Electromagnetic Induction Studies in the Borborema Province and Adjacent Terrains, Northeastern Brazil: 2013-INCTET Progress Report.

Ícaro Vitorello* (INPE), Antonio L. Padilha (INPE), Marcelo B. de Pádua (INPE), Sérgio L. Fontes (ON), Mauricio S. Bologna (USP), Santos, A.C.L. (INPE), Reinhardt A. Fuck (UnB).

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Abstract

The *National Institute of Space Research* (INPE) and the *National Observatory* (ON) have been conducting uninterrupted Electromagnetic Induction (EI) studies in northeastern Brazil since 2008, under the auspices of the *National Institute of Science & Technology for Tectonic Studies* (INCTET) project, with the main purpose of gathering deep geophysical data that can enhance present-day knowledge about the tectonic processes responsible for the geological evolution of the Borborema Province, presently abutted by distinct regions. Such studies contemplate the deep geophysical probing of this region with 2D and 3D Magnetotelluric (MT) surveys, along several geoelectric transects and an array of Geomagnetic Depth Soundings (GDS), which complement gravimetric and seismic refraction data, also gathered by the INCTET project. The focus of this study is directed to the identification of geoelectric variations in electric conductivity at distinct lithospheric depths and associations of geoelectric strikes and anisotropy with structural grain and stress patterns, particularly in the long ubiquitous structural features that crisscross the province at the surfaced crust. They constitute major geoelectric heterogeneities that probably represent ancient terrains marked by tectonic events related to lithospheric collision, subduction, rifting and delamination processes. Nonetheless, it is still unknown whether such features are persistent down the lower crust and upper mantle. In pursuit of such goals, a total of more than 430 broad-band, 210 long-period MT and 15 GDS soundings has been carried out along 16 linear profile segments, extending in length for more than 7,000 km, placed transversally to several geologically distinct domains of the Borborema region, and into the neighboring terrains.

Introduction

The ***National Institute of Science & Technology for Tectonic Studies* (INCTET) project** congregates many geoscientists from several Brazilian research institutions with the purpose of studying the deep crust and upper mantle structures. It is multidisciplinary in its approach, merging different techniques and methodologies, which allow the study of the Earth's interior based on different properties of its constituting rocks. The focus of this research is the study of the crust and upper mantle of the Borborema Province and adjoining São Francisco Craton and Parnaíba Basin. The Borborema Province is a complex association of crustal blocks with differing ages, origin and geologic evolution, and which were amalgamated mainly during the last orogenic event that took place in what is now the northeastern Brazilian territory, namely the late Neoproterozoic-early Phanerozoic Brasiliano orogeny, composing the western Gondwana supercontinent. Therefore, Electromagnetic Induction studies have been applied with the goal of making a major contribution to a better comprehension of the actual articulation of the amalgamated crustal blocks and the role of large transcurrent lineaments in bringing these blocks together, through an integrated multi-disciplinary geophysical approach. The results of this endeavor have been published in scientific journals and in the proceedings of several national and international scientific meetings, as listed in the References. Furthermore, many students, at undergraduate and graduate levels, benefitted from this opportunity to successfully conduct their dissertation and thesis.

Physical Principles

Magnetotelluric method (MT)

The MT method provides images of subsurface conductivity using natural, low frequency electromagnetic waves that diffuse into the earth's interior. The MT method requires the simultaneous time-series measurement of orthogonal components of magnetic (Bx, By, and Bz) and electric (Ex and Ey) variational fields. The ratio of the orthogonal horizontal components of E and B in the frequency domain is a measure of the Earth's electrical resistivity over a volume that increases with depth and width as the period increases. With pairs of orthogonal E and B fields, MT responses may be obtained in two polarizations, or modes. Above one-dimensional (1D) layered structures the two MT modes are identical, but for two-dimensional (2D) structures MT fields may be rotated to modes of electric field parallel to strike (TE mode) and perpendicular to strike (TM mode). Electrical current flowing along the strike direction defines the TE mode while the perpendicular response defines the TM mode. The depth of penetration of the MT signal is controlled by the skin depth relationship that defines that the penetration increases as the sounding frequency and the electrical conductivity of the Earth's interior decrease. For this study, the five MT components are recorded using commercial remote-referenced broadband and long-period MT systems.

Geomagnetic Depth Soundings (GDS)

Geomagnetic Deep Sounding (GDS) is an electromagnetic method of geophysics, which is capable of imaging the Earth's interior in terms of electrical conductivity only using the natural geomagnetic transient variations. The ratio of vertical magnetic field (Bz) to the horizontal fields (Bx and By), known as GDS transfer function responses, also provides a measure of lateral changes in resistivity. The magnetic transfer functions are commonly represented by rotated real induction arrows, at a period mainly affected by mid and lower crust and upper mantle structure. The presence of lateral electrical conductivity differences at depth perturbs the flow of induced currents and produces frequency-dependent anomalies in the X, Y and Z components. The detection of such anomalies can be facilitated by correlating data from closely spaced sites, recorded preferably by an array of simultaneously operating magnetometers. The GDS responses are often plotted in map view in the form of induction arrows that can be interpreted based on the intensity and direction of the arrows, facilitating a qualitative regional assessment of the degree of conductivity variations in the subsurface. The directions of the reversed real component of the arrows point towards more conductive regions. The method is particularly suited to map geological structures marked by large lateral conductivity contrasts.

Field Campaigns and Results

Figure 01 shows the widespread geographic distribution of all the MT soundings carried out in the northeast up to now, composed by more than 430 broad-band and 210 long-period MT carried out along 16 linear profile segments, extending for more than 7,000 km.

Figure 02 shows the electromagnetic signatures of different tectonic terrains of the study area, plotted as resistivity versus depth-profiles. These signatures indicate that the lithosphere presents a very variable electrical resistivity that distinguishes each distinct tectonic domain, particularly at mantle depths. The upper-mid crust usually shows up as a very resistive layer, down to 10-15km, overlying a much less resistive middle crust and even at the lower crust. At upper mantle depths, the signatures diverge significantly, persisting to great depths. The bluish depth-profiles in Fig. 02 show very resistive upper mantle, which is a characteristic of cratonic lithosphere, whereas the reddish profiles are characteristic of tectonically younger terrains, possibly subjected to re-fertilization processes. In the Borborema Province, the areas that show a deep lithosphere keel (more resistive) are the São José do Campestre Massif, Sergipana belt and Alto Moxotó Terrain. Exceptions to a resistive crust are found under the Seridó belt, Jatobá rift basin and the Araripe intracratonic basin, marked by an underlying crustal conductive zone. Laterally, the deeper portion of the crust and upper mantle is highly segmented in blocks with alternating juxtaposed higher and lower resistivity, as shown in Fig. 02. Disclosed geoelectric discontinuities mark some particular geological features such as the shear zones that separate tectonic domains This pattern is suggestive of highly deformed regions by transform dominated tectonic regimes, with the presence of contrasting mechanically strong cratonic keels against weaker zones likely subjected to delamination processes that might have produced magmatic related lithospheric re-fertilization by metasomatism. The observed geoelectric strikes are possible indicators of compressional-extensional stresses, including plate collisions dominated by subductions. The directions of the geoelectric strikes and of the induction vectors show similarities with the tectonic grain, particularly at higher frequencies, associated with the upper crust.

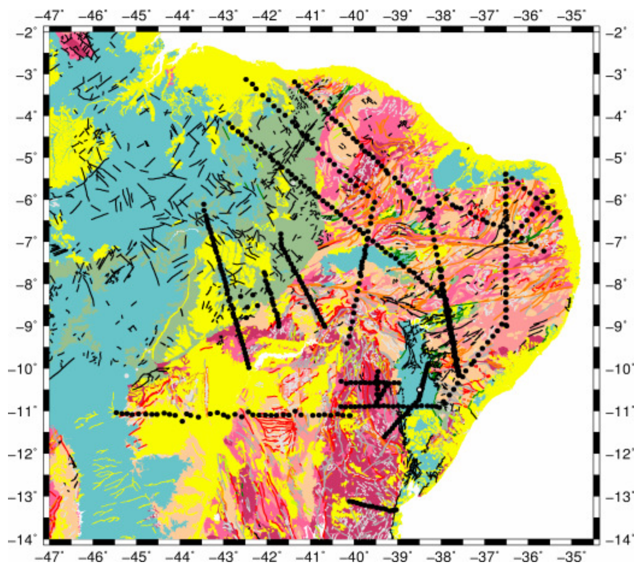

Figure 01 - Geologic map showing the geographic positions of the MT soundings (black dots) carried out in the Borborema Province and adjacent terrains.

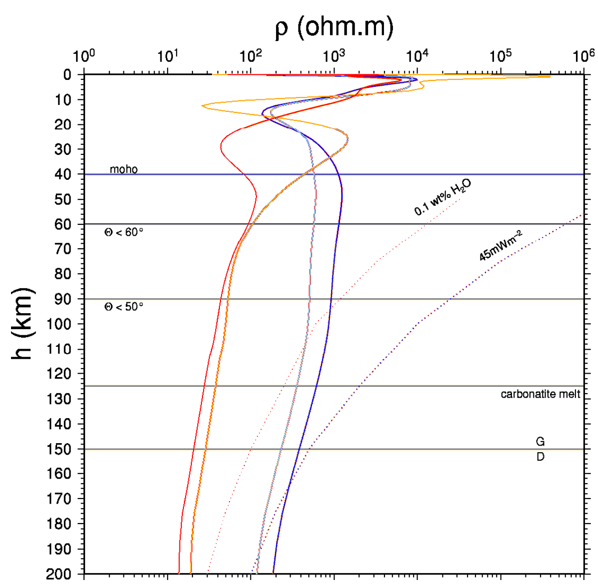

Figure 02 - Plot of resistivity versus depth-profiles of several MT data from sites located in different tectonic terrains of the study area and shown as colored continuous lines. Plotted as dotted blue and red lines, are, respectively, resistivity depth-profiles of nominally anhydrous and hydrous (0.1 wt.% H2O) upper mantle minerals for a 45 mW/m2 reference geotherm, Also shown are depth indications for the Moho, dihedral angles, onset of carbonatite melting, and for graphite (G)–diamond (D) stability field transition,

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