Precambrian Research 275 (2016) 70–83

Contents lists available at ScienceDirect

Precambrian Research

journal homepage: www.elsevier.com/locate/precamres

Deep magnetotelluric signatures of the early Neoproterozoic Cariris Velhos tectonic event within the Transversal sub-province of the Borborema Province, NE Brazil

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ARTICLE INFO

Article history:
Received 16 June 2015
Received in revised form 4 December 2015
Accepted 15 December 2015
Available online 23 December 2015

Keywords:
Northeast Brazil
Borborema Province
Magnetotellurics
Subduction zone
Neoproterozoic
Cariris Velhos Orogeny

ABSTRACT

The Borborema structural province, in northeast Brazil, consists of a complex set of crustal blocks of different ages, origin and evolution, with final amalgamation during the late Neoproterozoic Brasiliano Orogeny. In the central part of the province, its Transversal sub-province is characterized by elongate NE-SW terranes largely affected by the Brasiliano metamorphic overprinting and by a suite of early Neoproterozoic metavolcanic and metaplutonic rocks, reflecting a distinct tectonic event (Cariris Velhos). Magnetotelluric (MT) data were collected at 64 stations along four profiles across this central region of the province to assess its deep electrical resistivity structure. Dimensionality analysis shows that the subsurface is electrically dominated by 3D structure, and 3D inversions of the full impedance tensor and vertical magnetic transfer function (tipper) were carried out. Data fit is relatively good with an acceptable distribution of the misfit between the sites and the dominant features in the final model are north-dipping crustal conductors, which can be tentatively correlated between the different MT profiles and cross contrasting terranes at the surface of the province. Considering the geometry and distribution of the conductors, it is proposed that they might reflect remnants of a north-directed subduction zone with enhanced conductivity associated with graphitized biogenic material in metasedimentary rocks originally deposited in a restricted oceanic environment and subsequently metamorphosed and introduced into the deep crust by the subduction of the oceanic lithosphere. Constrained by isolated outcrops of early Neoproterozoic rocks with oceanic affinity, the proposed subduction event may have taken place during the Cariris Velhos Orogeny with the crustal remobilization by the Brasiliano Orogeny being restricted to the brittle upper crust. This interpretation gives support for an accretionary model to the Neoproterozoic geodynamic evolution of the Borborema Province.

1. Introduction

The Borborema Province (area of about 450,000 km^2; Almeida et al., 1981) is a complex orogenic system in northeastern Brazil commonly interpreted as resulting from the convergence and final collision of the West African-São Luis and São Francisco–Congo cratons in the context of West Gondwana amalgamation. Its current structural configuration is associated with the Brasiliano/Pan-African Orogeny that occurred in the late Neoproterozoic-early Phanerozoic, during which the province was strongly affected by diachronic episodes of deformation, metamorphism, and magmatism (Brito Neves et al., 2000). The Brasiliano Orogeny affected the entire Borborema Province and was responsible for low- to high-grade metamorphism, emplacement of a great abundance of granite plutons, and development of a complex network of continental-scale steeply dipping shear zones, mainly striking E-W and NE-SW (Vauchez et al., 1995). Two major E-W trending shear zones (Patos and Pernambuco) divide the province into three segments, informally referred to as northern, Transversal (or central) and southern sub-provinces (Van Schmus et al., 1995, 2011). Numerous ductile transcurrent shear zones cut these main sub-provinces, several of which interpreted as marking the limits between terranes of contrasting origin and evolution that allows the subdivision of the sub-provinces in different domains.

At the end of the Brasiliano Orogeny, the different crustal blocks appear to have been variably uplifted along the major lineaments (Monié et al., 1997), either as a result of reactivation of extensive shear zones under ductile-brittle conditions, associated

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http://dx.doi.org/10.1016/j.precamres.2015.12.012
0301-9268/

with post-tectonic isostatic adjustments or with thermal doming related to Tertiary volcanism (Morais Neto and Alkmin, 2001). Finally, superimposed on the Precambrian framework is a set of features related to the continental breakup that resulted in the opening of the Atlantic Ocean in the Cretaceous (Brito Neves et al., 2000). These include interior basins developed on zones of Precambrian weakness (Araripe, Rio do Peixe, Iguatu, Icó, Jatobá) and basins from the continental margin (Ceará, Potiguar, Pernambuco-Paraíba, Alagoas, Sergipe).

The structures of the province are supposed to stretch beyond its formal boundaries and are probably covered to the west by the Phanerozoic deposits of the Parnaíba Basin and to the north and east by Meso-Cenozoic basins of the coastal and continental margins (Brito Neves et al., 2000). Also, in pre-drift reconstructions, the Borborema Province lies adjacent to coeval Pan-African fold belts and cratonic terranes from western Africa (Toteu et al., 2001) and strong geologic evidence indicates that some major shear zones, litho-structural and tectonic domains of the province find their counterpart in the African continent (e.g., Arthaud et al., 2008; Castaing et al., 1994; Santos et al., 2008; Trompette, 1994; Van Schmus et al., 2008).

As a result of several programs of regional and detailed geological mapping, gravity and airborne geophysical surveys and significant advances promoted by geochemical and isotopic studies, the litho-structural and geochronological characteristics of surface rocks of the Borborema Province are reasonably well known (Brito Neves et al., 2000; Neves, 2003; Van Schmus et al., 2011). However, deep crustal and uppermost mantle structure is relatively unknown and, consequently, dynamic processes involved in the formation and evolution of the province are still poorly understood. As an example, the geodynamic evolution of the Borborema Province during the Neoproterozoic is disputed, with two opposing views for the tectonic setting in which magmatic and deformational events took place. In one model, the province is regarded as a system of allochthonous orogens that were amalgamated during accretionary orogenic events (Fuck et al., 2008). The other model proposes an essentially intracontinental development, with intraplate tectonism driven by far-field stresses reworking preexisting Archean–Paleoproterozoic crust (Neves et al., 2006).

To investigate the regional tectonics in the Borborema Province, a program of deep geophysical surveys is being conducted (Instituto Nacional de Ciência e Tecnologia de Estudos Tectônicos—INCT-ET) and includes deep seismic refraction experiments, seismological studies using teleseismic data and magnetotelluric (MT) surveys, supplemented by further structural, tectonic, geochemical and geochronological studies. This MT study is part of that effort and has as main goal to find possible sutures or relics of ancient structures in the concealed basement terranes that can be related to ocean closure, crucial to understand the Proterozoic evolution of the province, and also to identify distinct geophysical signatures in lithospheric blocks supposed to have independent origins and tectonic histories prior to the suggested accretionary events.

The MT method measures the electrical conductivity of the medium, which is sensitive to very small changes in minor but tectonically important constituents of the rock (fluids, graphite, melts, etc.), and hence provides an alternative and complementary view of lithospheric structure to those given by other geophysical or geochemical approaches. MT has proved to be an efficient technique for reliable reconstructions of ancient collisional and accretionary processes, especially in regions where many of the characteristic features of collision are no longer preserved in deeply eroded orogens. In fact, MT results from different ancient and modern subduction and/or collision zones have shown that suture zones resulting from the accretion of terrains usually produce a series of conductive and resistive features throughout the lithosphere (Jones, 1993; Unsworth, 2010). The most salient of these features are commonly dipping high conductivities observed along terrane boundaries and sutures in a number of ancient subduction zones, often interpreted as resulting from graphite or sulfides emplaced, metamorphosed and remobilized in the lower crust or deeper during subduction and/or orogenesis (Boerner et al., 1996). These dipping conductive features are reported at mid- and lower-crust depths in a number of MT studies carried out throughout the world in inactive tectonic regions and are interpreted as representing paleosutures related to the closing and consumption of oceanic lithospheres in fossil subduction zones (e.g., Bologna et al., 2014; Hjelt and Korja, 1993; Selway et al., 2009).

Examples of recent MT studies in other sectors of the Borborema Province are Padilha et al. (2014) and Santos et al. (2014). Padilha et al. (2014) discuss evidence of Neoproterozoic oceanic closure below the northwesternmost part of the northern sub-province. A double convergent subduction is proposed below a magmatic arc in this region, with former westward subduction leading to collision of an earlier passive margin with an intraoceanic arc followed by a latter reversion of subducting polarity. Santos et al. (2014) display differences in the rheological behavior between the southern and Transversal sub-provinces during Cretaceous extensional activity that culminated in the fracturing and rupturing of the Gondwana continent. It is shown that the southern domain was significantly stretched as a consequence of stresses generated by the South Atlantic Ocean opening, whereas the rheologically stronger Transversal domain worked as a region of higher resistance to stretching.

The study reported here was carried out along profiles crossing the Transversal sub-province, which lies between the Patos and Pernambuco shear zones. This is a complex, heterogeneous domain characterized by elongate NE-SW terranes, for which distinct petrotectonic associations, metamorphism, plutonism and geochronological signatures have been proposed (Brito Neves et al., 2000), and by a suite of early Neoproterozoic metavolcanic, metasedimentary and metaplutonic rocks reflecting a distinct event and lithostratigraphic assemblage (Cariris Velhos event; Santos et al., 2010). The geoelectric structure is investigated through three-dimensional (3D) inversion of the MT data, which provides models of the deep crustal electrical conductivity beneath this part of the province and allows mapping of dipping conductive features interpreted as remains of Neoproterozoic collision and subduction activities.

2. Geological background

The Borborema Province in northeasternmost Brazil was part of West Gondwana, which was affected by complex magmatic, tectonic, and thermal phenomena spanning from the Archean to the early Phanerozoic (Brito-Neves et al., 2000; Van Schmus et al., 2011). Generally, the geology of the province comprises several Mesoproterozoic to Neoproterozoic metasupracrustal sequences deposited over gneissic/migmatitic basement complexes, mostly formed during Paleoproterozoic orogenic events that preserved minor Archean blocks, and subsequently intruded by large granitoids of Neoproterozoic to early Phanerozoic age (Fig. 1).

The northern sub-province lies north of the Patos shear zone and is dominantly comprised of Paleoproterozoic meta-igneous basement including local Archean rocks and subordinate metasedimentary rocks. Based mainly on isotopic studies and geochronology of basement rocks, this sub-province has been traditionally divided into three main crustal blocks: Médio Coreaú, Ceará Central, and Rio Grande do Norte (e.g., Van Schmus et al., 2008). The Médio Coreaú and Ceará Central domains are divided by the Sobral-Pedro II shear zone, whereas the limit between the Ceará Central and Rio Grande do Norte is located along the Senador Pompeu shear zone (Brito