The renaissance of the magnetotelluric method: focus on land exploration in Brazil

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Abstract

The 10th Bid Round of the National Petroleum Agency (ANP) for oil and gas exploration in Brazil offered only blocks on onshore basins, most of them still of frontier character and very large.

The need to explore these areas also renewed interest in non-seismic methods which are able to survey these large areas quickly and provide important information on the interesting areas to design and undergo further exploration. These methods are also less expensive, non-invasive and the methodologies pose little or no environmental impact. These are important features, if we consider that most of the operators of onshore blocks are small independent companies and that the environmental agency (IBAMA) imposes severe restrictions to methods that cause potential impacts.

The Magnetotelluric (MT) method is a powerful frequency-domain electromagnetic technique that provides a resistivity model of the subsurface of the earth at depth. MT data acquisition is fast, environmentally friendly and provides the structural and stratigraphic information needed to explore these large onshore basins. For these reasons, we recently experienced renewed interest in the use of the MT method in Brazil.

In this paper, we show real data and modeling examples for different basins in Brazil and explain how these data can help improve the knowledge of Brazilian basins. This improved knowledge complements other geophysical data, indicates interesting areas and allow a better design of a high resolution survey, such as seismic data acquisition.

Introduction

Most of the onshore interior Brazilian basins are very little explored, of frontier character, mostly Paleozoic, with complicated geology by millions of years of tectonics and sedimentation. They are also very large, ranging from 355,400 km² in the Parecis to 1,127400 km² in the Paraná basin.

The Paraná Basin, for example, is covered by a thick basalt layer that hampers further exploration using seismic.

In the Potiguar basin, the Jandaíra and Barreiras formations complicate imaging of reservoirs.

The Proterozoic São Francisco basin attracted the interest of several oil companies, but most of its area is still not covered by geophysical data.

There are also several other basins with little or no geophysical data coverage: Parecis, Rio do Peixe, among others.

We have acquired MT data in some of these areas and we will show real data examples together with modeling results.

The Magnetotelluric (MT) Method

The MT method is a frequency-domain electromagnetic technique for probing the electrical resistivity distribution of rocks in the subsurface of the Earth. It uses natural time variation of the Earth's magnetic field as source of signals. These variations include frequencies ranging from 16KHz to 0.001Hz (Vozoff, 1991).

On land, we measure two components of the electric field and three components of the magnetic field. The telluric channels (electric field Ex and Ey) are measured using 100m dipoles in cross configuration connected to porous electrodes of lead chloride. Magnetic fields (Hx, Hy and Hz) are recorded with the use of high sensitivity magnetometers. The orthogonal electric (E) and magnetic (H) fields registered are aligned to north (Ex, Hx) and east (Ey, Hy) oriented by a compass. (figure 1).

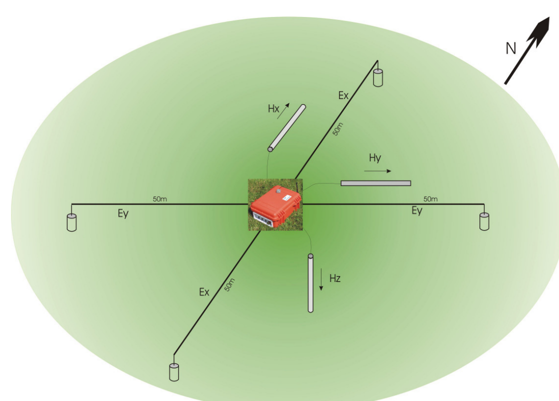

Figure 1: Field configuration on an MT data station.

Typical acquisition time for each station lasts between 12 to 24 hours, but can reach 72 hours, depending on the depth of investigation. The method can probe tens of meters for engineering applications, and tens of kilometers for crust/mantle studies. The elements of the impedance tensor (Z) are estimated in the frequency domain from the relationship between the electric and magnetic fields fields:

Z=E/H

The impedance tensor is usually then used to calculate the parameters apparent resistivity (ρa) and phase (Φ) that will be used for interpretation.

In a two-dimensional earth (2-D), electromagnetic fields are decomposed in two distinct modes of wave propagation: TE (transverse electric), in which the electric field (E) has a component only in the x-direction parallel to strike (Ex, 0, 0) and the associated magnetic field (H) has components in the y and z-direction (0, Hy, Hz) and TM (transverse magnetic), where the electric field has a component in the y-direction (0, Ey, 0) and the magnetic field has only a component in the x-direction (Hx,0,0) (Vozoff, 1991).

Example of Real Data: São Francisco Basin

The São Francisco Basin is located in central portion of Brazil. The basin is of Proterozoic age and occupies an area of approximately 305,000 km2, with maximum sediment thickness of about 5,000, encompassing parts of the states of Minas Gerais, Goias, Tocantins and Bahia.

This project consisted in the acquisition, processing and interpretation of 1,000 km of magnetotelluric (MT) data along two profiles crossing the southern portion of the São Francisco Basin (figure 2).

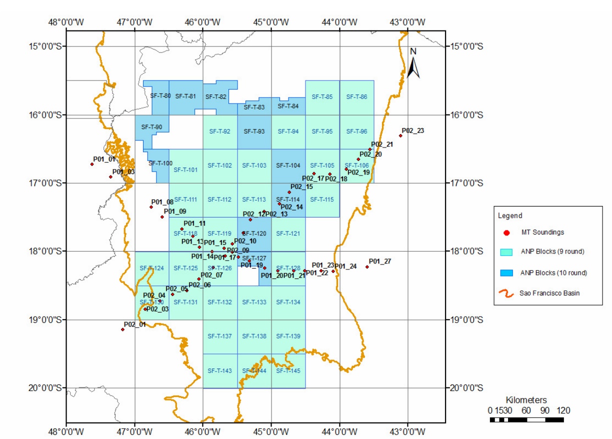

Figure 2: MT profiles MT-01 and MT-02 crossing the southern portion of the São Francisco Basin.

The spacing between MT stations was about 20km which was chosen with the objective of doing a quick regional study. The results from this project helped to define depth to the basement and overall structural framework of the basin, and to define the geoelectric stratigraphy corresponding to some lithostratigraphic units and their thickness in the studied region (figure 3).

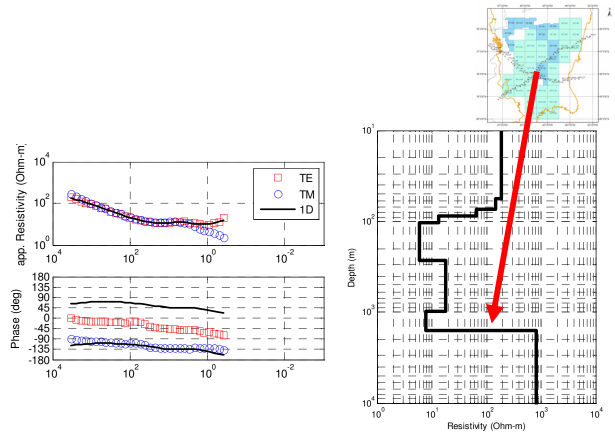

Figure 3: Station SF0211 shows shallow basement at 1.8 km.

Example of Real Data: Potiguar Basin

In this work we applied of a combination of non-seismic methods for oil exploration in an area in Brazil where the seismic image is poor due to the presence of a shallow carbonate layer. Also, the operator needed a quick response on where to drill, on a limited budget.

We first used a combination of High-Resolution Ground Magnetic (HRGM) and gamma-spectrometry to delineated microseepage anomalies. These anomalies guided a Controlled Source Audio-Magnetotelluric, Magnetotelluric and Time Domain Electromagnetic (CSAMT/MT/TDEM) program aimed at revealing the targets at depth. Figure 4 shows a resistive anomaly at depth in the CSAMT resistivity cube that corresponds to one microseepage anomaly.

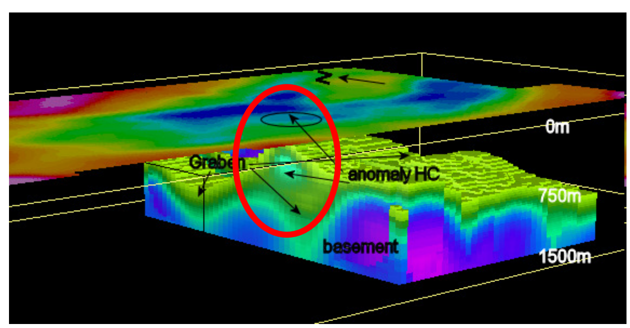

Figure 4: The CSAMT resistivity cube identifies a resistive anomaly at depth related to a microseepage anomaly. Residual magnetic map overlays the CSAMT.

Example of Modeling: Paraná Basin

Several onshore basins in Brazil would benefit from having an MT survey performed over their area.

We show an examples of numerical modeling for the Paraná Basin on how MT would respond and the information that this method can bring.

The Paraná basin is located in South-Southwest portion of Brazil, with sedimentary and magmatic rocks from the Neo-Ordovician and the Neocretaceous. It occupies an area of approximately 1,127,400 km2, with estimated 7,000 m sediment thickness. The main challenge in the exploration of the Paraná is the Serra Geral basalt coverage, which can be up to 2,000m or more thick in some areas.

MT modeling (figure 5) shows that several parameters can be defined from the inversion of synthetic MT data produced by modeling including, depth to the basement, presence of source rocks and sediments below the basalt. We used different thickness of the Serra Geral to show that the basalt was not a barrier for MT.

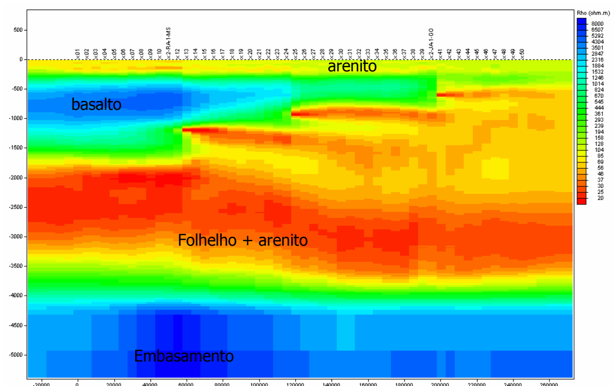

Figure 5: Resistivity model obtained from inversion of synthetic data from the Paraná basin.

Conclusions

In this paper we show through real data and modeling examples that the MT method can bring significant information about the structure and stratigraphic information of the onshore basins in Brazil. The method uses the naturally occurring electromagnetic field of the Earth as source which makes it free of any environmental risk.

Mt is also quite inexpensive and can quickly bring information that will help understand and better explore these basins.

Acknowledgments

We would like to remember Prof. Luiz Rijo who was one of the great enthusiasts of the use of the MT method.

References

Vozoff, K., 1991, The magnetotelluric method, in Nabighian, M. N., Ed., Electromagnetic methods in applied geophysics, 2: Soc. Expl. Geophys., 641–711.