Geoelectrical structures retrieved from a Magnetotelluric Transect in the northwestern Borborema Province, NE Brazil

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Abstract

We report here preliminary interpretations of a magnetotelluric transect across Rio Grande do Norte, Ceará Central and Médio Coreau domains of the Borborema Province. The focus of this research is the study of geoelectric directions and dimensionality of crustal structures and mantle lithosphere of this sector of the province. The profile analyzed consists of 27 broadband stations spaced by about 15 km. The wide range of periods available (0001-1000 s) allows the probing of depths from about 200 meters until the order of 80 km in some stations. Our analysis suggests a relatively homogeneous lithosphere near the Portalegre lineament. In the central portion of the transect, a major lateral variation takes place beneath the Orós belt instead of Senador Pompeu lineament. To the west, a more complex resistivity pattern is observed, including an including a severe change of strike with depth (from ~N30°W to ~N20°E) probably within the crust of the Santa Quitéria Massif. In the western end of the transect, a major electrical discontinuity occurs near the Sobral-Pedro II Lineament associated with the western border of the Ceará Central Domain.

Introduction

The Borborema Province is a complex association of crustal blocks with differing ages, origin and geologic evolution, and which were amalgamated during the last orogenic event that took place in what is now the Brazilian territory, namely the late Neoproterozoic-early Phanerozoic Brasiliano orogeny, composing the Gondwana supercontinent. Despite considerable knowledge about its geology and geochronology lithospheric structure is still poorly known. Consequently, dynamic processes involved in the origin and evolution of the province are still poorly understood. Therefore, magnetotelluric (MT) and others electromagnetic induction studies are being developed 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 study.

Particularly, the electrical resistivities measured by the magnetotellurics are sensitive to very small changes in minor but tectonically important constituents (fluids, graphite, melts, etc) of the Earth interior, and hence is a complementary parameter to other geophysical techniques, such as potential field methods and most seismic methods. The focus of this research is the study of geoelectric directions and dimensionality of crustal structures and lithospheric mantle of this sector of the province and of the spatial relationship of conductive layers, discontinuities and geoelectric anisotropy with the main geological features over the northern sector of the Borborema Province.

As seen in figure 1 the long profile (~400 km) run in a WNW-ESE direction sub parallel to the northern sea shore. It consists of 27 MT sites, most of which are in the Ceará State. For this study, five MT components (Ex, Ey, Hx, Hy and Hz) were recorded using single-station broadband MT system.

The magnetotelluric method

The MT method utilizes a large range of transient variation of the geomagnetic field as the signal source for determining the structure of electrical resistivity of the Earth's interior. The MT signals are generated primarily by global thunderstorms in the lower atmosphere and interactions between the solar wind and Earth's magnetosphere. According to the principle of electromagnetic induction, such fluctuations induce electric currents inside the Earth and its distribution and magnitude depend on the electric structure of the subsurface. The electrical conductivity is determined from the relationship between the orthogonal components of electric and magnetic fields observed on the surface. The depth of investigation of the method depends on the period of oscillations and the conductivity of the medium. In general, signals ranging from milliseconds to 1000 s probe depths from tens of meters to tens of kilometers. But in regions with low resistivity, the signal is attenuated more quickly, reducing the depth of the research method.

Data analysis

The robust remote refering code of Gary Egbert (Egbert, 1997) were applied to estimate the complex 2x2 impedance tensor as well as the magnetic transfer functions in periods ranging from 0.001 s to 1000 s. The impedance tensor links the two horizontal magnetic components Hx and Hy and electric fields Ex and Ey, whereas the magnetic transfer function relates the vertical and the two horizontal components of the magnetic field in the frequency domain. For most of the sites along the profile the data are of excellent quality.

Induction arrows from the magnetic transfer functions are generally useful for assessing lateral contrasts in electrical resistivity within a certain region. For sites not affected by large laterally positioned conducting features, orientation of the induction arrows must be roughly parallel to the profile, and consequently perpendicular to the geologic strike. Figure 2 display induction arrows at three diferent periods (1.14 s, 12.8 s and 102 s). Periods of ~1s are influenced mainly by the upper crust, whereas around 100 s there is a predominance of structures in the lower crust or lithospheric mantle. Overall the vectors indicate that the region is more homogeneous in the extreme southeast of the profile, around the Portalegre lineament (stations from 019 to 023), where the magnitudes of the arrows are relatively small. To the west, the magnitude increases and a major reversal is observed around the station 028, whose position coincides with the eastern limit of the Orós belt. As the reversal occurs in all three periods, we believe that the discontinuity is large-scale (at least crustal). In the central-northwestern part of the profile, over the Tróia-Tauá Archean nucleus and Santa Quitéria Massif (stations from 033 to 041) the induction arrows have a more complex pattern, with many pointing away from the profile. This is indicative of the presence of 3D structures, especially in shorter periods (and therefore shallower depths). Another reversal occurs in the most northwestern part of the profile, coinciding with the position of the lineament Sobral-Pedro II. Over longer periods the arrows tend to point to the sea, suggesting the presence of the coast effect, a distortion caused by anomalous electrical currents along the continental margin. In fact, this effect has been predicted by a 3-D numerical modeling of the vertical magnetic field (Pádua et al., 2007).

Distortion analysis was used to assess both the dimensionality of the electrical structures and to determine their directions. We have performed the tensorial decomposition code developed by McNeice and Jones (2001) on the MT response estimates for each site along the profile. Usually, tensor decomposition gives acceptable fits to the measured impedance data of this study. Figure 3 shows the geoelectric directions in two bands of periods obtained independently at each station. The strikes are far more variable over shorter periods, except in the southeastern part of the profile around the lineament Portalegre. The most important change in behavior is observed on the strikes of sites in the Massif of Santa Quitéria, where the directions remain consistently around N30°W (or N60°E, due to ambiguity of 90°). Moreover, the phase difference (anisotropy) between the off-diagonal elements of the impedance tensor is relatively large in this region, emphasizing the importance of this structure in this band of 0.1 – 1 s. In longer periods (1 - 100 s), the strikes are consistently aligned in the NNE direction. Hence, there is a rotation of nearly 50° in the strike from short period to long period beneath the Santa Quitéria Massif, a possible indication of electrical decoupling. Also, whereas the strikes in long periods are aligned with the direction of the main lineaments, this does not occur across the Senador Pompeu lineament, which suggests that such a structure does not penetrate deeply in the crust.

Conclusions

The major lateral discontinuities inferred in this work coincide with the positions of Orós and Sobral-Pedro II lineaments. In such lineaments, occur a clear reversal of the induction arrows at different periods and geoelectric strikes are roughly parallel to the general direction of these lineaments. Indeed, previous 1-D modeling (Nunes et al., 2007, Bologna et al., 2010) indicated an increase in electrical conductivity in these structures, which is consistent with the inferences made in this work. On the other hand, Portalegre and Senador Pompeu lineaments seem to have little effect on MT data, especially over long periods. This suggests that these structures are relatively shallow and therefore should not represent limits of tectonic terrains.

Under the Santa Quitéria Massif, we observe a severe change in electrical direction with depth that suggests a decoupling of the lower crust (or upper mantle) but farther analysis has to be made. Anyway, present results show that at upper crustal depths the geoelectric structures have a very different direction (N30°W) in relation to the main shear zones (~N30°E) of the study area. This could be useful in understanding the geodynamic processes involved in this tectonic domain.

Although the geoelectrical structure of this portion of the Borborema Province is relatively complex, based on directional and dimensional analysis presented by this work, we argue that for longer periods, representing lower crustal/lithospheric mantle depths, a 2-D treatment is quite feasible. In this case, the general strike direction for processing the data of this profile should be around N20°E and N40°E for the western and eastern parts, respectively.

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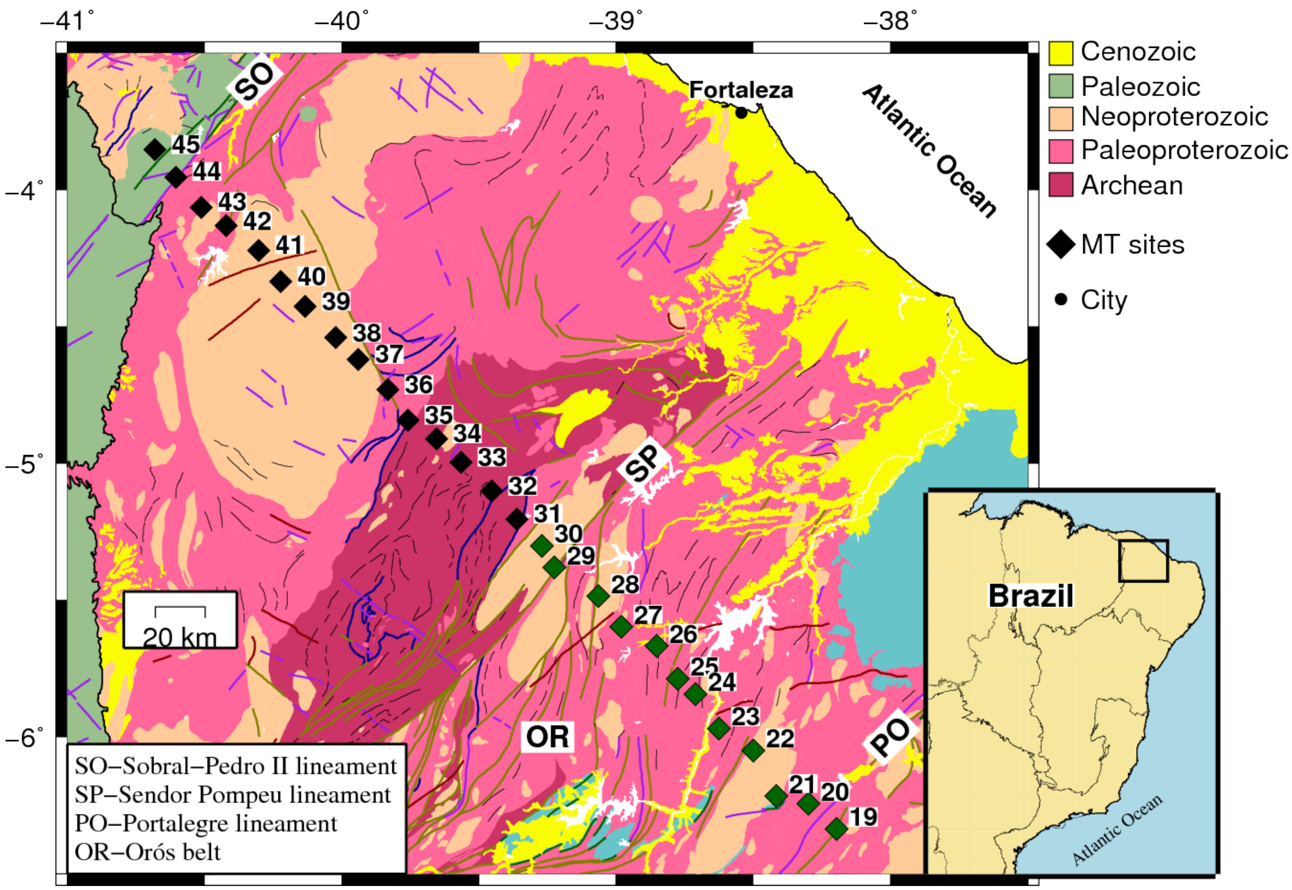

Figure 1 – Geologic map with positions of the MT soundings carried out in the Borborema Province across Ceará and Rio Grande do Norte states.

Corrigir Senador (Sendor) na legenda da figura.

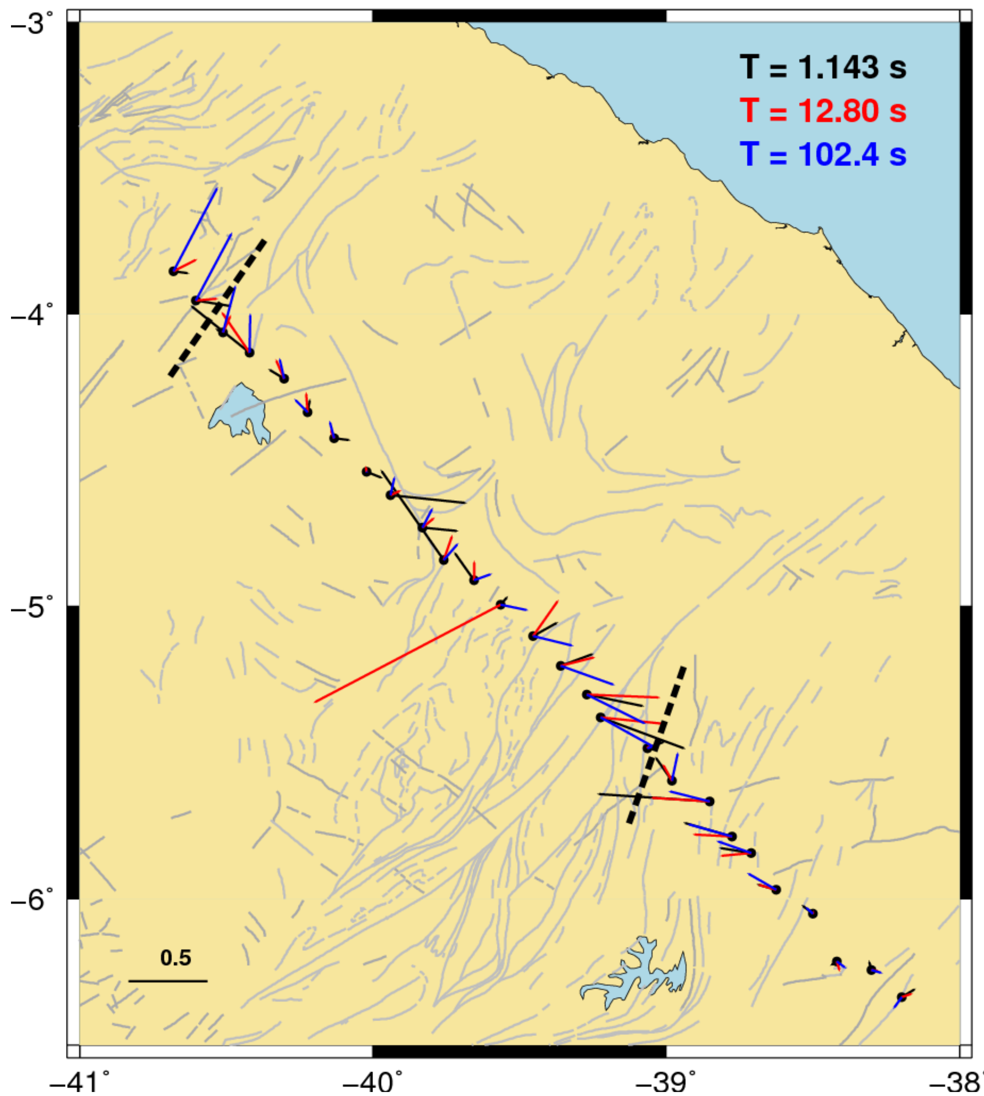

Figure 2 – Real induction arrows from single-station transfer functions for three periods at increasing depths in the Earth. Responses in the periods of 1 s and 100 s are thought to be influenced mainly by the upper crust and lower crust/lithospheric mantle, respectively. Arrows have been reversed to point towards induced internal currents.The dashed lines represent major geoelectrical discontinuities inferred by reversion in the arrow directions.

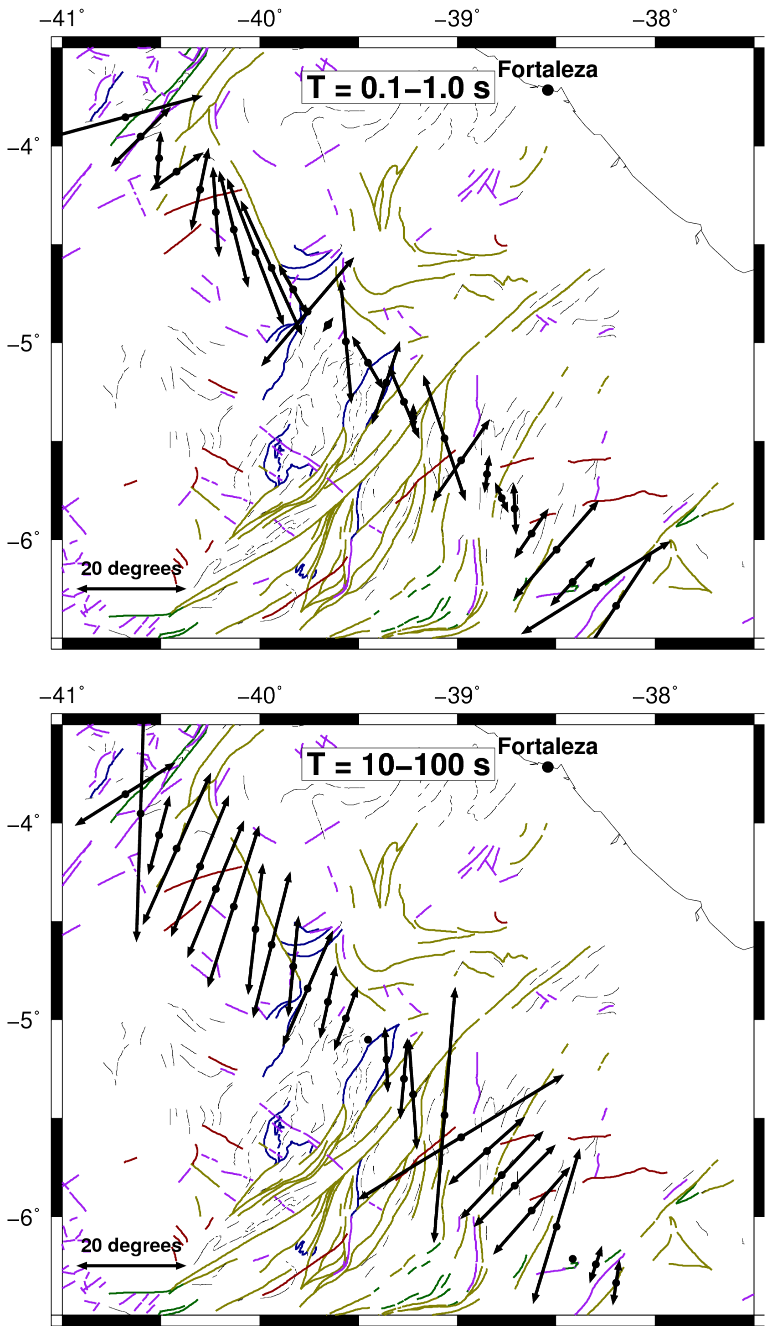

Figure 3 – The unconstrained Groom – Bailey regional strike is shown (headed bars) for each site at two period bands at increasing depths in the Earth. Bar lengths are proportional to the average phase difference between the off-diagonal elements of the recovered regional 2D impedance tensor.