Geoelectrical framework between the onshore Espírito Santo Basin and the Araçuaí Orogen from 3D magnetotelluric inversion

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Abstract

The Espírito Santo Basin and the Araçuaí Orogen were extensively investigated in previous studies. However, geophysical studies comprising these two domains at the same time and considering the diverse aspects of their evolutions are limited. Thus, this study investigated the region comprehended by the onshore Espírito Santo Basin and the Araçuaí Orogen through a MT profile distributed W-E along the Espírito Santo State. Three-dimensional magnetetulleric inversion was performed to model the data. A resistivity profile was extracted from the 3D model to perform interpretations. The resistivity pattern of the profile revealed three conductors in the crust. These conductors might be consequences of a recent circulation of saline fluids that may be related to plume action in the region. The structures that these fluids circulate present different genesis along the profile, corresponding to evolutionary processes of each domain. Westwards associated with the gravitational collapse of the Orogen and eastwards with the basin development.

Introduction

The investigated region in this study corresponds to a part of the onshore portion of the Espírito Santo (ES) Basin and its limits with the adjacent crystalline portion, associated to the Araçuaí Orogen, in southeastern Brazil.

Two main geological contexts characterize the study area: 1) formation and evolution of the Araçuaí-West Congo Orogen (when considering the African counterpart) during the Neoproterozoic that resulted in the crystalline zone corresponding to the Araçuaí Orogen (Alkmim et al, 2007); 2) development of the South American continental margin basins which started with the breakup of the supercontinent Gondwana that resulted in the sedimentary zone characterized by the onshore portion of the Espírito Santo Basin with the rocks of the Araçuaí Orogen as basement. Figure 1 illustrates the division between the older crystalline zone and the more recent sedimentary zone, showing the maximum ages identified for surface rocks in the Espírito Santo State. The location of the MT stations used in this study is also shown in the map.

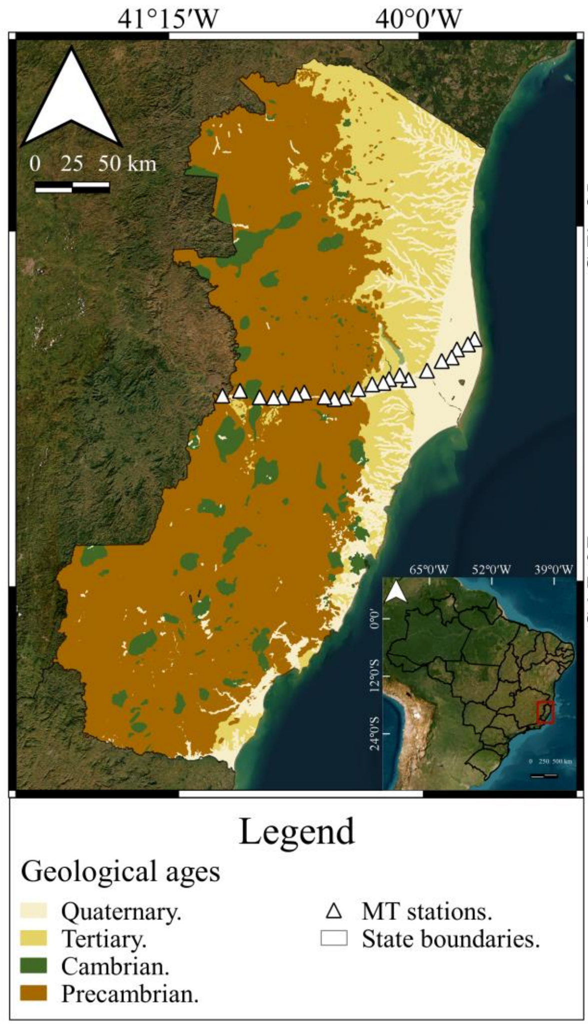

***Figure 1** – Study area location. Simplified map for maximum geological ages in the Espírito Santo state. The location of the magnetotelluric stations is indicated by the triangles.*

Furthermore, magmatic-tectonic events that occurred during the two contexts of the region's evolution are possible to highlight. Initially, with the processes resulting from the formation and evolution of the Rio Doce arc and the gravitational collapse of the Orogen and the generation of plutons and dikes associated with the main structural lineaments of the region (Belém, 2014; Gradim et al., 2014; Santiago et al., 2019). In the case of the study region, the Colatina Lineaments. Subsequently, with the events that formed the Espírito Santo Basin, where two main moments of magmatic activity are recognized: the first during the Rift phase (which generated the Cabiúnas Formation) and the second during the Drift phase (which resulted in the Abrolhos Bank) (França et al., 2007). Figure 2 presents the geology within the boundaries of the area of interest, so that one can identify the different types of granites generated along the orogenic evolution, as well as the sedimentary formations associated with the basin. The limits of the Colatina Lineaments are also displayed in Figure 2.

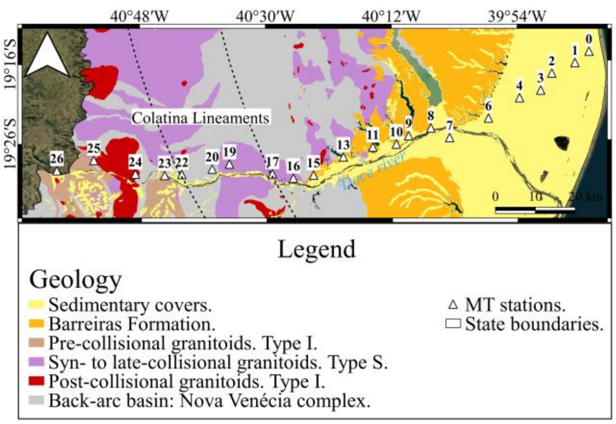

Figure 2 *– Simplified geological map of the study area. The limits of the Colatina lineaments, a main structural feature in the area, are also shown in the map.*

In addition, the possible action of a plume in the vicinity of the study region can also be noted. Such consideration is mainly based on the observation of the submarine Vitória-Trindade chain and its compositional genetic correspondences with magmatic provinces in the interior of the continent (Stanton et al., 2021).

Extensive studies were performed in this region for understanding the Orogen and its evolutionary processes (e.g., Alkmim et al., 2007; Pedrosa-Soares et al., 2007; Alkmim et al., 2017) and for understanding the basin and its implications for industry (e.g., Biassusi et al., 1990; França et al., 2007; Tagliari et al., 2013). However, the study region has few works that performed geophysical investigations aiming for a broader understanding of the implications that evolutionary events of the region have on the arrangement of elements in the subsurface of each domain (crystalline and sedimentary portions).

A geophysical study in this area was performed by Costa (2005). A magnetotelluric (MT) investigation with stations arranged along a profile cutting the state of Espírito Santo from east to west was performed and the data was modeled through 2D MT inversion. Costa (2005) identified deep conductive structures in the crust associated with the Precambrian crystalline basement (the Araçuaí Orogen). However, the limitations imposed by the 2D inversion methodology in regions where there is a strong three-dimensional trend (Garcia et al., 1999) in the data raise the possibility that the model may not be as representative of the region.

Thus, to obtain a new and more representative model for the study region, this work revisited the MT data used by Costa (2005) with the objective of modeling the region using a 3D magnetotelluric inversion methodology. For this purpose, the ModEM program (Egbert and Kelbert, 2012; Kelbert et al., 2014) for 3D MT inversion was used.

Method

The MT data was acquired between 2001 and 2002 by staff from the National Observatory, using EMI equipment. The time series acquired for each station were recorded in three frequency bands: TS1 (2 Hz), TS3 (32 Hz) and TS4 (512 or 1000 Hz).

Data processing was done using the robust method (Egbert and Booker, 1986) from the EMTF program, with the assistance of routines developed by Professor Marcelo Banik de Padua (INPE). Dimensionality analysis of the data using the phase tensor was performed to observe the subsurface behavior of this data.

After processing, the need to perform some further curve smoothing procedures was also observed, as a way to remove inconsistencies and undesirable effects that could not be circumvented with processing alone, such as some scattered or noisy points and the dead band effect. This was important for the inversion of the data, as it allowed models with lower errors to be obtained.

Finally, 3D MT inversion was performed using the full impedance tensor through the ModEM algorithm (Egbert and Kelbert, 2012; Kelbert et al., 2014). Several tests with variation of parameters, e.g., initial resistivity, smoothing or not of the curves, consideration or not of the ocean in the model, discretization of the model, and error floors, were made until the selection of the preferred model.

Results

Dimensionality Analysis

The dimensionality analysis was performed using the phase tensor (Caldwell et al., 2004), through the MTpy package (Kirkby et al., 2019; Krieger et al., 2014). From the analysis of the skew parameter of the phase tensor it was possible to observe that the ellipses showed values that indicate a 3D behavior in several periods of the data. According to the literature, (e.g., Panetto et al., 2018; Fernandes et al., 2018; Benevides et al., 2019), for skew values between -4º and 4º there is an approximately 1D or 2D trend, and for skew values >4º and <4º there is an approximately 3D trend. In this sense, short to long periods of the data presents skew angles corresponding to a 3D behavior, as displayed in Figure 3. Thus, this analysis reinforced the motivation to obtain a three-dimensional model that is more representative of the subsurface of the region.

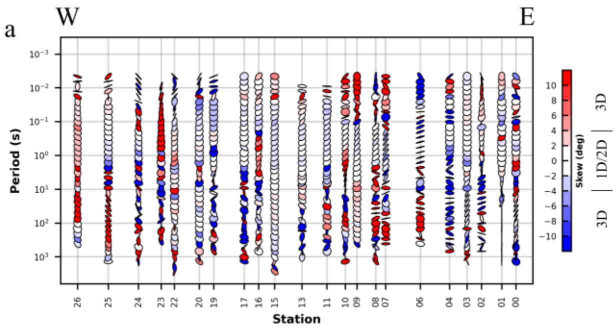

Figure 3 *– Dimensionality analysis of the data using the skew. Values of skew >-4º and <4º indicate 1D/2D tendencies of the data. Values of skew <-4º and >4º indicate 3D tendencies of the data.*

3D MT inversion

The selected model was generated from a grid with a more refined portion in the region that contains the data. The refined mesh was compounded of 30×45 cells (each cell with horizontal dimensions of 3723 m). Fourteen padding cells were added in all directions, with an increasing factor of 1.3, to avoid undesirable edge effects in the inversion process. The depth discretization was done using 90 layers, with an initial thickness of 20 m and an increasing factor of 1.1. The greater refinement of the shallower portions of the model is a way to deal with galvanic distortions present in the data.

The region is close to the ocean and coastal effects tend to have an undesirable influence on the inversion if not incorporated into the initial model. Therefore, this information was also included in the model with bathymetry data from NOAA (National Oceanic and Atmospheric) considering a resistivity of 0.3 Ω m for the ocean. The resistivity of the remaining portion of the initial model was set at 100 Ω m.

The inversion was performed using the full impedance tensor of 22 MT stations. The error floors were set at 10% of $|Zxx \times Zxy|^{1/2}$ and $|Zyx \times Zyy|^{1/2}$ for Zxx and Zyy, respectively, and 5% of |Zxy| and |Zyx| for Zxy and Zyx, respectively. The nRMS obtained with the final model was 1.68. Figure 4 presents the total nRMS for each station and the nRMS of each component of the impedance tensor for each station.

For the model interpretation, a profile (A-A') was defined from the mesh (Figure 5). The procedure of 3D interpretation of MT data distributed over a profile can be found in other studies in the literature (e.g., Panetto et al., 2017; Solon et al., 2018) that showed satisfactory results.

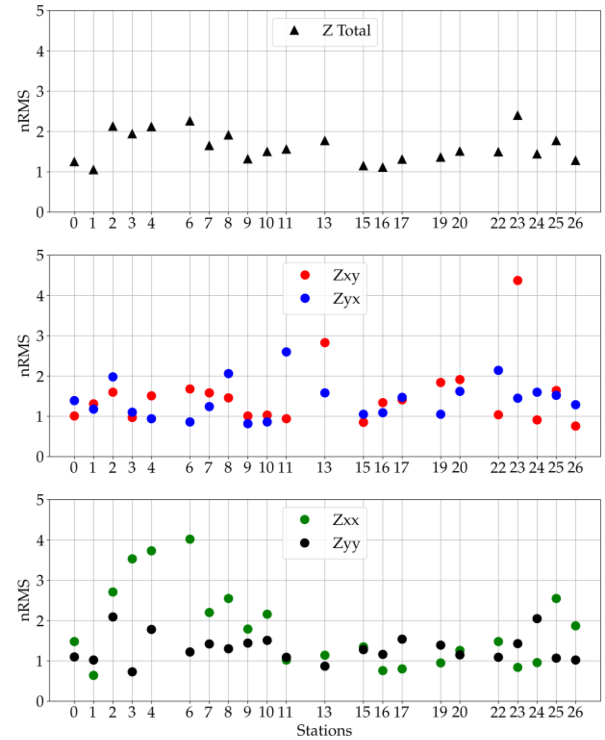

Figure 4 *– The total nRMS for each station (Z Total), and the nRMS of each component (Zxx, Zxy, Zyx and Zyy) of the full impedance tensor (**Z**) for each station.*

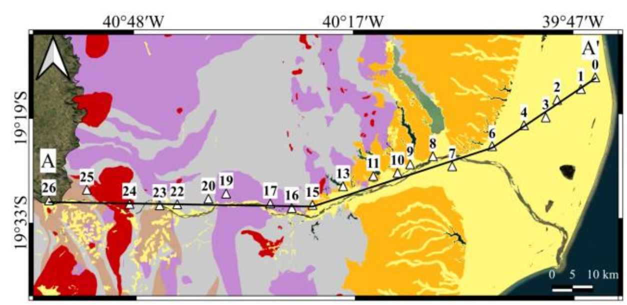

Figure 5 *– Multisegment slice used to generate the resistivity profile that was interpreted. Plot over the simplified geological map (Figure 2).*

Discussion

The A-A' resistivity profile is displayed in Figure 6. In general, the resistivity model in the region indicates a more resistive signature to the west and in the central portion of the profile (resistor R1 and R2) - in the crystalline region corresponding to the Araçuaí Orogen, and more conductive to the east - in the sedimentary region corresponding to the onshore portion of the Espírito Santo Basin. The basin is well delimited by the surface conductor in the eastern portion of the profile.

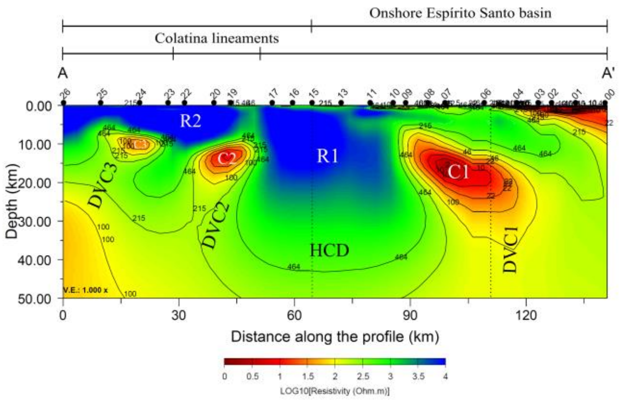

Figure 6 *– Resistivity profile used for interpretation, extracted from the 3D grid. On top of the profile are indicated the limits of the onshore Espírito Santo Basin and of the Colatina Lineaments. In the resistivity profile the main features are indicated: the conductors (C1, C2, and C3); the deep vertical conductors (DV1, DV2, and DV3) associated with the conductors; the resistors (R1 and R2) associated with the Precambrian basement (Araçuaí Orogen); and the high conductive domains (HCD). The vertical dashed lines indicate the direction changes in the multisegment (Figure 5).*

However, the presence of three crustal conductors inserted in the context of the Precambrian crystalline basement (C1, C2 and C3 conductors) is noted. These conductors are presented in association with their respective deep vertical conductors (DVC1, DVC2 and DVC3).

The association of the conductors with their respective deep vertical conductors allows to consider the possibility of a mantle origin. Thus, it is possible to mention three processes that can explain the origin, distribution, and positioning of the conductors along the profile:

I. During the gravitational collapse of the Orogen there was the generation of plutonic suites and dykes associated with the major structural lineaments developed by the orogeny that served as conduits for this ascending material (Santiago et al., 2019).

II. During the separation of Gondwana there was a reactivation of the existing lineaments. Therefore, with the rifting process and a new heat source acting in the region, there was a new circulation of material in these structures (Santiago et al., 2019).

III. During the Upper Cretaceous and Cenozoic is possible to comprehend the action of a plume in the region represented by the Vitória-Trindade chain, but it can also be comprehended in the interior of the continent in magmatic provinces (Stanton et al., 2021) In addition, post-rift events with reactivations of the structural lineaments occurred during the Upper Cretaceous and Cenozoic (Calegari et al., 2021). This favored fluid circulation in the region.

Accordingly, the conductors can be understood as a combination of these processes, so that the lower resistivities reflect a recent circulation of saline fluids in the region. Analogous to what can be seen in Costa (2005) and Panetto et al. (2018). In the present study, it is possible to relate the circulation to the plume action during the Upper Cretaceous and Cenozoic. However, the origin of the structures associated with these fluids can be distinct along the profile.

The westernmost conductors (C2 and C3) located under the boundaries of the Colatina Lineaments present flattened shapes and its DVCs show an approximately subvertical disposition. Thus, it is possible to associate them with circulation of fluids in the structures resulting from the gravitational collapse of the Orogen that resulted in the generation of plutons and dikes according to the main lineaments of the region, in this case the Colatina Lineaments.

Similarly, the easternmost conductor (C1) is possibly associated with circulation of fluids in the structures resulting from the rifting process, considering its position closer to the basin and its greater length compared to the other conductors.

Conclusions

The new investigation performed for the MT data allowed the generation of a new resistivity model for the study region based on a more representative approach, that is the three-dimensional inversion methodology. Therefore, it was possible to recognize and associate the main geological events that occurred during the region's evolution with the resistivity anomalies observed along the profile selected for interpretation.

Acknowledgments

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