1D joint inversion analysis of VES and TDEM soundings at Termas de Ibirá region, Paraná Basin, Brazil

Conference Paper · September 2013

DOI: 10.3997/2214-4609.20131388

4 authors, including:

Marco Antonio Couto Jr.
University of São Paulo

Jorge Luís Porsani
University of São Paulo

Cassiano Bortolozo
Centro Nacional de Monitoramento e Alertas de Desastres Naturais

We P 03

1D Joint Inversion Analysis of VES and TDEM Soundings at Termas de Ibirá Region, Paraná Basin, Brazil

M.A. Couto* (IAG-USP), J.L. Porsani (IAG-USP), C.A. Bortolozo (IAG-USP) & D.N. Leite (IAG-USP)

SUMMARY

In this work, the authors present results of 1D joint inversion of Vertical Electrical Soundings (VES) and Time Domain Electromagnetic (TDEM) soundings at Termas de Ibirá region, countryside of São Paulo State, Brazil. The objective is the analysis and comparison of the results of individual inversion and joint inversion. The VES results can solve the shallow layers (until the depth of 100 m) and the TDEM results solve the deep layers (between 100 - 1000 m depth). Therefore, the joint inversion explore the best of each method and it allows to make a more reliable interpretation about the local geology.

Keywords: TDEM, VES, Joint inversion, Paraná basin, Termas de Ibirá, Brazil.

Introduction

In applied geophysics to natural resources exploration the ambiguities in the interpretation process always exist. One possible way to reduce this feature is to use two or more geophysical methods in a complementary way. With a larger and more complete data set, the result can be more reliable and robust, and the ambiguities will be reduced. Therefore, the question point is to search for more accurate information about physical properties of subsurface. That information can refer to the same physical property or a group of them, which can be studied in different point of views. For example, the electrical resistivity can be obtained from DC-resistivity methods or by Electromagnetic (EM) methods.

Thinking in a complementary point of view, information from the DC-resistivity method complements the information from Time Domain Electromagnetic (TDEM) method and vice-versa. With the DC-resistivity method using Vertical Electrical Sounding (VES) technique, the apparent electrical resistivity is obtained as a function of the distance between the current electrodes. In the TDEM case, this physical property is obtained as a function of the transient decay of the associated magnetic field. These features generate equivalences of each response, which demands a computational method to eliminate them. A very common method to do this is the joint inversion of the both methods. In this case, the inversions of VES and TDEM data are made simultaneously. The pioneering work related to joint inversion of magnetotelluric data (MT) and vertical electrical sounding (VES) are assigned to Vozoff and Jupp (1975). These authors reduced the ambiguities of each method obtained in their individual inversion. Other important work which highlight the advantages of joint inversion of VES and TDEM can be found in Meju (1996).

In this paper, the authors analyse the applicability of the 1D joint inversion of VES and TDEM data to hydrogeological investigation at Termas de Ibirá region, countryside of the State of São Paulo in Brazil. The joint inversions were made with the Curupira software, developed by Bortolozo and Porsani (2012).

Methodology: VES and TDEM

The DC-resistivity method is based on the injection of electrical currents by current electrodes fixed on the earth's surface. With two other electrodes (potential electrodes), the measure of difference of electrical potential ΔV is made, and the apparent resistivity value can be calculated from this response. In this work, we used the DC-resistivity with Vertical Electrical Sounding (VES) technique with Schlumberger arrangement. In this technique, the apparent resistivity is calculated (Kearey et al. 2002) by the equation:

$$\rho_a = K\frac{\Delta V}{I} \tag{1}$$

Where K is geometric factor (depends of the geometry of the arrangement) and I is the electric current.

In the TDEM method, a DC electrical current is injected in a square transmitter loop, which is positioned on the surface. Then, this current is ceased, which causes time variation of the primary magnetic field associated with the current in the transmitter coil. According to the Faraday's Law of Classical Electrodynamics, an electromotive force (EMF) is induced in subsurface, generating eddy currents. These eddy currents are attenuated, which cause time variation of the secondary magnetic field associated with them. This time variation of the secondary field induces more EMF and then more eddy currents, such that this effect diffuses in depth like a smoke ring effect. The measurements of EMF associated with time variation of the secondary magnetic field are made with a receiver coil. The apparent resistivity value is calculated from EMF value $V(t)$ as (Kaufman and Keller, 1983):

$$\rho = k \left(\frac{M}{V(t)} \right)^{2/3} \frac{1}{t^{5/2}} \tag{2}$$

Where M is the magnetic momentum, t is the time and k is a constant calculated by:

$$k = -\frac{\mu_0}{\pi} \left(\frac{an}{20} \right)^{2/3} \tag{3}$$

μ_0 is the magnetic permeability of the vacuum, a and n are the effective area and the number of wires of the receiver coil, respectively. The TDEM method was already successfully applied to hydrogeological investigation as shown in Danielsen et al. (2003), Porsani et al. (2012a, 2012b), Bortolozo et al. (2012).

Acquisition and joint inversion procedure

The VES and TDEM data were acquired at Termas de Ibirá region, countryside of São Paulo State, Brazil. This area is localized on the Paraná Sedimentary Basin. Geologically, the area is composed by a sandstone layer (Adamantina Formation, Bauru Group) over a fractured basalt layer from the Serra Geral Formation. Bellow the basalt layer there is the well selected sandstone from the Botucatu Formation. Figure 1 shows the area location and the lithological description of a borehole localized at the area.

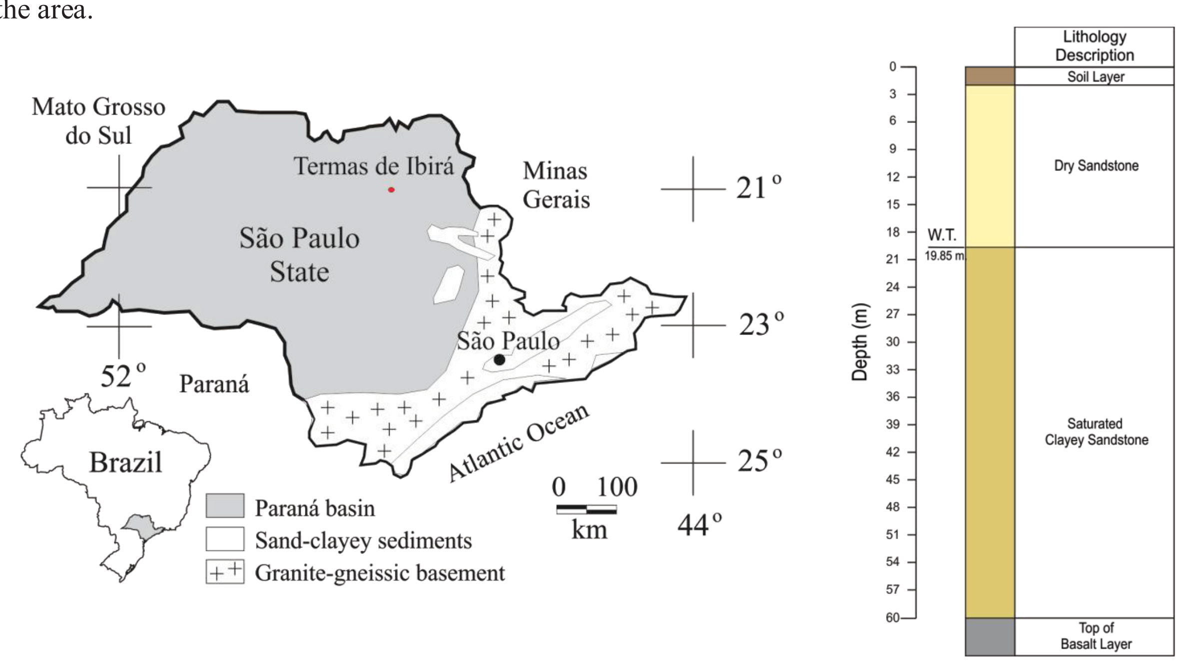

Figure 1: *Area location and lithology description of borehole at the area.*

For VES technique, the maximum distance between the current electrodes $AB/2$ and the maximum source voltage were $200\,m$ and $800\,V$, respectively. Therefore, the maximum theoretical depth of investigation was $\sim 100\,m$. For TDEM method, we used a square transmitter loop of $100\,m$ side, worked with $3\,Hz$, $7.5\,Hz$ and $30\,Hz$ as acquisition frequencies and values of electrical current between $28\,A$; which allows a maximum theoretical depth of investigation of $\sim 1000\,m$. Until now, there were acquired three TDEM soundings with an associated VES sounding at the center of the loop (for the joint inversion) and 4 more individual VES soundings at the area.

In this work, the Curupira software (Bortolozo and Porsani, 2012) was used for joint inversion of VES/TDEM data. This software uses the Controlled Random Search (CRS) algorithm to minimize the objective function. The CRS (Price, 1977) is a robust and stable algorithm, with great capacity of convergence.

Joint inversion results

Figure 2 shows the result of individual inversion of VES and TDEM data and the joint inversion of both methods for one sounding point. The VES individual inverted model (Figure 2-a) shows that the sandstone layer starts in $2\ m$ depth and has $38\ m$ thick. The basalt layer starts at the depth of $40\ m$. In the TDEM individual inverted model (Figure 2-b), the first ten meters were not defined, with no definition for the boundary between the soil and Bauru sandstone layers. The basalt layer was defined in $72\ m$ depth.

The joint inverted model (Figure 2-c) shows all layers defined in individual inversions and has a good correlation with the individual VES results for the shallow layers and with individual TDEM results for the basalt layer. This model shows the Bauru sandstone layer starts at $2\ m$ depth and has $80\ m$ thick. The basalt layer starts at the depth of $82\ m$. This results show that the joint inversion worked with the VES and TDEM methods in a complementary way and improved their individual results.

The joint inversion result is according to well log information from the area (Figure 1). At the area, the top of basalt layer can vary a few meters ($\sim 15\ m$). Therefore, for the top of basalt layer depth, the joint inversion prioritizes the result of TDEM.

Conclusions

The joint inversion improved the individual features of VES and TDEM and complemented their results. Its shallow layers results agree with VES individual results and its basalt layer results agree with individual TDEM results. Furthermore, its results agree with well log information at the area. In this way, a better and robust interpretation can be made.

Acknowledgements

We thanks to Fundação de Amparo à Pesquisa do Estado de São Paulo (FAPESP), a Brazilian research agency, for providing financial support for this research (Grant 2012/15338-4) and Scholarship for MACJ (Grant 2012/07385-2) and CAB (Grant 2011/06404-0 and 2012/15719-8). The IAG/USP is also acknowledged for providing infrastructure support. We thank Ernande, Marcelo, Vinícius, Emerson and Divanir for helping in data acquisition.

References

Bortolozo, C. A., Couto, M.A., Almeida, E.M., Porsani, J.L., Santos, F.M. [2012] Geoelectrical characterization by joint inversion of VES/TEM in Paraná basin, Brazil. AGU Fall Meeting, Extended Abstracts, NS31B-1686.

Bortolozo, C.A., Porsani, J.L. [2012] CURUPIRA V1.0. 1D joint inversion of VES/TDEM data computational software. Software registration number 12988-1. Agência de Inovação Tecnológica da USP, São Paulo, Brasil.

Danielsen, J. E., Auken, E., Jørgensen, F., Søndengaard, V., & Sørensen, K. I. [2003]. The application of the transient electromagnetic method in hydrogeophysical surveys. Journal of Applied Geophysics , **53**, 181-198.

Kauffman, A., Keller, G.V. [1983] Frequency and Transient Soundings. First Edition. Elsevier, Amsterdam.

Kearey, P., Brooks, M., & Hill, I. [2002] An Introduction to Geophysical Exploration. Third Edition. Blackwell Science Ltd, England.

Meju, M. [1996] Joint inversion of TEM and distorted MT soundings: some effective practical considerations. Geophysics , **61**(1), 56-65.

Porsani, J.L., Bortolozo, C.A., Almeida, E.R., Santos Sobrinho, E.N., Santos, T.G. [2012a] TDEM survey in urban environmental for hydrogeological study at USP campus in São Paulo city, Brazil. Journal of Applied Geophysics, **76**, 102–108.

Porsani, J., Almeida, E., Bortolozo, C., & Santos, F. A. M. [2012b] TDEM survey in an area of seismicity induced by water wells in Paraná sedimentary. Journal of Applied Geophysics , **82**, 75-83.

Price, W.L. [1977] A Controlled Random Search Procedure for Global Optimization. The Computer Journal, **20**, 367-370.

Vozoff, K., Jupp, D. [1975] Joint inversion of geophysical data. Geophysical Journal International , **42** (3), 977–991.

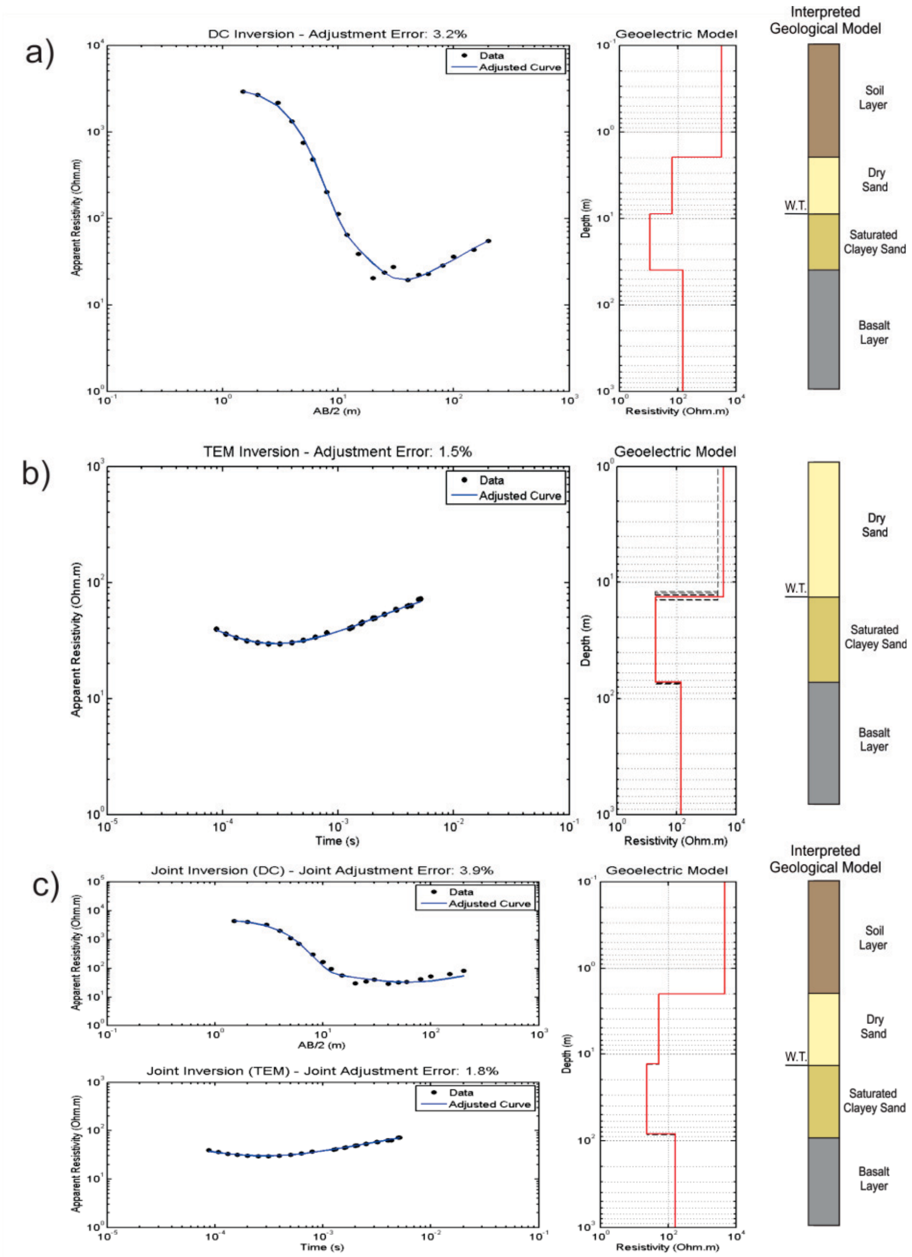

Figure 2: *Individual and joint inversion of a VES and TDEM data. a) Individual inversion of VES. b) Individual inversion of TDEM. c) Joint inversion of both methods.*