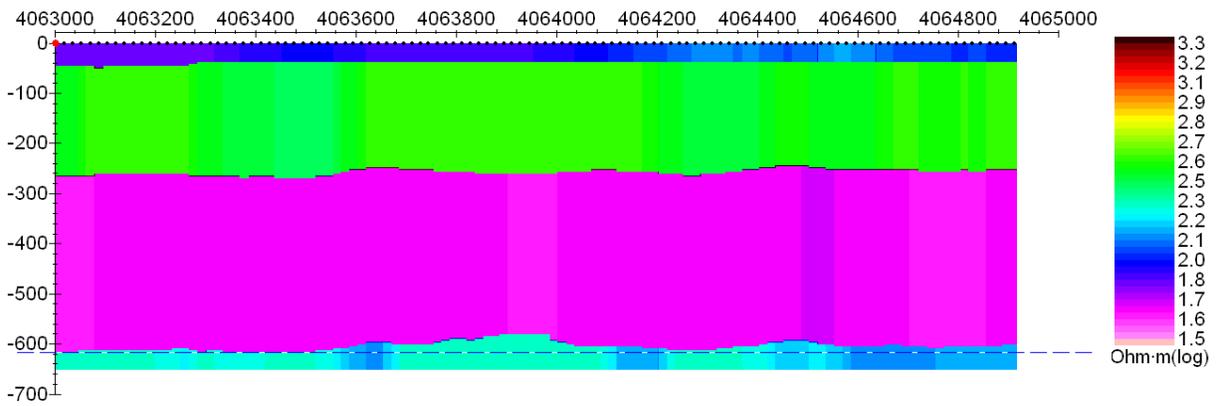


Figure 3: Third inversion result, using 4 kHz upper bandwidth frequency. Result is consistent with geology.

Conclusions

It was found that one significant factor affecting the quality of inversion results is accurate knowledge of system parameters. These are critical for obtaining meaningful inversion results for airborne TEM. Key system parameters include pulse width, waveform type, precise time channel locations, and impulse response of the receiver coils. These must be accurately represented in the inversion algorithm. Careful analysis of the waveform files provided by the survey company can be helpful in determining the correct settings. We have shown that seemingly minor differences in system parameters can have a significant effect on the results. However, if these parameters are precisely known, then we can develop an accurate structural model of the earth. Wide-offset ground TEM is advantageous for determining deep structure, but airborne surveys allow large areas to be surveyed quickly.

References

- Davis, L.J. and R.W. Groom, 2009. A comparison of airborne and ground electromagnetic data near the Grand Canyon: **79** *SEG Annual Meeting*, Extended Abstracts, p. 764-768.
- Groom, R. and R. Jia, 2005, On time-domain transient electromagnetic soundings: **18** *SAGEEP Annual Meeting*, Proceedings, p. 514 –518.
- Jia, Ruizhong, L.J. Davis, and R.W. Groom, 2009. Some issues on 1D TEM inversion utilizing various multiple data strategies: **79** *SEG Annual Meeting*, Extended Abstracts, p. 739-743.