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Deep structure of a stretched lithosphere: Magnetotelluric imaging of the southeastern Borborema province, NE Brazil

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ABSTRACT

Magnetotelluric data were collected at 25 stations along a NNW–SSE linear profile deployed perpendicularly to the main structures in the southeastern portion of the Borborema province, northeast Brazil. The geotectonic scenario is characterized by a broad range of tectomagmatic events including periods of compressive tectonism associated with amalgamation of lithospheric blocks during the Brasiliano orogeny in the Late Neoproterozoic, superimposed by extensional events related to the continental break-up and plate drift that led to the formation of the southern Atlantic Ocean in the Early Cretaceous. Strike analysis and distortion decomposition show that most of the data are two-dimensional (2D) but sensitive to distant off-profile structures. Data fit an ENE regional geoelectric strike direction, consistent with the geological and tectonic setup. A joint 2D inversion of the TE and TM modes defined by this strike direction was undertaken and the obtained model exhibits signatures of the different tectonic events in the area. The model suggests that the SE Borborema province is electrically separated into two parts. The first, comprising the southern domain of the province (Sergipano belt and Pernambuco–Alagoas block), has a highly heterogeneous crust and an anomalously conductive upper mantle. The second, comprising the transversal domain of the province (Alto Moxotó terrain), displays crust and upper mantle predominantly homogeneous and resistive. A deep Neoproterozoic lithospheric shear zone (Pernambuco lineament) marks the limit between the two contrasting domains. Also, the region where the Jatobá basin is located in the southern domain presents a striking conductor at upper- to mid-crustal depths beneath the basin. These results correlate well with seismic refraction data that indicate thicker crust for the transversal domain than for the southern domain, with the thinnest crust coinciding with the location of the Jatobá basin. The data support the conclusion that the lithosphere of the southern domain of the Borborema province was significantly stretched in the Cretaceous during the opening of the South Atlantic Ocean, allowing refertilization of depleted upper mantle with incompatible elements from enriched deeper mantle material and reactivation of older crustal fabrics. The conductivity increase below the Jatobá basin is associated with ionic conduction in a currently reactivated fracture zone filled with high salinity fluid. Apparently, the Alto Moxotó terrain worked as a region of higher resistance to stretching, causing the crustal thinning and geoelectric effects to be concentrated to the south of the Pernambuco lineament.

1. Introduction

The Borborema structural province, located in the northeast of Brazil, consists of a complex set of crustal blocks of different ages, origin and evolution, amalgamated during the Brasiliano/Panafrican orogeny (700 to 450 Ma). This orogeny encompasses a series of tectonic–orogenic events occurring at the end of the Late Neoproterozoic that resulted in the formation of various magmatic, metamorphic and sedimentary units in the crust (Almeida et al., 1981; Brito Neves et al., 2000). The Brasiliano orogeny strongly reworked all older terrains involved in the Borborema amalgamation, including Paleoproterozoic and Archean basement units, as well as rocks and structures formed in the Early Neoproterozoic Cariris Velhos orogeny (1000 to 920 Ma; Santos et al., 2010; Van Schmus et al., 2011). Different studies, based mainly on geochemical and geochronological data, have added to the current knowledge of the geologic and structural setting of the Borborema province (e.g. Neves, 2003; Silva Filho et al., 2002; Van Schmus et al., 2008, 2011). However, these efforts have been insufficient to understand the tectonic complexity of northeast Brazil, where the Neoproterozoic Brasiliano orogeny was superimposed by events related to the continental breakup that separated South America and Africa and led to the formation of the southern Atlantic Ocean in the Early Cretaceous (130–110 Ma).

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There are a considerable number of segments in the Borborema with their own geologic characteristics, grouped into the various domains and sub-domains proposed for the province. Although they are reasonably well known and delimited on the surface, the true nature of their limits at depth has still not been established, especially when represented by important and extensive shear zones. Also, their possible differences in geophysical signatures have not been fully determined in spite of several gravimetric, gammaspectrometric and aeromagnetic studies (e.g. Medeiros et al., 2011; Oliveira, 2008; Ussami et al., 1986) and recent seismic refraction profiles of the crust (Soares et al., 2011).

The magnetotelluric method (MT) is a passive electromagnetic (EM) geophysical exploration technique for determining the electrical conductivity distribution within the Earth. It is based on the simultaneous measurement of natural time variations in the geomagnetic field components (Hx, Hy and Hz) and the orthogonal horizontal components of the induced electric field (Ex and Ey) at the Earth's surface. Apparent resistivity and phase lags can be calculated from these mutually perpendicular EM fields at any measured period. The penetration depth of the signals increases with period and resistivity and allows the inference of lateral and vertical variations of electrical conductivity in the Earth's interior (for more details see Simpson and Bahr, 2005; Chave and Jones, 2012). MT has been extensively used over regions of complex geology in different parts of the world (examples of recent studies are Dennis et al., 2012; Savvaidis et al., 2012; Zhao et al., 2012; Padilha et al., 2013; Khoza et al., 2013).

In this paper we discuss a geoelectric model obtained by 2D inversion of MT soundings carried out in regions of different geological structures in the southeastern portion of the Borborema province in northeast Brazil. The utilized data were collected with modern instrumentation and processed and modeled with the methodology currently available to the electromagnetic induction community for studies of the Earth's interior. The 2D geoelectric section derived from the procedure described in this paper is robust in relation to the different sensitivity tests and adequately represents the distribution of electric conductivity below the profile. The results show the importance of the MT method as a tool for understanding the dynamic processes that have formed and shaped the lithosphere of the Borborema province, allowing the characterization of their different domains and sub-domains and the definition of the boundaries between them.

2. Geological setting

The Borborema province is a complex orogenic system in the northeasternmost corner of the Brazilian shield that was formed as a result of the convergence of the West African-São Luis and São Francisco–Congo cratons during the assembly of West Gondwana. Based on U–Pb and Sm–Nd isotopic data, the Borborema province comprises three large sub-provinces, delimited by extensive E–W trending lineaments (Patos and Pernambuco lineaments), known informally as northern, transversal and southern sub-provinces (Van Schmus et al., 1995, 2011). Each of these sub-provinces admits subdivisions in different domains and sub-domains characterized by some peculiar geological features and properties that allow distinguishing them from the adjacent domains and sub-domains.

The study area is located in the transversal and southern sub-provinces of the Borborema, between the Alto Moxotó terrain and the Sergipano belt. The transversal zone, where the Alto Moxotó terrain is located, is limited by the Patos and Pernambuco lineaments and encompasses several other internal segments with NE–SW structural trend (Santos and Medeiros, 1999). The southern sub-province, situated between the Pernambuco lineament and the northern margin of the São Francisco craton, consists of the Pernambuco–Alagoas (PE–AL) block, and the Sergipano and Riacho do Pontal belts (Van Schmus et al., 2011). The MT survey crosses the Alto Moxotó terrain and the PE–AL block, separated by the Pernambuco lineament, the Sergipano belt (Poço Redondo, Canindé, Marancó and Macururé sub-domains) and, the Jatobá sedimentary basin at right angles (Fig. 1).

The gneissic basement of the Alto Moxotó terrain is dominated by banded, diorite to granodiorite orthogneiss. U–Pb and Pb–Pb evaporation zircon ages indicate crystallization of their protoliths mainly around 2.1 Ga (Neves et al., 2006; Sá et al., 2002). Overlying metasedimentary rocks are grouped into two main sequences, Sertânia and Caroalina complexes (Gomes, 2001). Sertânia is dated at around 2.0 Ga (Santos et al., 2004), whereas Caroalina is interpreted to be correlated with another complex with maximum age of deposition dated at 665 Ma (Gomes, 2001; Neves et al., 2006). Both complexes are intruded by deformed mafic and felsic rocks. The Pernambuco lineament is described as a transverse and continuous shear zone, starting in the coastal plain of Recife and extending to the Parnaíba basin. It developed in the Neoproterozoic during the collisional phase of the Brasiliano orogeny. The shear zone is interpreted as a deep feature that would have reached the base of the continental crust, separating crustal blocks or terrains of distinct ages (Van Schmus et al., 1995). This interpretation was corroborated by recent geophysical investigations that suggest that the Pernambuco lineament is effectively an important divisor of different lithospheres (Oliveira, 2008; Santos, 2012). A different view has been forwarded by Neves and Mariano (1999), according to which the Pernambuco lineament is not a continuous structure, but comprises two distinct segments: the East Pernambuco shear zone and the West Pernambuco shear zone. In this way, it could not be considered as a boundary separating different terrains.

The PE–AL block is located immediately to the south of the Pernambuco lineament and has been also called as a “batholith”, “massif” or “terrane”, but in fact it is composed of many different types of protoliths and plutons (Silva Filho et al., 2002). It is mainly formed of orthogneisses and migmatites with quartzite intercallations, and also presents peraluminous granite bodies and banded migmatites with mesosomes of diorite to tonalite composition and syenogranite leucosomes. Neoproterozoic plutonism is represented by peraluminous intrusions, and a smaller volume of calc-alkaline intrusions (Silva Filho et al., 2002). East and north portions of the basement include remains of the Paleoproterozoic crust and Archean relics, while the southeast portion presents Mesoproterozoic ages (Van Schmus et al., 2008).

The Jatobá sedimentary basin represents the northernmost portion of the Recôncavo–Tucano–Jatobá (RTJ) rift system and extends for more than 5000 km^2 across the continent in NE Brazil (Costa et al., 2007). The basin is located on the PE–AL block and is filled with a package of more than 3000 m of siliciclastic rocks, made up mainly of sandstones, siltstones, shales and conglomerates. Its origin is related to a series of thermomechanical events that took place in Early Cretaceous and is structurally characterized as a hemigraben with the substrate composed predominantly of rotated blocks (Peraro, 1995). Ussami et al. (1986) suggested that this basin was formed by the extension and lithospheric rifting that led to the South Atlantic opening.

According to Oliveira et al. (2010) much of the Sergipano belt was formed by compression between the São Francisco craton and the Borborema province during the Brasiliano orogeny. During this convergence, the PE–AL acted as a major crustal block, compressing units of the Sergipano belt against the São Francisco craton. The Sergipano belt consists of six lithostratigraphic domains: Estância, Vaza Barris, Macururé, Marancó, Poço Redondo and Canindé, each separated from the other by major shear zones. The Estância and Vaza Barris domains are not part of the study area and therefore they will not be discussed further in this paper. The Macururé domain lies to the north of the Vaza Barris from which it is separated by the São Miguel do Aleixo shear zone, a major crustal boundary. The Macururé domain comprises amphibolite facies, garnet-bearing metaturbidites, feldspathic aluminous micaschists with minor intercalations of quartzite, marble and meta-volcanic rocks, and lenses up to 200 m across of amphibolite, garnet amphibolite and chlorite schist, intruded by granite plutons. Depositional