Electromagnetic studies in the Parnaíba Basin: structural characterization by MT imaging

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Abstract

A 1430 km magnetotelluric (MT) transect E-W direction crossing the Parnaíba basin has been performed in order to characterize the structural features that are highlighted through electromagnetic (EM) imaging. This transect is coincident with a deep crustal seismic reflection profile and integrates a multidisciplinary study, fostered by BP Energy do Brasil, being held in Parnaiba basin between Observatório Nacional, University of Oxford and UFRN that aims to review the basin evolution models and provide an exploratory context to this basin. The MT study comprises a total of 220 broadband and 57 long-period MT stations along the MT profile. MT data have been modeled/inverted using 2-D algorithms and an electromagnetic imaging were obtained (section of electrical resistivity x depth). The resistivity model indicates an asymmetric structured western margin with diabase intrusions and a smoothly dipping eastern margin marked by the presence of high resistive vertical structures. These features could be associated with dikes, commonly found in this basin and yet a challenging scenario for a systematic interpretation in the basin in order to better characterize them as to their morphology, genesis and possible implications for the evolution of the petroleum system. Another geolectric feature draws attention to the eastern margin near Neoproterozoic Borborema block. This boundary is interpreted as the extension of the Transbrasiliano shear zone.

Introduction

Recent gas discoveries confirmed the importance of igneous rocks for the petroleum system in the basin. Seismic data allowed the recognition of unconventional traps associated with diabase sills, configuring unconventional geological exploratory plays of economic success. However, little discussion is found to date in the literature about a systematic interpretation of these igneous bodies in the basin in order to better characterize them as to their morphology, genesis and possible implications for the evolution of the basin. It is noteworthy that the physical property of subsurface materials most affected by changes in fluid content and igneous intrusions is the electrical resistivity. Thus, important information can be deduced from the measurement of bulk electrical resistivity. We propose a MT survey across the Parnaíba basin to map the structure of this intracratonic basin of NE Brazil. This information will help to constrain basin evolution models and provide an exploratory context to this basin.

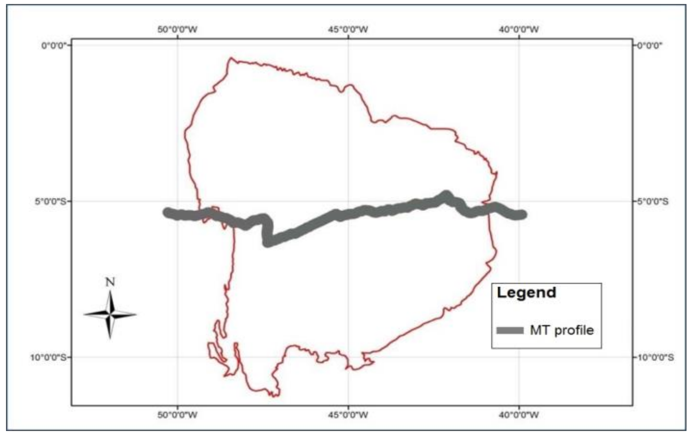

Fig. 1: EW magnetotelluric profile crossing Parnaiba Basin.

2D MT forward modeling

As mentioned before, the petroleum system in the basin may have been controlled by the presence of dikes and sills. In order to check the detectability of diabase dikes and sills by the MT method a 2D forward modeling study was performed. We created a bi-dimensional resistivity model (Fig. 2a) based on geological information and respecting the same characteristics of the actual MT profile, i.e. the same spacing and the same range of frequencies obtained in the apparent resistivity and phase curves. After, a 2D MT inversion of the synthetic data was performed using the algorithm proposed by Rodi and Mackie (2001). The obtained estimation is shown in Fig. 2b and the misfits between observed and calculated data are shown in p-sections in Fig. 3. We notice that with this experiment, except for the sill structure, the inversion was able to produce a smooth distribution of resistivity very similar to the forward model. This indicates that a dike could be recovered by the method but the sill could not.

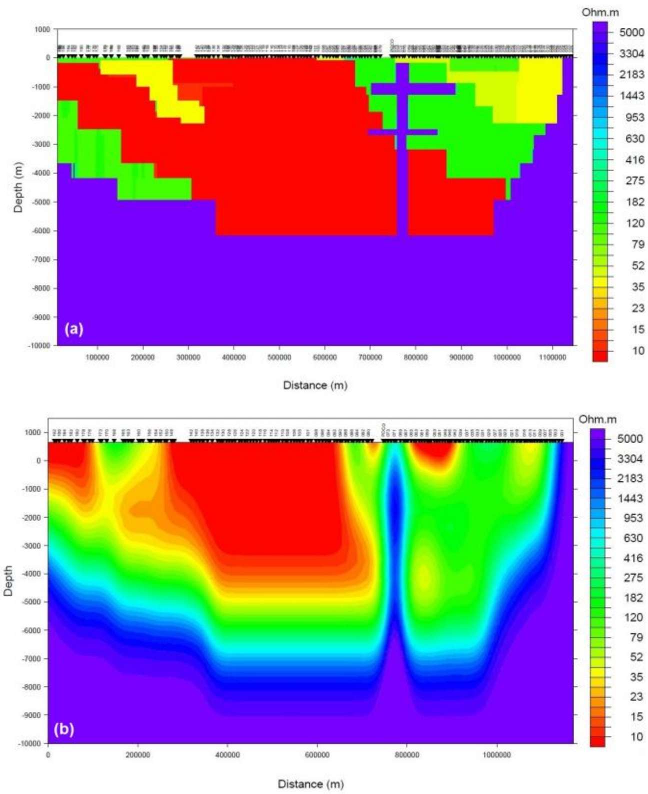

Fig. 2: 2D MT forward modeling study in Parnaiba basin. (a) Resistivity bi-dimensional model based on geological and borehole information, (b) Resistivity distribution obtained from the 2D inversion of synthetic data produced by the resistivity model on Fig. 2a.

Detectability of a sill

In order to analyze the detectability of a sill we made a 1D forward modeling study. Based on a borehole where the presence of a sill with 160m thickness and top at 840m depth was verified, we simulated the apparent resistivity and phase curves, contaminated with Gaussian noise and named reference MT data. The 1D resistivity model containing the sill was named as reference model (Fig. 4). Fixing the resistivity of the sill and of the adjacent layers we simulated 2500 sill models with thicknesses varying from 50 m to 800 m and the sill's top depth ranging from 400m to 2500 m. For each one of the sills we calculated the impedance tensor, apparent resistivity and phase and contaminated with Gaussian noise. After we calculated the square of the L2 norm between the reference and calculated data and plotted in function of thickness and sill's top depth (Fig. 5). We notice clearly a blue region in the graphs indicating that different sill models generate very similar data to the one produced by the reference model.

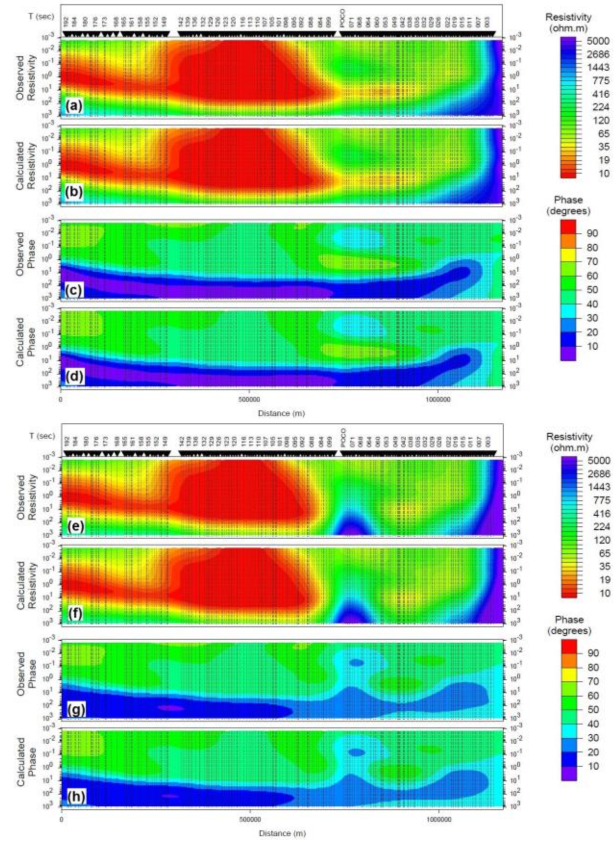

Fig. 3: Set of MT observed and calculated data used and obtained in MT inversion. The pseudo-sections illustrates: (a) TE observed apparent resistivity; (b) TE calculated apparent resistivity; (c) TE observed phase; (d) TE calculated phase; (e) TM observed apparent resistivity; (f) TM calculated apparent resistivity; (g) TM observed phase and (h) TM calculated phase.

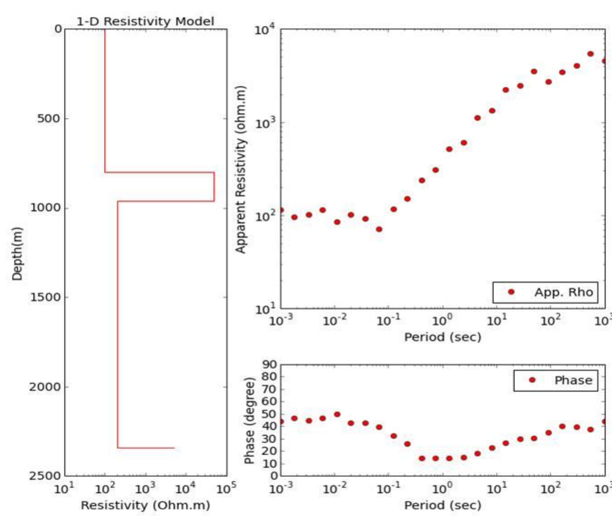

Fig. 4: MT data (right) produced by a sill with the same characteristics from the borehole and represented in a 1D resistivity model (left).

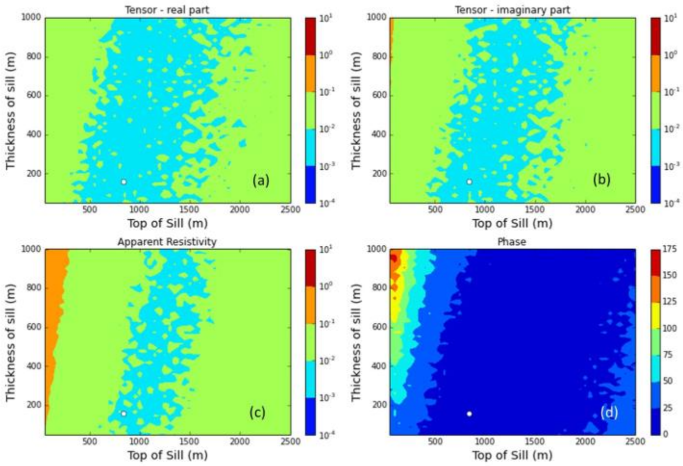

Fig. 5: Plot of the square L2 norm of the difference between the calculated and reference data in function of thickness of the sill and depth at the sill's top. The white dots represent the reference model, i.e. thickness and the sill's top depth observed in the borehole. (a) real part of impedance tensor, (b) imaginary part of impedance tensor, (c) apparent resistivity and (d) phase.

Preliminary results from 2D MT Inversion

To determine the magnetotelluric parameters (apparent resistivity and phase), all data were processed using the robust processing routine proposed by Egbert and Booker (1986). This routine is based on the estimate of the elements of the impedance tensor through least squares.

To estimate a distribution of resistivity that explains the observed data we applied a 2D inversion algorithm proposed by Rodi and Mackie (2001). The obtained estimate is shown in Fig. 6 and the misfits between the observed and calculated data are shown in Fig. 7. The high resistivity region characterizes the basement in the eastern margin and center of the basin. Depths in this region range from 4000 to 5000m, and are compatible with the seismic. Quite resistive vertical features (black dashed line) are also highlighted in the resistivity obtained model. These features are compatible with dikes and may be associated with these types of structures. Another feature that draws attention still on the east margin is a little discontinuity of low resistivity (red dashed line). This region is located near the Neoproterozoic Borborema block and matches the Transbrasilian Lineament. It is possible that the discontinuity is associated with a displacement of sedimentary blocks in depth due to the tectonism that generated the Transbrasilian Lineament. A more detailed analysis through forward modeling is being performed in order to verify the consistency of this model.

Discussions and future perspectives

From the forward modeling studies we observe that dike structures can be recovered by MT method but there is an ambiguity in recovering sills. Different sill models produce the same or very similar MT data.

In a regional context we believe that the resistivity model characterize the major geological framework and the basement in our study area. The resistivity model generated by 2D inversion of real data details better a zone characterized by lower values of resistivity, compatible with the sedimentary package, and also a resistive zone, that we expect to be the basement. This resistive zone smoothly gets deeper from the eastern margin to the center of Parnaiba Basin. Also, the 2D inversion highlights the presence of two resistive vertical structures suggesting the presence of dikes we that observe to be geologically meaningful once these kind of structures are commonly found in this basin

It is expected better results in deeper regions of the model with the inversion including long period MT data.

Acknowledgements

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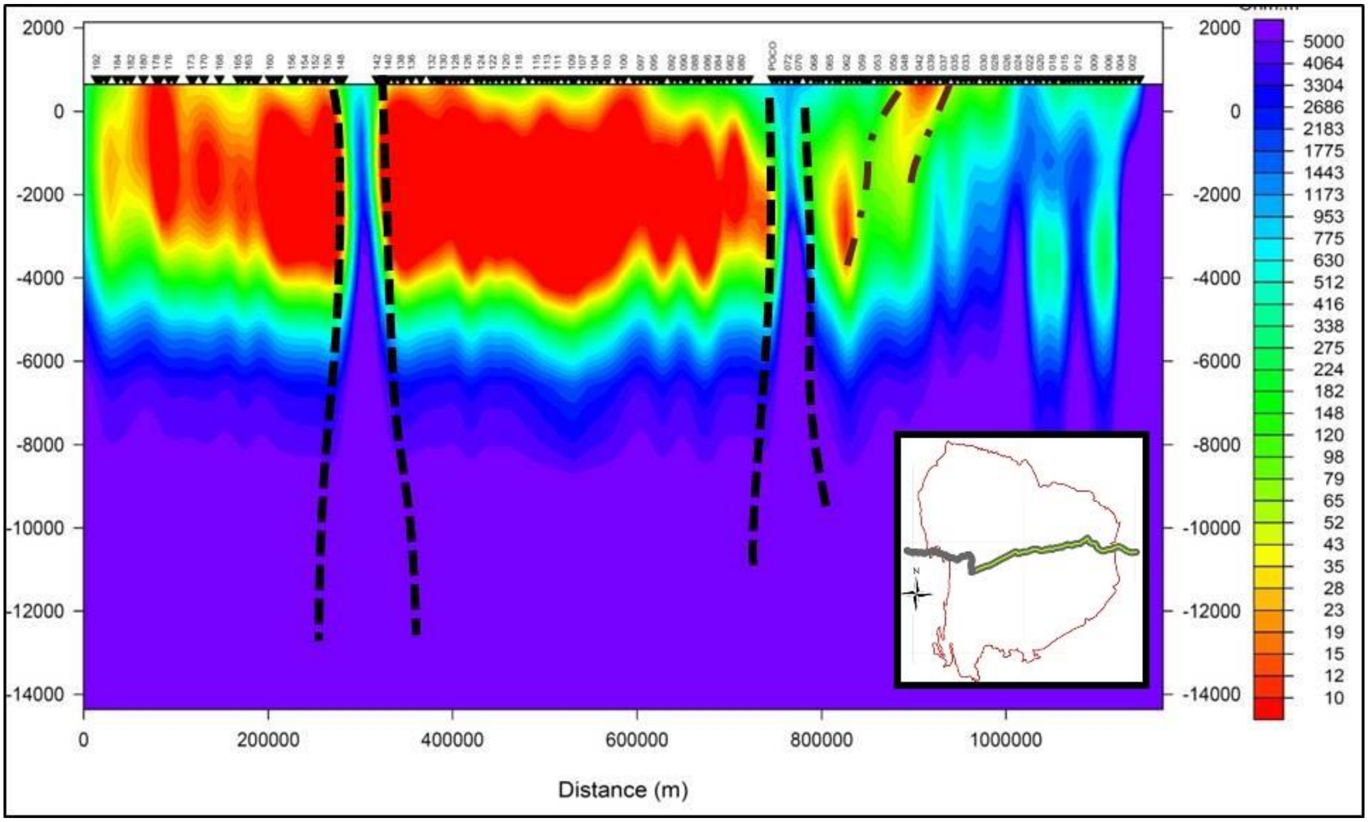

Fig. 6: Preliminary estimate of the resistivity distribution in subsurface obtained through 2D inversion of MT data. The data used in this inversion is shown in green profile in the square at the bottom right. The black dashed line indicates two vertical resistive structures that may be associated with dikes. The dashed line in red is laterally coincident with Transbrasilian Lineament region.