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Deep crustal structure of the Sergipano Belt, NE-Brazil, revealed by integrated modeling of gravity, magnetic, and geological data

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Abstract

The Sergipano Belt is located in the Southern Subprovince of Borborema Province in the Northeast of Brazil. Its tectonic framework was consolidated in the Pan-African-Brasiliano Orogeny at the end of the Neoproterozoic. The most recent geological models indicate that its evolution occurred over a complete Wilson Cycle. Gravity and magnetic data profiles that crossed the Sergipano Belt from south to north were modeled jointly by the forward method to provide a 2D view of the deep crustal structure. The modeling process was linked and supported by the use of geological data and models. The result revealed the deep structure of the crust and identified the geometry of the main geological domains to the depth of Moho discontinuity. The folds and thrusts toward the São Francisco Craton are a persistent and deep feature in the Southern crust of the Sergipano Belt. The general tectonic context of the models is compatible with the subduction and collision of the São Francisco Paleoplate under the Pernambuco-Alagoas Superterrane, sutured in the São Miguel do Aleixo Shear Zone. The presence of dense blocks at the base of the crust was interpreted as layers of ophiolites placed by obduction. The metasediments of the Vaza Barris and Macururé domains are tabular bodies with thicknesses lower than 5 km, which dip horizontally or at a low angle on the flanks of the shear zones. Small vertical bodies of lower density within the Macururé Domain have correlation with granitic intrusions. In the Canindé Domain there is a dense layer in the lower crust that was interpreted as the relicts of the oceanic crust that based a back-arc basin. The granitic bodies modeled north of the Canindé Domain and correlated with the Serra do Catu batholith in Pernambuco-Alagoas Superterrane, may be the record of subduction of this crust to the north. The data and models revealed geophysical differences between the Jirau do Ponciano and Rio Coruripe domains, and the crust north of the Palmeira dos Índios Shear Zone. These terranes are separated by shear zones with evident expression in gravity and magnetic data. However, the existence of Neoproterozoic metasedimentary supracrustal rocks partially covering both the domains and zones and the boundary shear indicates that the junction among these blocks occurred before the deposition of Neoproterozoic sediments.

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1. Introduction

The geotectonic models of the Sergipano Belt (Figure 1) have changed over time from a geosynclinal basin (Santos and Silva Filho 1975; Brito Neves et al. 1977; Silva Filho et al. 1978) to a complete Wilson Cycle (Oliveira et al. 2010). In the intermediate phases of the knowledge evolution, the lithological and structural differences observed among the Estância, Vaza Barris, Macururé, Marancó, Poço Redondo and Canindé domains (Figure 1) favored the conception of allochthonous terranes collage through large horizontal displacements of shear zones (Davison and Santos 1989). The formation of a classic orogenic basin between the São Francisco Caton and the Pernambuco-Alagoas Superterrane (Brito Neves and Silva Filho 2019) followed by the deformation and metamorphism of the sediments generating a belt of folded and thrusted rocks to the São Francisco Craton during the Brasiliano Orogeny was proposed by D'el-Rey Silva (1995a). Although there is no definitive evidence of the existence of ophiolites, the most recent model of a complete Wilson Cycle was favored by the observation of the relation between deformation, geochronological and geochemical data that indicated the occurrence of accretionary processes associated with the interaction between the São Francisco Craton and the Pernambuco-Alagoas Superterrane, both sutured in the São Miguel do Aleixo Shear Zone (Oliveira et al. 2010; Oliveira

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and Medeiros 2018). In this context, an important component was the U-Pb dating of granitic magmatism that recorded the pre, sin and post collisional stages of the orogenic cycle (Bueno et al. 2009; Oliveira et al. 2015a); as well as, the U-Pb geochronology of detrital zircons and Nd isotopes of sediments that allowed the identification of erosion sources of the rocks that filled the Neoproterozoic basins (D'el-Rey Silva 1999; Oliveira et al. 2010; Oliveira et al. 2015b). This model was also favored by the existence of a regional geological context that connects the Sergipano Belt with the Yaoundé Belt in Africa and establishes its importance in the formation of the West Gondwana Supercontinent (Oliveira et al. 2006; Van Schmus et al. 2008). More recently, Passos et al. (2021) identified the formation of back-arc basins in the Canindé Domain, providing further evidence for the evolution model of the Sergipano Belt by opening and closing of oceans.

The use of geophysical data integrated with geological information is a fundamental tool for the in-depth reconstruction of the crustal framework of geotectonic domains. In particular, gravity and magnetic data have been used to understand the configurations of terranes with different types of tectonic evolutions, especially folded belts of different ages (e.g., Gibb et al. 1983; Karner and Watts 1983; Ussami and Molina 1999; Holm et al. 2007; Mishra and Ravi Kumar 2014; Rajaram and Anand 2014; Oliveira and Medeiros 2018; Almeida et al. 2021; Drenth et al. 2021; Santos et al. 2021). However, geophysical data have been little used to understand the deep crustal structure of the Sergipano Belt. In a regional research study of the Borborema Province, Oliveira (2008) observed that, compared to the Riacho do Pontal Belt, the region of the Sergipano Belt located between the Tucano Basin and the Sergipe-Alagoas Basin does not present in the gravity data an evident suture line with the São Francisco Craton. According to Oliveira (2008), no paired positive-negative gravity anomalies of large amplitude and wavelength were identified in the Sergipano Belt indicating fossil records of sutures associated with thrust and flexure of plates similar to the pattern described by Thomas and Tanner (1975), Gibb and Thomas (1976) and Gibb et al. (1983) in the Canadian Shield and also observed in Brazilian orogenic belts, such as the Araguaia belt (Usami and Molina 1999), Brasília (Berrocal et al. 2004) and Riacho do Pontal (Oliveira and Medeiros 2018). With the knowledge evolution, Oliveira and Medeiros (2018) using gravity and magnetic data reviewed the interpretations of Oliveira (2008) and proposed a suture line in the São Miguel do Aleixo Shear Zone, according to the proposal of the geotectonic model of Oliveira et al. (2010). Likewise, 2D modeling of gravity and magnetic data performed by Dutra et al. (2019) were able to separate the signal associated with the upper crust from the Vaza Barris, Macururé, Jirau do Ponciano and Rio Coruripe domains, but did not demonstrate how these domains are tectonically articulated in depth. More recently, Almeida et al. (2021) processed and interpreted magnetic data and concluded by separating the Sergipano Belt by the Belo Monte - Jeremoabo Shear Zone in two domains: external to the south and internal to the north. A range of magnetic anomalies with a width of 10 km, length of 100 km and with a strong magnetization gradient, coinciding with the Rio Coruripe and Canindé domains, was named by Almeida et al. (2021) High-Intensity Magnetic Zone (HIMZ) and considered the suture between the São Francisco Craton and the Pernambuco-Alagoas Superterrane. In turn, with the use of a magnetotelluric profile of direction NE-SW, which crossed the Tucano Basin in an oblique angle, Corrêa-Gomes et al. (2022) interpreted the geoelectric section image as being the interaction between two crustal blocks, the most resistive to NE representing the crust of the Pernambuco-Alagoas Block and the least resistive to SW representing the São Francisco Craton. The interface between the two blocks, with dip to the southwest, was interpreted as a suture produced by the indentation of the NE Block in the SW Block during a Brasiliano collision.

In this context, this study presents the results of direct 2.5D joint forward modeling of gravity and magnetic data, in integration with the available geological knowledge, of two N-S oriented profiles that cross the eastern portion of the Sergipano Belt (Figure 1). The objective was to build sets of density and magnetic susceptibility models that help the understanding of the deep crustal structure of the Sergipano Belt crust resulting from the collision of the São Francisco Craton with the Pernambuco-Alagoas Superterrane, in the region located between the Tucano and Sergipe-Alagoas basins. The geological interpretation of geophysical models for the understanding of regional tectonic frameworks is a task that requires the ability to understand the limitations that geophysical data impose on the interpreter and the expertise of integrating geophysical and geological data. In this study, the modeling was linked and supported by the use of geological data. It is a fact that geophysical models can offer only a frozen view of the final events that have acted in the tectonic environment under study. However, there is no other way to access deep information beyond the use and modeling of geophysical data. Therefore, the method used and the results of this work were able to produce an adequate and geologically coherent view of the deep crustal structure of the Sergipano Belt to the depth of the Moho discontinuity resulting from the collision between the São Francisco Craton and the Pernambuco-Alagoas Superterrane at the end of the Neoproterozoic.

2. Geological synthesis of the Sergipano Belt

The Sergipano Belt, located in the Southern Subprovince of Borborema Province (PB) (Figure 1), has a tectonic configuration that was produced by the collision of the São Francisco Craton (CSF) with the Pernambuco-Alagoas Superterrane (PEAL) in the Ediacaran during the Pan-African–Brasiliano Orogeny (Davison and Santos 1989; D'el-Rey Silva 1995a, 1995b; D'el-Rey Silva 1999; Oliveira et al. 2010). In this work we adopted the designation Pernambuco-Alagoas Superterrane, according to the understanding of Brito Neves and Silva Filho (2019), replacing traditional names of massif and domain.

The tectonic compartmentalization of the Sergipano Belt is traditionally separated into five domains composed of metasedimentary or metavolcano-sedimentary Neoproterozoic sequences (Figure 1), Estância, Vaza Barris, Macuré, Marancó-Poço Redondo and Canindé; and three domains with rocks of the Archean-Paleoproterozoic basement: the São Francisco Craton in the south, and the Jirau do Ponciano and Rio Coruripe domains in the north. In this paper, we will consider that the basement rocks of the Neoproterozoic metasediments in the Jirau do Ponciano and

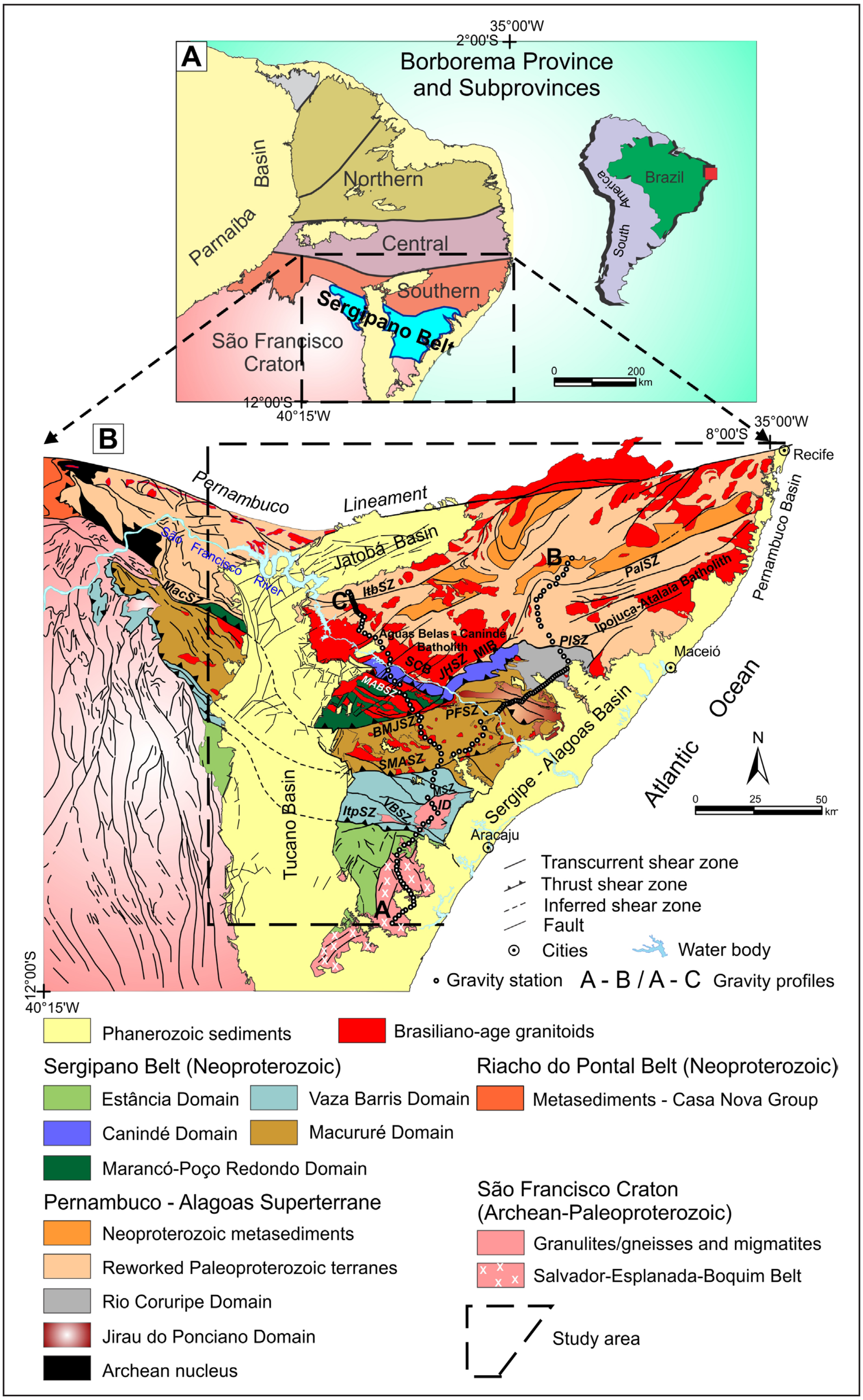

FIGURE 1 – A) Borborema Province and its subprovinces in the geographic context of Brazil and South America. B) Regional geological-tectonic context of the Sergipano Belt in the Southern Subprovince of the Borborema Province and northeast of the São Francisco Craton, modified and simplified from Bizzi et al. (2003). The gravity stations of the profiles are indicated. ID - Itabaiana Dome, SCB - Serra do Catu Batholith, MIB - Major Isidoro Batholith. The shear zones (SZ) are identified by the following abbreviations: ItpSZ - Itaporanga, VBSZ - Vaza Barris; MSZ - Mocambo, SMASZ - São Miguel do Aleixo, BMJSZ - Belo Monte - Jeremoabo, MABSZ - Mulungu - Alto Bonito, JHSZ - Jacaré dos Homens, PFSZ - Porto da Folha, PISZ - Palmeira dos Índios, PalSZ - Palmares, ItbSZ - Itaíba, MacSZ - Macururé.

Rio Coruripe domains are exposures of the Pernambuco-Alagoas Superterrane in the Sergipano Belt.

In the south, on the crust of the São Francisco Craton, there are late-orogenic (Ediacaran) continental siliciclastic-carbonate deposits, little deformed and of low metamorphic degree of the Estância Group (Estância Domain) (Silva Filho et al. 1978; Davison and Santos 1989). The Vaza Barris Domain consists of Cryogenian metasedimentary sequences (Miaba and Vaza Barris groups; Silva Filho et al. 1978; Davison and Santos 1989) and domes of the Archean basement (D'el-Rey Silva 1995b), structured by large-sized antiformal and synformal folds, with vergence for SSW, associated with thrusts and shear belts (Oliveira et al. 2010). The Macururé Domain represents the metamorphosed and deformed core of a Neoproterozoic basin filled with turbidites of dominantly pelitic composition, with sandstones on the base in unconformity contact with the Archean-Paleoproterozoic Basement of the Jirau do Ponciano Domain and Paleoproterozoic of the Rio Coruripe Domain (Silva Filho et al. 1978; Davison and Santos 1989; Mendes et al. 2009; Oliveira et al. 2010; Oliveira et al. 2015b). The Marancó – Poço Redondo Domain is separated into two subdomains: the Marancó where a sequence of felsic, mafic and ultramafic metavolcanic rocks with intercalations of metasediments (Tonian to Ediacaran) (Silva Filho 2006; Oliveira et al. 2010); and the Poço Redondo composed of gneisses and tonalitic-granodioritic migmatites, whose calc-alkaline composition and the orthogneisses dating suggest generation in a continental magmatic arc in Tonian (Van Schmus et al. 1995; Carvalho 2005; Oliveira et al. 2010). To the north of the Marancó - Poço Redondo Domain, a metavolcano-sedimentary sequence hosts an intrusive mafic-ultramafic suite both composing the Canindé Domain, interpreted as an intracontinental rift (Oliveira et al. 2010) or a back-arc basin (Lima et al. 2018; Passos et al. 2021). The dating of these rocks indicated a sedimentation and magmatism activity that may have started in the Cryogenian (Oliveira et al. 2010). Additionally, the tectonic extension processes that occurred in the Canindé Domain may have evolved to the stages of oceanic crust formation, followed by subduction and formation of magmatic arcs (e.g., Passos et al. 2021).

From the evaluation of geological, structural and geochronological data, Oliveira et al. (2010) attributed to the Sergipano Belt a complete orogenic cycle associated with the formation of the Western Gondwana Supercontinent. In the collision, the São Francisco Craton, with an important Archean heritage and consolidated in Paleoproterozoic (e.g., Teixeira et al. 2000), behaved as a western foreland, more rigid and stable than the Paleoproterozoic basement of the Pernambuco - Alagoas Superterrane (Brito Neves and Silva Filho, 2019), that was reworked during Brasiliano Orogeny and worked as the continent where Neoproterozoic magmatic arcs were installed (Brito et al. 2009; Silva et al. 2015; Soares et al. 2022). At the final stage of the orogenic cycle, transcurrent and compressional shear zones were produced (Itaporanga, São Miguel do Aleixo, Belo Monte - Jeremoabo, and Porto da Folha shear zones) that juxtaposed different crust levels and terrains with distinct geological characteristics (Davison and Santos 1989).

During the Brasiliano Orogenesis, granitic magmatism occurred with greater expression in the Macururé and Marancó - Poço Redondo domains (e.g., Silva Filho et al. 1997; McReath et al. 1998; Bueno et al. 2009; Oliveira et al. 2010; Oliveira et al. 2015a). Most of these intrusions are high-K calc-alkaline, magnesian and meta-aluminous (Oliveira et al. 2015a). Also, at the edge of the Sergipano Belt with the Pernambuco-Alagoas Superterrane granitic intrusions were identified that may represent the record of continental magmatic arcs generated by subduction of oceanic crust under the Pernambuco-Alagoas Superterrane (e.g., Brito et al. 2009; Silva et al. 2015; Soares et al. 2022). In this context, the Serra do Catu batholith with lithotypes belonging to the shoshonitic-ultrapotassic series presents geochemical signature related to subduction in a continental arc environment (Brito et al., 2009). In addition, the medium to high-K calc-alkaline Major Isidoro tonalite-granite batholith may represent a relic of a magmatic arc installed in the Pernambuco-Alagoas Superterrane during the Ediacaran (Silva et al. 2015).

3. Materials and methods

3.1 Geophysical data

Bouguer gravity anomaly data is part of an organized database for the Borborema Province and adjacent oceanic region. The methodologies used to survey, process, adjust and integrate this database are described in detail in Oliveira (2008), Oliveira and Medeiros (2012) and Oliveira and Medeiros (2018). The data are referenced to the International Gravity Standardization Net-1971. It was calculated: instrumental drift, normal gravity (International Gravity Formula of 1967), tide correction, gravity value and free-air and Bouguer anomalies referenced to the average sea level. In the calculation of Bouguer anomaly, the average topography density of 2,670 kg/m³ was adopted. The residual component of the Bouguer anomaly (Figure 2) was obtained prior removal of a wavelength of 300 km from the original data, according to the procedure described in Oliveira (2008) and Oliveira and Medeiros (2018). The removal of the long wavelength of the original gravity data highlighted intracrustal sources, in a way to provide a better correlation in map with known geological data and models (e.g., D'el-Rey Silva 1995a; D'el-Rey Silva 1999; Davison and Santos 1989; Oliveira et al. 2010; Passos et al. 2021). Most of the gravity data presented in this work are public domain and can be obtained from the National Gravimetric Database (BNDG-Banco Nacional de Dados Gravimétricos) of the Brazilian National Agency of Petroleum (ANP-Agência Nacional de Petróleo).

Airborne magnetic (Figure 3) and gamma-ray spectrometric data (Figure 4) were surveyed from the Paulo Afonso-Teotônio Vilela, Pernambuco-Paraíba, Borda Leste do Planalto da Borborema, and Oeste de Tucano projects by the Geological Survey of Brazil – CPRM. Data and reports can be accessed at https://geosgb.cprm.gov.br/ (download - geophysical surveys and associated products). The survey method consisted of flight and control lines spaced 500 m and 10,000 m, oriented in the N-S and E-W directions, respectively. The flight height was set at 100 meters above the ground. The magnetometer with cesium vapor sensor mounted on the tail of the aircraft measured the Earth's total magnetic field. The gamma-ray spectrometer with sodium iodide (NaI) crystal detectors measured potassium (K), equivalent uranium (eU), and equivalent thorium (eTh). The magnetic data, after removal of the International Geomagnetic Reference Field (IGRF), were leveled and interpolated in a 125 m x 125 m grid by the bi-

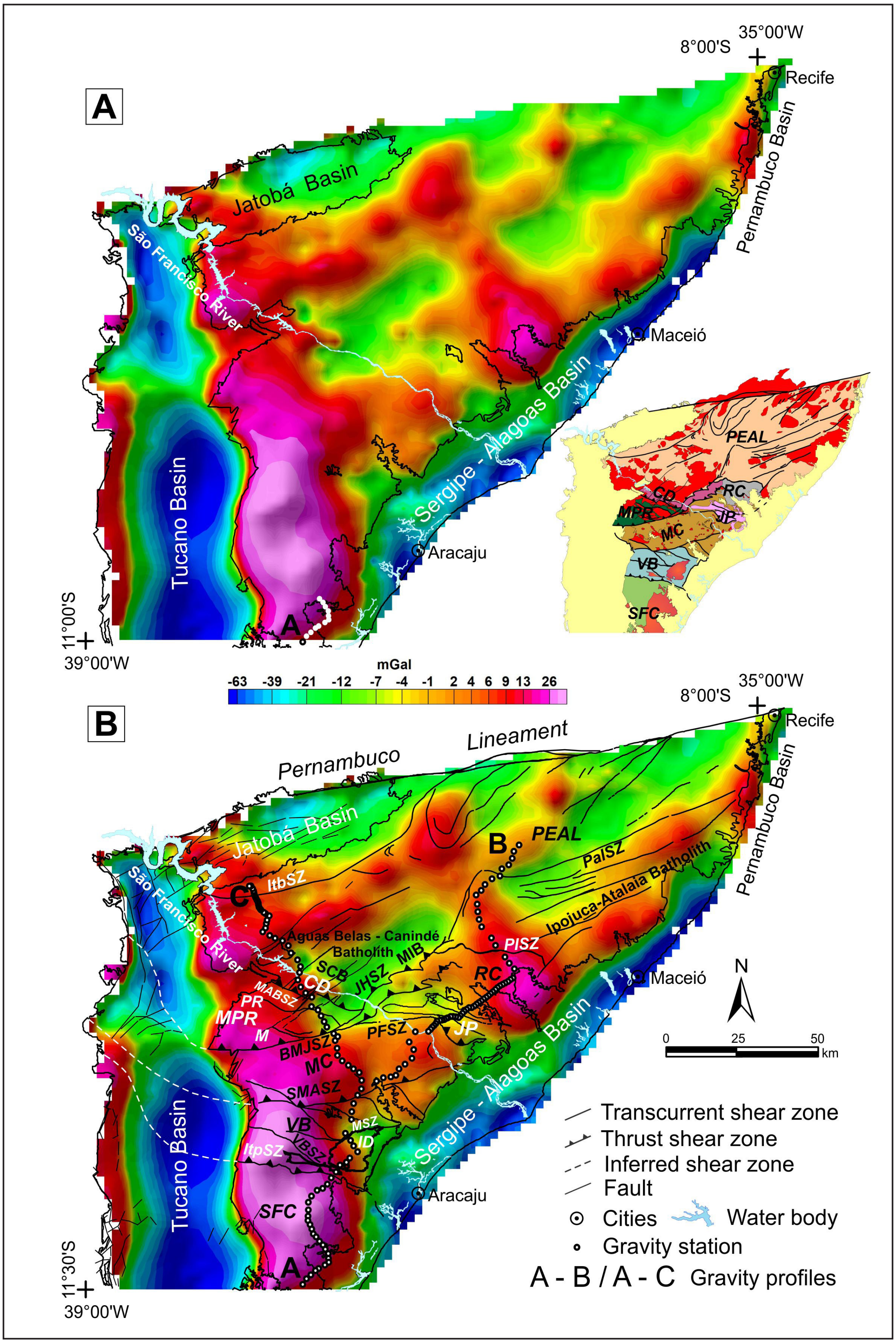

FIGURE 2 – A) Residual component of the Bouguer gravity anomalies in an interpolated grid of 5 km x 5 km in the region that encompasses the eastern part of the Southern Subprovince of the Borborema Province and the northeast portion of the São Francisco Craton. Gravity data were compiled and processed by Oliveira (2008). B) Main geological elements of the study area and gravity stations of the profiles superimposed on the residual component of the Bouguer gravity anomaly. ID - Itabaiana Dome, SCB - Serra do Catu Batholith, MIB - Major Isidoro Batholith. The geological domains are identified by the following abbreviations: VB - Vaza Barris, MC - Macururé, MPR - Marancó - Poço Redondo, M - Marancó Subdomain, PR - Poço Redondo Subdomain, CD - Canindé, JP - Jirau do Ponciano, RC - Rio Coruripe, PEAL - Pernambuco - Alagoas Superterrane, SFC - São Francisco Craton. See the caption of Figure 1 for the abbreviations of the shear zones names.

directional method. The gamma-ray spectrometric data of K, eTh and eU channels, after being corrected and leveled were interpolated in a 125 m x 125 m grid by the minimum curvature method. To join all projects, the Gridknit module (Oasis Montaj) was used, which uses mesh fusion techniques that reduce the effect of artifacts that usually occurs in the interfaces among data of different projects. Despite the Gridknit efficiency, it was not possible to remove the effect produced by the junction of the airborne geophysical projects on the western edge of the Tucano Basin (see alignment N-S in Figure 3). In this paper, for the three channels of the gamma-ray spectrometric data (K-eTh-eU), a ternary RGB composition is presented (Figure 4).

3.2. Guidelines of 2.5D joint forward modeling of magnetic and gravity data

A 2.5D joint modeling of two magnetic-gravity profiles (A-B and A-C in Figures 1, 2 and 3) was implemented, with the application of Gm-Sys Profile, aiming to model the cross section by the method developed by Talwani et al. (1959) and Won and Bevis (1987). Magnetic and gravity profiles A-B (320 km straight) and A-C (270 km straight) (Figures 1, 2 and 3) cross in the SSW-NNE (A-B) and S-N (A-C) directions the north end of the São Francisco Craton, the Vaza Barris, Macururé, Marancó - Poço Redondo, Canindé, Jirau do Ponciano, Rio Coruripe domains and extends to the interior of the Pernambuco-Alagoas Superterrane (Figures 1, 2 and 3). The large lengths of the profiles allowed the distinction of gravity and magnetic signatures associated with the deep regional structure of the crust and made it possible to model it up to the crust/mantle interface (Moho).

The gravity stations used to compose the modeled profiles (Figures 1 and 2) were taken from the database organized by Oliveira (2008). The data were collected to assist the geological mapping programs performed by the Geological Survey of Brazil - CPRM, for the PhD degree of Oliveira (2008) and for the study of the Tucano-Jatobá Basin by the Petróleo Brasileiro S/A (Petrobrás). So that all the gravity sources could be incorporated into the modeling, no components of the Bouguer anomaly were removed. The magnetic data used to compose the modeled profiles were taken point by point, in correspondence to gravity data, from the airborne magnetic anomaly data grid (Figure 3). A low-pass filter with a 25 km wavelength cut was applied to the magnetic profile to remove very shallow magnetic sources and harmonize the dimensions of magnetic sources with the dimensions of gravity sources. The profiles were built according to the original locations of the stations. However, Gm-Sys resets all the stations along a straight line that connects the starting station with the final station.

In the joint modeling, the following procedures were adopted: i) addition of density blocks and magnetic susceptibility with the same geometric contours and according to surface geological information; ii) calculation of effects; (iii) comparison of the calculated effects with the observed data until the profile adjustment is obtained for a coherent model compatible with known geological information. The geological models used as reference are published in D'el-Rey Silva (1995a), D'el-Rey Silva (1999), Oliveira et al. (2010), Lima et al. (2018) and Passos et al. (2021).

The crust of the region was affected by the events of rifts that caused the opening of the Atlantic Ocean, producing thinning of the crust along the continental margin, whose effect can be observed in the positive gravity gradient toward the ocean (Figure 2). Data published by Blaich et al. (2008) and Assumpção et al. (2013) indicated thicknesses of less than 35 km for the unthinned crust of the study area. Also, the interpretation of a deep seismic profile presented by Mohriak et al. (1995) estimated thickness of 26 km for the region of the edge of the Sergipe-Alagoas Basin. Based on this information, the position of the crust-mantle interface was fixed according to the isostatic model of the crust thickness of Oliveira and Medeiros (2012). As a consequence, the thickness of the crust was defined at 28 km in the south of the models, with a gradual increase up to 33 km in the north end of the models. The progressive thickening of the crust to the north is well evidenced by the increase of the negative regional gravity trend towards the NNE (profile A-B) and NNW (profile A-C) directions (Figures 5 and 6).

The density values used in the modeling are compatible with the average values measured in igneous and metamorphic rocks, according to the densities table presented in Telford et al. (1990). As an initial working hypothesis, the average density of 3,200 kg/m^3 was attributed to the upper mantle, 2,800 kg/m^3 for the upper crust and 2,900 kg/m^3 for the lower crust. The magnetic susceptibility varies according to the quantity and texture of magnetic minerals contained in rocks (Isles and Rankin 2013). Measurements made in the field show important variations, even in the outcrop scale. Because of this strong variation that usually occurs in magnetic susceptibility and the practical impossibility of assigning realistic values to large geological domains, the final values were established as a result of the adjustment between observed and calculated data. Estimates of Curie Depth (CT) performed by Dutra et al. (2018) for the study area, based on airborne magnetic data, calculated variations between 13 and 33 km. The visual analysis of the map from Dutra et al. (2018) indicated mean CT values around 20 km; therefore, this depth was considered as the maximum limit for the magnetization of rocks and, as a consequence, the modeling of magnetic bodies (Figures 5 and 6).

Despite the controls used in data processing, the approach used has limitations. For example, even if adequate density and susceptibility values are employed, there is a great degree of freedom in defining the shape of anomalous bodies. However, the limitations are minimized by the joint modeling of two different geophysical methods and by the careful use of geological information.

4. Correlations of geophysical data with geological domains of the Sergipano Belt

In the study region, the gravity data of Bouguer anomaly showed the existence of contrasts of densities that separate the different geological domains (Figure 2), associated with faults or shear zones. Large-amplitude and large-wavelength negative anomalies are correlated with the Tucano-Jatobá and Sergipe-Alagoas basins, formed in Mesozoic during the separation of the Pangea Continent (e.g., Matos 1992). The large-amplitudes of the anomalies are due to contact between the basement rocks and the sediments that fill the basins, with thicknesses of up to 10 km (e.g., Blaich et al. 2008). In magnetic data (Figure 3), the sedimentary filling of these basins, which are devoid of magnetic rocks, is the cause of the smooth relief of magnetic anomalies related to the depth of the underlying basement (Figure 5).

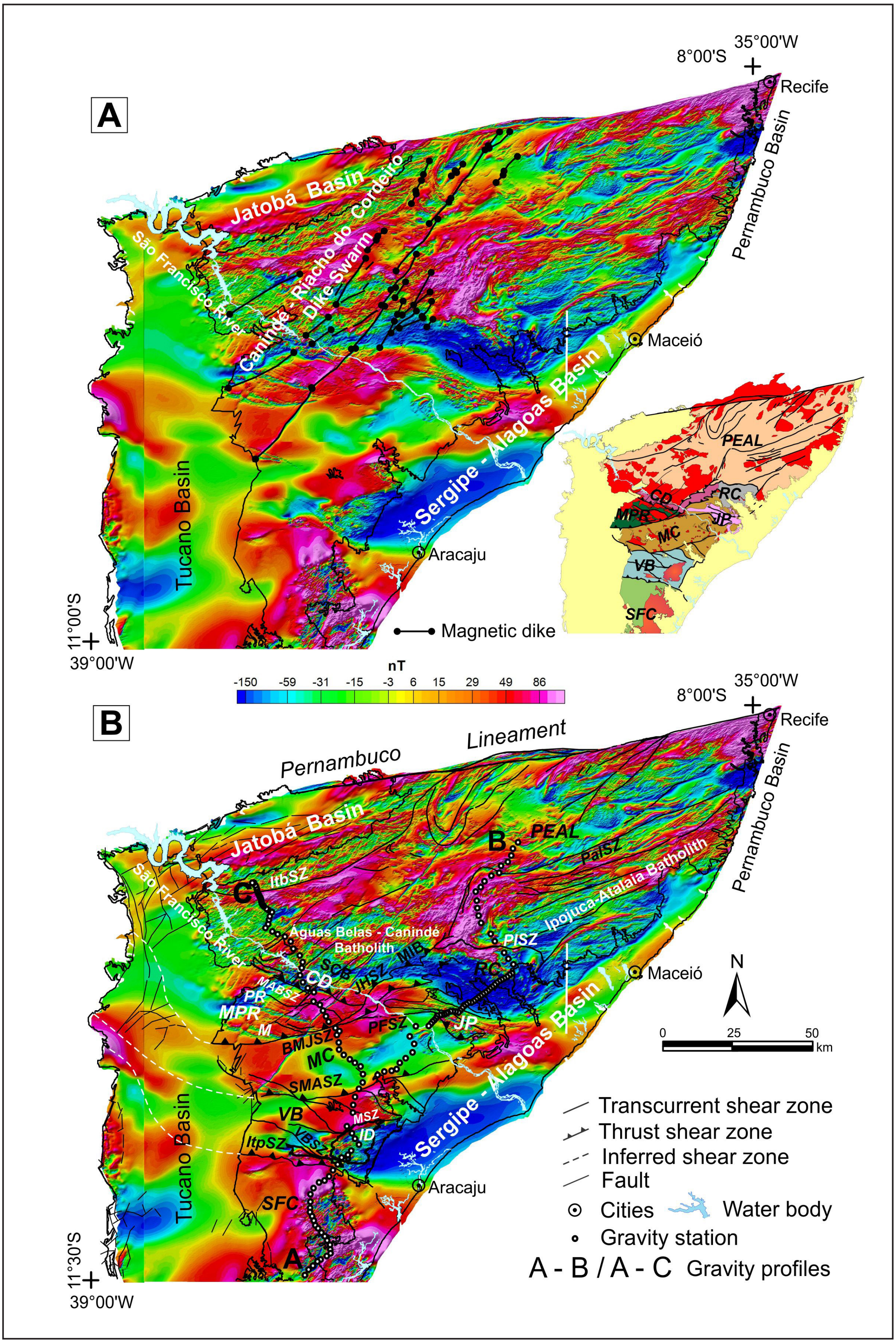

FIGURE3 – A) Magnetic anomalies in an interpolated grid of 125 m x 125 m in the region that encompasses the eastern part of the Southern Subprovince of the Borborema Province and the northeast portion of the São Francisco Craton. The magnetic data were surveyed in the Paulo Afonso - Teotônio Vilela, Pernambuco-Paraíba, Borda Leste do Planalto da Borborema e Oeste de Tucano aerogeophysical projects contracted by the Geological Survey of Brazil (https://geosgb.cprm.gov.br/). The location of the Canindé - Riacho do Cordeiro magnetic dike swarm is indicated. B) Main geological elements of the study area and gravity stations of the profiles superimposed on the magnetic anomalies. See the caption of figures 1 and 2 for the used conventions and abbreviations for the shear zones and geological domains.

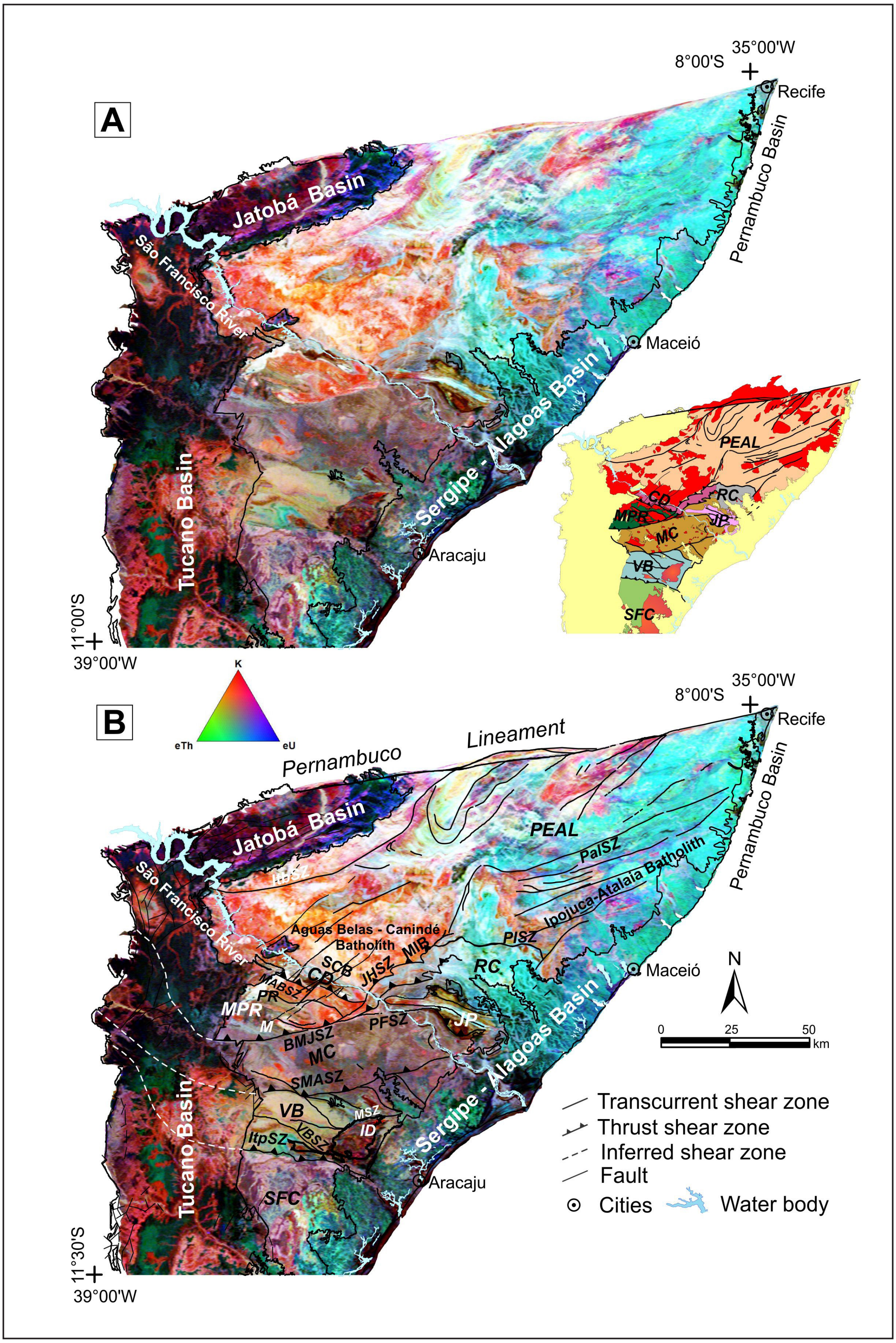

FIGURE 4 – A) RGB ternary radiometric composition (K-eTh-eU) in the region that encompasses the eastern part of the Southern Subprovince of the Borborema Province and the northeast portion of the São Francisco Craton. The gamma-ray spectrometric data were collected in the Paulo Afonso - Teotônio Vilela, Pernambuco-Paraíba, Borda Leste do Planalto da Borborema e Oeste de Tucano aerogeophysical projects contracted by the Geological Survey of Brazil (https://geosgb.cprm.gov.br/). B) Main geological elements of the study area superimposed on the RGB ternary radiometric composition. See the caption of figures 1 and 2 for the used conventions and abbreviations for the shear zones and geological domains.

In the Southern region, the São Francisco Craton is defined by an expressive positive gravity anomaly (Figure 2) and N-S magnetic anomaly stripes (Figure 3) produced by charnocktites and enderbites of the Salvador-Esplanada-Boquim Belt (Figure 1) (Barbosa et al. 2018). Adjacent to the north of the Itaporanga Shear Zone, surrounded by the rocks of the Vaza Barris Domain, the Itabaiana Dome crops out, representing a possible fragment of Archean rocks of the São Francisco Craton (Rosa et al. 2020) (Figure 1). The data analysis reveals that the magnetic pattern, associated with the rocks that crop out in the Itabaiana Dome, continues under the metasediments of the Sergipano Belt and the sediments of the Sergipe-Alagoas Basin, bounded to the north by the magnetic alignment associated with the São Miguel do Aleixo Shear Zone (Figure 3). This shear zone is considered as the suture zone in the Sergipano Belt (Oliveira et al. 2010; Oliveira and Medeiros 2018; Almeida et al. 2021).

In the region between the Tucano and Sergipe-Alagoas basins, positive gravity anomalies occur, produced by metamorphic rocks of granulitic facies (Arapiraca Complex of the Rio Coruripe Domain) and metavolcano-sedimentary sequences with intercalation of mafic-ultramafic rocks and iron formations (Nicolau - Campo Grande Complex of the Jirau do Ponciano Domain). The Rio Coruripe Domain has a very expressive magnetic signature, with concave axis to the north, 70 km of wavelength and amplitude of 400 nT (Figure 3). These parameters suggest for this region the existence of a crustal block with singular geophysical expression, distinct from the adjacent crust. Almeida et al. (2021) called this anomaly High-Intensity Magnetic Zone (HIMZ), interpreted its continuity in the Canindé Domain and concluded that the HIMZ was the main suture between the PEAL Block and the São Francisco Craton.

In the central and southern portions of the Sergipano Belt, a positive gravity signal dominates (Figures 1 and 2), indicating the influence of the dense basement under the metasediments of the Vaza Barris and Macururé domains. The absence of magnetic rocks intercalated in the metasediments of these domains is the cause of smooth magnetic relief, with anomalies of large wavelength (30 to 50 km) and small amplitude (<100 nT) produced by the basement magnetic sources, whose signal was attenuated by the increase in distance from the magnetic sensor. The metasediments of the Vaza Barris and Macururé Domains are impoverished in the three radioisotopes; however, the granitic stocks intruded in these rocks are enriched in K (reddish colors inside the MC in Figure 4).

In the north of the Sergipano Belt, the Marancó-Poço Redondo Domain (Figure 1) has stripes of magnetic anomalies with width between 1 and 3 km (Figure 3), produced by mafic and felsic metavolcanic rocks (M in Figure 3). Otherwise, migmatitic orthogneiss of granodioritic-tonalitic composition do not have an expressive magnetic signature, but show correlation with enrichment in K and depletion in eTh and eU (reddish colors within the PR in Figures 3 and 4). In the Bouguer anomaly map, the Marancó-Poço Redondo Domain has a relatively smaller signal than the domains Macururé to the south, and Canindé to the north. In the Canindé Domain, the metavolcano-sedimentary rocks produce an anomalous magnetic stripe with direction WNW-ESE, width up to 8 km (Figure 3), positive gravity signal (Figure 2) and depletion in the three radioisotopes (Figure 4).

In the Pernambuco-Alagoas Superterrane there is the alternation from east to west of positive and negative stripes of Bouguer anomalies with NE-SW direction, with an average wavelength of 60 km and an average amplitude of 15 mGal (Figure 2). This alternation between blocks of dense and light rocks suggests a context of tectonic collage by the juxtaposition of crust with different origins or evolutions. In the magnetic data, the Pernambuco-Alagoas Superterrane presents high magnetic gradients, with alignment in NE-SW and E-W directions, related to shear zones and faults, and anomalies with wavelengths ranging from 1 to 15 km (Figure 3), produced by magnetic granitoids and rocks of Paleoproterozoic gneissic-migmatitic complexes (e.g., Brito Neves and Silva Filho 2019). The radiometric data indicate that the metasedimentary rocks of the Pernambuco-Alagoas Superterrane are enriched in eTh (greenish color in Figure 4) and the granitoids are enriched in K in regions where intrusions with siennitic composition dominate (reddish colors in Figure 4); as well as, intrusions enriched in K-eTh-eU occur in this terrane (whitish colors in Figure 4).

5. Integrated quantitative modeling

5.1 General considerations on the attributes of the models

In the A-B gravity profile, expressive positive anomalies are observed in the São Francisco Craton and Rio Coruipe Domain, with wavelengths of 100 km and amplitudes around 40 mGal (1 and 2 in Figure 5). These gravity anomalies are associated with expressive magnetic anomalies (numbers 3 and 4 in Figure 5), indicating that the crusts of these domains have high densities and susceptibility (Figures 2, 3, 5 and 6) produced by the granulite rocks of the Salvador-Esplanada-Boquim Belt in the São Francisco Craton (Melo de Oliveira 2014; Barbosa et al. 2018) and the Arapiraca Complex in the Rio Coruripe Domain (Mendes and Brito 2016). As we have already mentioned, there are no paired positive-negative gravity anomalies, with the positive in the folded belt and the negative in the craton, as it occurs in other collisional orogens in South America and other continents (e.g., Thomas and Tanner 1975; Gibb and Thomas 1976; Gibb et al. 1983; Ussami and Molina 1999; Ranganai et al. 2002; Mandal et al. 2015; Oliveira and Medeiros 2018).

The models of density and magnetic susceptibility (Figures 5 and 6) are simplified versions of the crustal tectonic structure. Nevertheless, these models incorporate the key aspects of the published geological models (D'el-Rey Silva 1995; D'el-Rey Silva 1999; Oliveira et al. 2010; Passos et al. 2021), which reveals a good consistency between geological information and geophysical data (Figures 7 and 8). Clearly, the blocks correlated with the most expressive anomalies are associated with the highest estimated contrasts of density and magnetic susceptibility. A striking aspect of the models is the presence of horizontal dip angles in the center-south part, suggesting a stacking of blocks with densities greater than 2,900 kg/m^3. In contrast, in the northern part of the model, the upper and lower crusts are separated by well-defined sub-horizontal interfaces, delimited by subvertical interfaces, which suggest the lateral juxtaposition of crustal blocks. In this case, the Rio Coruripe Domain (RC in Figure 5) stands out, with a singular structure, which presents the very dense lower crust and very magnetic upper crust. In Figures 5 and 6, the dashed line indicates the mean depth of the Curie point (CT) estimated by Dutra et al. (2018). Therefore, even if the dense rocks of the lower crust of the Rio Coruripe were rich in magnetite, the occurrence of temperatures above the Curie point would prevent their magnetization.

In the models there are shallow horizontal layers with densities around 2,800 kg/m^3 and without magnetization that represent the metasedimentary rocks (number 5 in Figure 5 and 6); in addition to small bodies density of 2,650 kg/m^3, also without magnetization, which correspond to granitic stocks (number 6 in Figures 5 and 6). The modeling results present polygons with positive or negative magnetic susceptibility (k) values. When k is positive, the rocks are paramagnetic and the magnetic field is reinforced by induced magnetization. Alternatively, when k is negative, the rocks are diamagnetic and the magnetic field is weakened by induced magnetization (e.g., Isles and Rankin 2013). As an example, based on the observation of magnetic data (Figure 3), the rocks of the Rio Coruripe Domain (RC in Figure 3) (Arapiraca Complex, Mendes and Brito 2016) are paramagnetic, while the metasediments of the Macururé Domain (MC in Figure 3) are diamagnetic. There is also the possibility that originally paramagnetic rocks may lose or decrease magnetic susceptibility by processes of mineral alterations (e.g., Clark 1997; Airo 2002). For example, dense rocks are commonly composed of magnetic minerals; however, in the comparisons of density and susceptibility models, it is observed that it is not always that high density has correlation with paramagnetism. In such cases, possibly, the dense rocks located at depths with a temperature lower than the Curie temperature (~570ºC), are originally diamagnetic or have been altered by processes of destruction or transformation of magnetic minerals.

In the south of the models, between the depths of 5 and 20 km, the adjustment required the insertion of several irregular blocks above the interface of the deeper block (number 7 in Figures 5 and 6). The set of bodies presents high densities and susceptibility varying between positive and negative. The interpretation of this feature is hampered by the lack of superficial evidence. However, when considering the tectonic evolution of the Sergipano Belt, a geological hypothesis for the presence of these bodies will be discussed.

Based on the density and susceptibility attributes, eight crust compartments were distinguished (Figures 7 and 8) that have reference in the known geological data (e.g., Davison and Santos 1989; D'el-Rey Silva 1995a; Oliveira et al. 2010; Mendes and Brito 2016; Brito Neves and Silva Filho, 2019): São Francisco Craton, Vaza Barris, Macururé, Marancó-Poço Redondo, Canindé, Jirau do Ponciano, Rio Coruripe and Pernambuco-Alagoas Superterrane.

5.2. Inspection of the models in each geological domain

São Francisco Craton: The northern margin of the craton was rifted at the beginning of the Neoproterozoic, possibly with sufficient separation rates to form oceanic crust (Oliveira et al. 2010; Caxito et al. 2016). During the closure of this ocean and according to the geological models (Oliveira et al. 2010; Passos et al. 2021), the São Francisco paleoplate was subducted to the north, forming magmatic arcs on the Pernambuco-Alagoas Superterrane. The São Francisco Craton crust presents high density values (3,000 kg/m^3) and the top geometry of the block with low-angle dip to the north (SFC in Figures 5 and 6). This geometry is compatible with a subduction to the north, accompanied by thrusts of the metasediments of the Sergipano Belt to the south. In the models, a superposition of dense and magnetic blocks stacked on the upper part of the crust is observed (number 7 in Figures 5 and 6), which rest under the metasediments of the Estância, Vaza Barris and Miaba groups (Figures 7 and 8). The most probable geological correlation of these geophysical anomalous blocks is with the gneissic-migmatite-granulite complexes of the Salvador-Esplanada-Boquim Belt that outcrop south of the Itaporanga Shear Zone (Figures 7 and 8) (Melo de Oliveira 2014; Barbosa et al. 2018).

Vaza Barris Domain: Located between the Itaporanga and São Miguel do Aleixo shear zones (Figure 1), the Vaza Barris Domain is composed of Ediacaran metasedimentary sequences (Miaba and Vaza Barris groups) and domes of the Archean basement (D'el-Rey Silva 1995b), structured by large-scale antiformal and synformal folding, with SSW vergence, associated with thrusts and shear zones (e.g., Oliveira et al. 2010). According to D'el-Rey Silva (1995b), the structuring of this region of the Sergipano Belt, developed in the tectonic convergence phase, was controlled by the reactivation of structures developed in the extension phase that formed the Neoproterozoic basin and started the orogenic cycle.

The results of the modeling present in a simplified way this complex articulation (Figures 5 and 6). The blocks associated with the metasedimentary sequences of the Miaba and Vaza Barris groups have a horizontal or prismatic tabular shape with dip to the north, thicknesses less than 3 km, non-magnetic and with an average density of 2,800 kg/m^3 (VB in Figures 5 and 6). In the modeled section it is observed that the metasediments of this domain surround a large crust block (density around 2,900 kg/m^3), with dip to north and juxtaposed in the low-angle upper interface of the São Francisco Craton. This block is associated on the surface with the Itabaiana Dome (ID in Figures 5 and 6).

Macururé Domain: Contains turbidites of dominantly pelitic composition, with sandstones on the base (Macururé Group) in unconformity contact with the Archean and Paleoproterozoic basement of the Jirau do Ponciano and Rio Coruripe domains (e.g., Oliveira et al. 2010; Oliveira et al. 2015b). The units of this group are deformed in polyphasic style with general orientation NW-SE and metamorphosed in the amphibolite facies (e.g., Oliveira et al. 2010). There are granite stocks intruded in successive phases of magmatic pulses (Guimarães et al. 1997; Bueno et al. 2009). In the north limit, despite the existence of several shear zones, there is no evidence of tectonic structures in the contact between the rocks of the Macururé Group and its basement (Jirau do Ponciano and Rio Coruripe domains) (Mendes et al. 2009), suggesting the preservation of sedimentation conditions, possibly on a passive margin deposited on the Pernambuco-Alagoas Superterrane (Oliveira et al. 2015b).

The modelling results (Figure 5 and 6) and their geological interpretations (Figures 7 and 8) show in a simplified way the tabular conformation of the metasediments of the Macururé Group, with thicknesses below 5 km, non-magnetic and with an average density of 2,800 kg/m^3 (MC in Figures 5 and 6). It is important to note that the substrate of the Macururé

Group can be interpreted as a large block of the crust with a density of 2,900 kg/m^3 (8 in Figures 5 and 6), which has more affinity with the Jirau do Ponciano Dome (JP in Figure 5) than with the São Francisco Craton. It is also observed that the infracrustal block of the Macururé Domain presents at the top a diamagnetic block (9 in Figures 5 and 6). This diamagnetic block can represent layers of rocks for or orthometamorphic varieties preexisting to the Macururé Group deposition. In addition to this diamagnetic block observed in sections A-B (Figures 5) and A-C (Figure 6), there is also a dense (~3,000 kg/m^3) and magnetic block in Section A-C (10 in Figure 6). This block can be interpreted as a slice of rock rooted in the Belo Monte - Jeremoabo Shear Zone, under the metasediments (geological interpretation in Figure 8). Also, at the base of this block there is a layer with density around 3,000 kg/m^3 (11 in Figures 5 and 6), inserted in the boundary between the São Francisco Craton and the Macururé Domain crusts. Its tectonic positioning and anomalous density are compatible with the interpretation of an obducted oceanic crust fragment (Figures 7 and 8).

Marancó-Poço Redondo Domain: This domain was modeled only in section A-C (Figures 6 and 8). It is separated from the Macururé Domain through the Belo Monte-Jeremoabo Shear Zone, which constitutes a sinistral oblique contractile structure with expressive signature on gravity and magnetic maps (Figures 2 and 3). In the Marancó Subdomain (M in Figures 2 to 4), a sequence of metavolcanic felsic, mafic and ultramafic Ediacaran rocks with intercalations of metasediments crop out (e.g., Oliveira et al. 2010). Peridotites and serpentinized gabbros interleaved in the metasediments were interpreted by Silva Filho (2006) as slices of the lithosphere mantle or ophiolites. These bodies are associated with narrow magnetic anomalies (<1 km) and small amplitude (<50 nT) (M in Figure 3) and have no expression in the modeled magnetic profile (Figure 6). In the Poço Redondo Subdomain (PR in Figures 2 to 4), gneisses and tonalitic-granodioritic migmatites (e.g., Oliveira et al. 2010) outcrop. The calc-alkaline composition and the geochronology of the Poço Redondo orthogneisses suggest that they were generated in a continental magmatic arc setting in the Tonian (Van Schmus et al. 1995; Carvalho et al. 2005). In this same region, a new and voluminous intrusion of calc-alkaline granitoids provided evidence for the hypothesis of the development of a second magmatic arc at the end of the Neoproterozoic (Oliveira et al. 2010).

The Marancó - Poço Redondo Domain correlates with a gravity anomaly with a negative amplitude of -20 mGal (12 in Figure 6), whose modeling resulted in a stratified block of the crust, with an average density of 2,750 kg/m³ (Figure 6). At the top of the main block a subblock occurs with prismatic geometry that represents orthogneisses, metavolcano-sedimentary sequences and granitic intrusions. This sub-block has a minimum thickness of 2 km and a maximum of 10 km, with a base dipping north, with the deepest part rooted in the Mulungu - Alto do Bonito Shear Zone (Figure 8).

Canindé Domain: It is limited to the south with the Marancó Domain by the Mulungu - Alto Bonito Shear Zone composed of metavolcano-sedimentary sequences and an intrusive mafic-ultramafic suite. The geochronology of these rocks indicated a sedimentation activity, which may have started at the beginning of Neoproterozoic, and magmatism between 740 Ma and 610 Ma, with acid magmatism concentrated in the last 20 Ma (Oliveira et al. 2010). There is no consensus regarding the tectonic environment in which these rocks were deposited and intruded (e.g., Silva Filho 1976; Jardim de Sá et al. 1986; Oliveira and Tarney 1990). In the most recent proposals, Oliveira et al. (2010) suggested the development of an intracontinental rift that may have evolved until producing oceanic crust. On the other hand, the studies by Lima et al. (2018) suggested the deposition of sediments in an oceanic environment from the erosion of island arc and back-arc basin; whereas, Passos et al. (2021) interpreted a system formed by the junction of arc and back-arc on a slab of oceanic crust descending to the north.

The Canindé Domain has correlation with positive gravity anomaly with amplitude of 15 mGal and magnetic anomaly with amplitude of 150 nT (13 and 14 in Figure 6, respectively), whose joint modeling provided a dense and magnetic block with thickness of 12 km (CD in Figure 6). The upper crust is stratified into two layers, the lower one being denser (orange color in the density model in Figure 6) and more magnetic than the upper one (light green color in the density model Figure 6). Below these two layers, the Canindé Domain presents a very dense third layer (3,200 kg/m^3) that corresponds to the lower crust (15 in Figure 6). The limits of the Canindé Domain have dips greater than 45^o to the north (Figure 8), suggesting a tectonic event occurring at a higher angle than that observed in the south of the Sergipano Belt.

Jirau do Ponciano Domain (Dome): In this work we interpret this domain as an exposure of the Pernambuco - Alagoas Superterrane in the Sergipano Belt. The Jirau do Ponciano Domain is formed by the Jirau do Ponciano and Nicolau - Campo Grande complexes and its structural conformation indicates an inverted anticline that crops out as a dome mantled by the metasediments of the Macururé Domain (Figure 1) (Mendes et al. 2009; Mendes and Brito 2016). The Nicolau-Campo Grande Complex consists of a Paleoproterozoic metavolcano-sedimentary sequence that occurs interspersed in the banded leucocratic orthogneisses to migmatitic of the Jirau do Ponciano Complex (Mendes et al. 2009; Mendes and Brito 2016). The studies of Lima et al. (2019) indicated that the Nicolau - Campo Grande Complex is the core of a Paleoproterozoic magmatic arc, which together with the Jirau do Ponciano Complex was exhumed by thrusts during the Brasiliano Orogeny in a gneissic-migmatitic dome structure.

The magnetic anomalies associated with the Jirau do Pociano Domain are linear, of small amplitude (<100 nT) and small wavelength (<1.0 km), usually associated with mafic rocks, iron formations of the metavolcano-sedimentary sequence and shears with E-W direction (magnetic lineaments in Figure 3). The interpretation of these magnetic lineaments and their correlation with numerous shear zones (Figure 1) suggests that this region was affected by transcurrent deformation during the Brasiliano Orogeny. The metavolcano-sedimentary rocks are correlated with a negative gravity anomaly with an amplitude of -10 mGal and a wavelength of 10 km. The results of the modeling (JP in Figure 5) show a non-magnetic upper crust block, with a density of around 2,900 kg/m^3, covered and interleaved with rocks with a density of 2,800 kg/m^3, which form a synformal structure in the central part of the block.

Rio Coruripe Domain: In this work we interpret this domain as an exposure of the Pernambuco - Alagoas Superterrane in the Sergipano Belt. The Rio Coruripe Domain is composed of gneissified and migmatized metasediments, locally granulitized, with lenses and layers of metamafic, marbles,

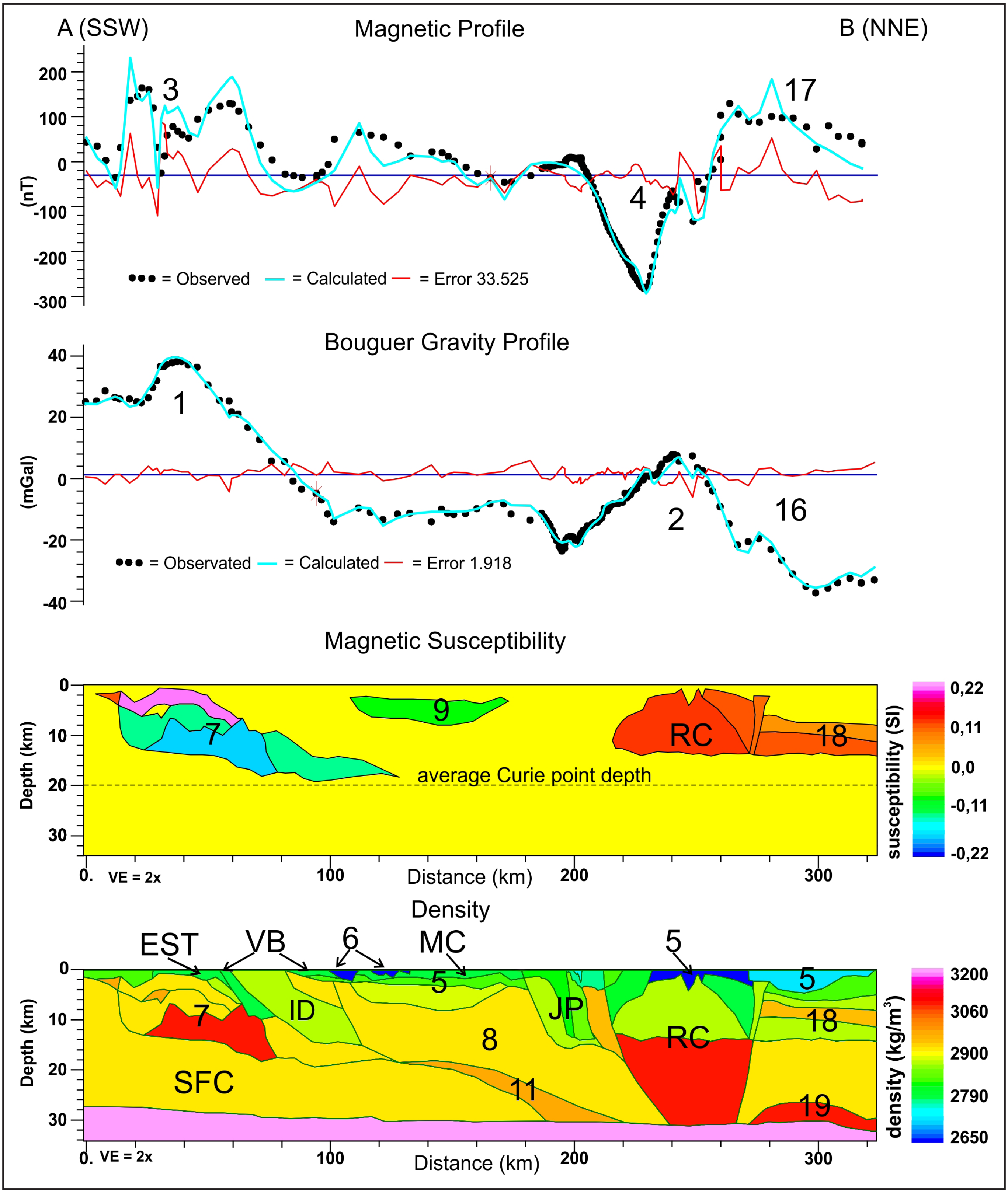

FIGURE 5 – Joint modeling of gravity and magnetic data from the A-B Profile. The magnetic anomaly is not reduced to the pole. The position of the crust-mantle interface was fixed according to the isostatic crust thickness model of Oliveira and Medeiros (2012). The mean estimate of the Curie Depth (CT) was based on the results of Dutra et al. (2019). The location of this profile can be seen in Figures 1 to 3. Numbers and abbreviations refer to comments and explanations in the text. The geological domains are identified by the following abbreviations: EST - Estância, IB - Itabaiana Dome, VB - Vaza Barris, MC - Macururé, JP - Jirau do Ponciano, RC - Rio Coruripe, PEAL - Pernambuco - Alagoas Superterrane, SFC - São Francisco Craton.

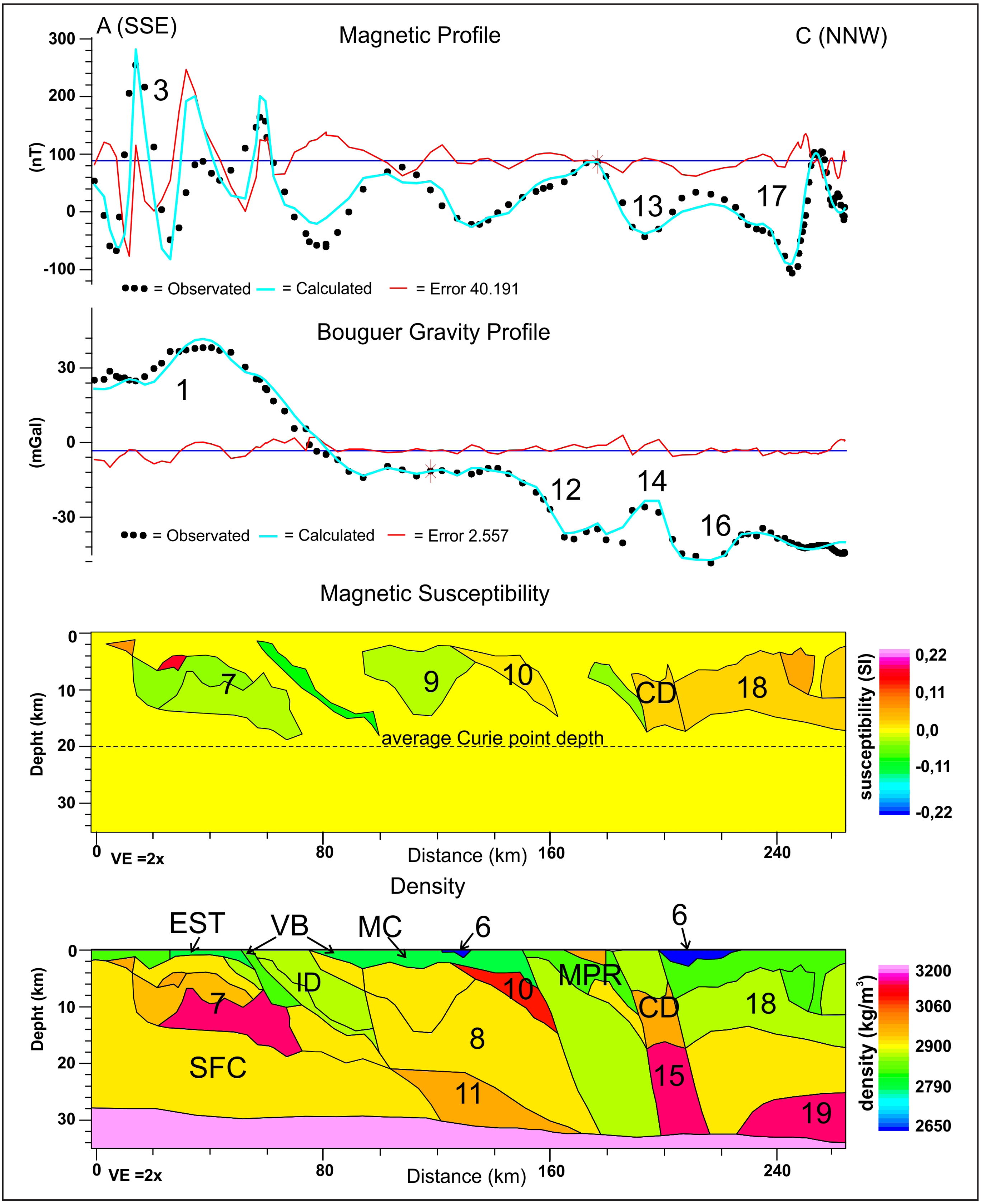

FIGURE 6 – Joint modeling of gravity and magnetic data from the A-C Profile. The magnetic anomaly is not reduced to the pole. The position of the crust-mantle interface was fixed according to the isostatic crust thickness model of Oliveira and Medeiros (2012). The mean estimate of the Curie Depth (CT) was based on the results of Dutra et al. (2019). The location of this profile can be seen in Figures 1 to 3. Numbers and abbreviations refer to comments and explanations in the text. The geological domains are identified by the following abbreviations: EST - Estância, ID - Itabaiana Dome, VB - Vaza Barris, MC - Macururé, MPR - Marancó - Poço Redondo, CD - Canindé, JP - Jirau do Ponciano, RC - Rio Coruripe, PEAL - Pernambuco - Alagoas Superterrane., SFC - São Francisco Craton.

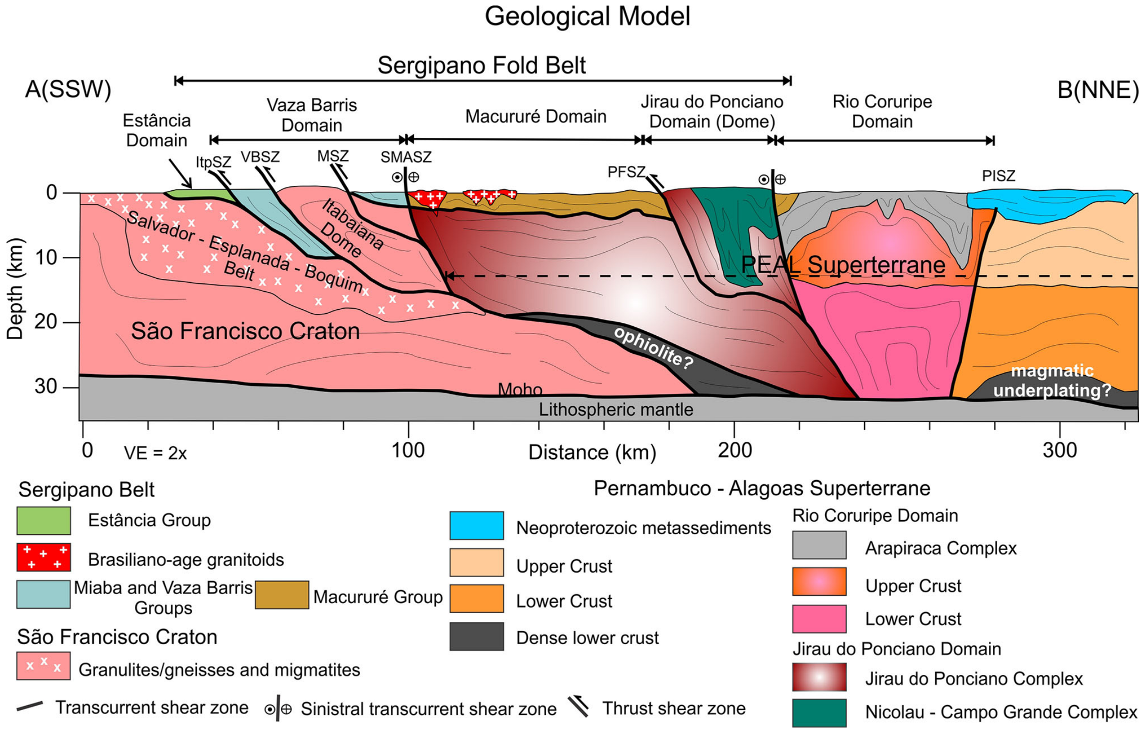

FIGURE 7 – Geological interpretation of the joint modeling of gravity and magnetic data from the A-B profile. Model based on the results of this study and on the geological sections of D'el-Rey Silva (1995a), D'el-Rey Silva (1999), Oliveira et al. (2010), Lima et al. (2018), Brito Neves and Silva Filho (2019) and Passos et al. (2021). The shear zones (SZ) are identified by the following abbreviations: ItpSZ - Itaporanga, VBSZ - Vaza Barris; MSZ - Mocambo, SMASZ - São Miguel do Aleixo, PFSZ - Porto da Folha, PISZ - Palmeira dos Índios.

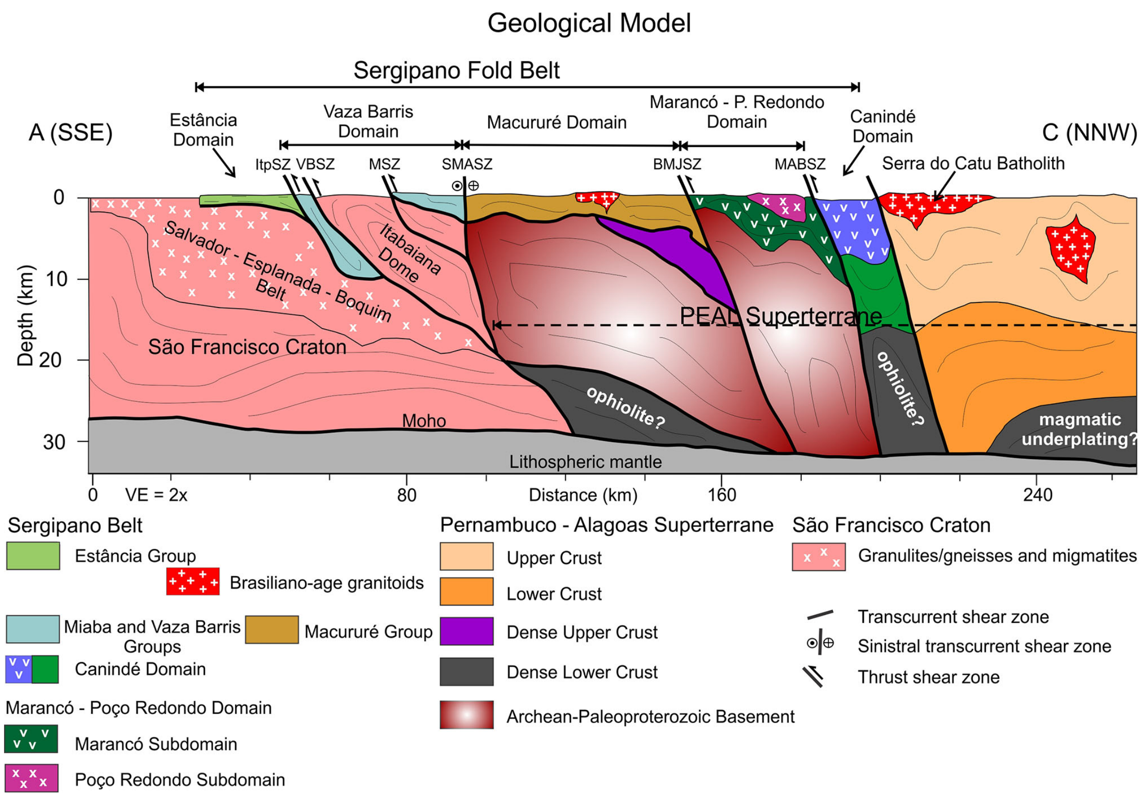

FIGURE 8– Geological interpretation of the joint modeling of gravity and magnetic data from the A-C profile. Model based on the results of this study and on the geological sections of D'el-Rey Silva (1995a), D'el-Rey Silva (1999), Oliveira et al. (2010), Lima et al. (2018), Brito Neves and Silva Filho (2019) and Passos et al. (2021). The shear zones (SZ) are identified by the following abbreviations: ItpSZ - Itaporanga, VBSZ - Vaza Barris; MSZ - Mocambo, SMASZ - São Miguel do Aleixo, BMJSZ - Belo Monte - Jeremoabo, MABSZ - Mulungu - Alto Bonito.

calc-silicate rocks, banded iron formations (Lake Superior type), quartzites and metamafic-metaultramafic complexes (Mendes et al. 2009; Mendes and Brito 2016). U-Pb dating performed by Brito et al. (2006) shows crystallization ages of 1965 Ma in zircon from ultramafic rocks and 2049 Ma in inherited zircon. Recent research performed by Tesser et al. (2022) identified in the Rio Coruripe Domain an ultrahigh-temperature (UHT) event. The crystallization age of molten rocks was dated between 2.03 and 1.96 Ga (U-Pb zircon). This event was accompanied by the generation of sapphirine, a rare mineral found in contact with the metamorphic rocks. The results of Tesser et al. (2022) suggest that the Rio Coruripe Domain may constitute a scattered block of the São Francisco Craton.

The Rio Coruripe Domain has a very expressive magnetic signature, which appears in map as a curved strip with concavity to the north, 70 km of wavelength and amplitude of 400 nT (Figure 3). The same rocks that produce the magnetic anomaly are also the cause of an expressive positive gravity anomaly with an amplitude of 30 mGal and a wavelength of 40 km (Figure 2). These parameters suggest for this region the existence of a crustal block with singular geophysical expression, distinct from the crust of the Jirau do Ponciano Domain. The result of the joint modeling of magnetic and gravity data presents a stratified crust, where the upper crust is very magnetic and the bottom crust is very dense (RC in Figure 5). This domain has vertical contacts with adjacent crust blocks, in contrast to the preponderance of low-angle dip interfaces that occur south of the Jirau do Ponciano Domain.

Pernambuco-Alagoas Superterrane: This domain was originally conceived as a massif of gneiss-migmatite rocks surrounded by younger metasediments (Brito Neves et al. 1982). Later, the recognition of the tectonic-lithological and isotopic dissimilarities of its units led the researchers to interpret it according to the concepts of tectonostratigraphic terranes (Brito Neves and Silva Filho 2019). In this work we consider that the Jirau do Ponciano and Rio Coruripe domains were part of the Pernambuco - Alagoas Superterrane during the Brasiliano Orogenic cycle and, according to the stratigraphic relations, formed the basement in which the sediments of the Macururé Domain were deposited (Mendes et al. 2009; Mendes e Brito 2016; Oliveira et al. 2010). In the region crossed by the geophysical A-B profile north of the Rio Coruripe Domain (Figure 1), Paleoproterozoic and Neoproterozoic mobile belts with intrusions of granitic Brasiliano batholiths crop out (e.g., Brito Neves and Silva Filho, 2019). In the evolution of the Sergipano Belt, the evidence suggests that the Pernambuco - Alagoas Superterrane : i) was the source and passive margin of the Macururé sediments (Oliveira et al. 2015b); ii) was the upper plate under which the subduction of the oceanic crust formed in the extension phase of the orogenic cycle occurred (Oliveira et al. 2010; Passos et al. 2021); iii) was the site of the installation of the magmatic arcs generated by subduction, represented by the batholiths of Serra do Catu (Brito et al. 2009) and Major Isidoro (Silva et al. 2015).

In the gravity profiles, the crust of the Pernambuco - Alagoas Superterrane, north of the Rio Coruripe and Canindé domains, is correlated with negative anomalies (16 in Figures 5 and 6), possibly because of the voluminous magmatism of granitic composition generated in the Brasiliano Orogeny, that together with the belts of metasedimentary rocks produced a decrease in the average density of the upper crust. In the magnetic profile (Figures 5 and 6), anomalies of small amplitudes and wavelengths also contrast with the strong magnetic signal of the Rio Coruripe and Canindé domains (17 in Figures 5 and 6). The modeling result presents the stratified upper crust (Figures 5 and 6), with a dense intermediate layer (3,000 kg/m^3) and magnetic layer (0.10 SI) (18 in Figures 5 and 6), superimposed on a lower crust with normal density (2,900 kg/m^3). For the best fit of the model it was necessary to insert a dense layer (3,100 kg/m^3) on the base of the crust (19 in Figures 5 and 6).

6. Discussions and tectonic implications

Although there are important disagreements, the proposed evolution models for the Sergipano Belt converge in several aspects. In summary, the Sergipano Belt was formed by the collision between the São Francisco Craton and the Pernambuco-Alagoas Superterrane in the Ediacaran, having occurred accretionary processes on the margin of the São Francisco Plate and its subduction under the Pernambuco-Alagoas Superterrane (Figure 9) (e.g., Oliveira et al. 2010; Passos et al. 2021; Almeida et al. 2021). As an example, Oliveira et al. (2010) advocate an evolution that covers a complete Wilson Cycle. Also, recently, new conceptions of the Borborema Province evolution suggest that the terranes of the north of the Sergipano Belt could form blocks that were dispersed from the São Francisco Craton and aggregated again in the Neoproterozoic (Caxito et al. 2020; Ganade et al. 2021; Tesser et al. 2022). At this point, it is important to clarify that all these inferences are based on geological information of the surface, and the models of the crust (e.g., D'el-Rey Silva 1995a; D'el-Rey Silva 1999, Oliveira et al. 2010; Passos et al. 2021) were built without basis on geophysical data that allowed to outline the continuity of geological structures and crustal blocks in depth. Therefore, considering the results of the modeling (Figures 5, 6, 7 and 8), a description of the Sergipano Belt crustal structure and adjacent tectonic blocks that incorporate deep information can now be performed.

In plate tectonic models, the subduction of the continental lithosphere occurs in the final stages of continent-continent collisions, after the complete consumption of the oceanic crust (e.g., Condie 1997; Kearey and Vine 1996). In some cases, by passive or active mechanisms, the dense oceanic crust can be obducted over the continental lithosphere (e.g., Agard et al. 2007; Edwards et al. 2015). However, despite the possibility that an ocean has been closed in the orogenic cycle of the Sergipano Belt, there is no record of an obducted oceanic crust on the outcropping edge of the São Francisco Craton. However, the modeling results (Figures 5 and 6) suggest the presence of a dense block near the base of the overlying crust in the São Francisco Craton, in the same style observed in processes of obduction (e.g., Agard et al. 2014). In this context, in case this block represents oceanic crust (Figures 7 and 8), it is possible to suggest its placement through the same tectonic mechanism of inversion and closure of the basin and uplifting of the Itabaiana Dome, as presented by D'el-Rey Silva (1995b). Therefore, a possible passive obduction of the oceanic crust could have been triggered by the compression of the structures developed in the extension and formation of the oceanic crust. As a possibility, the research by Agard et al. (2007) proposes the transition zone between the continental crust and the oceanic

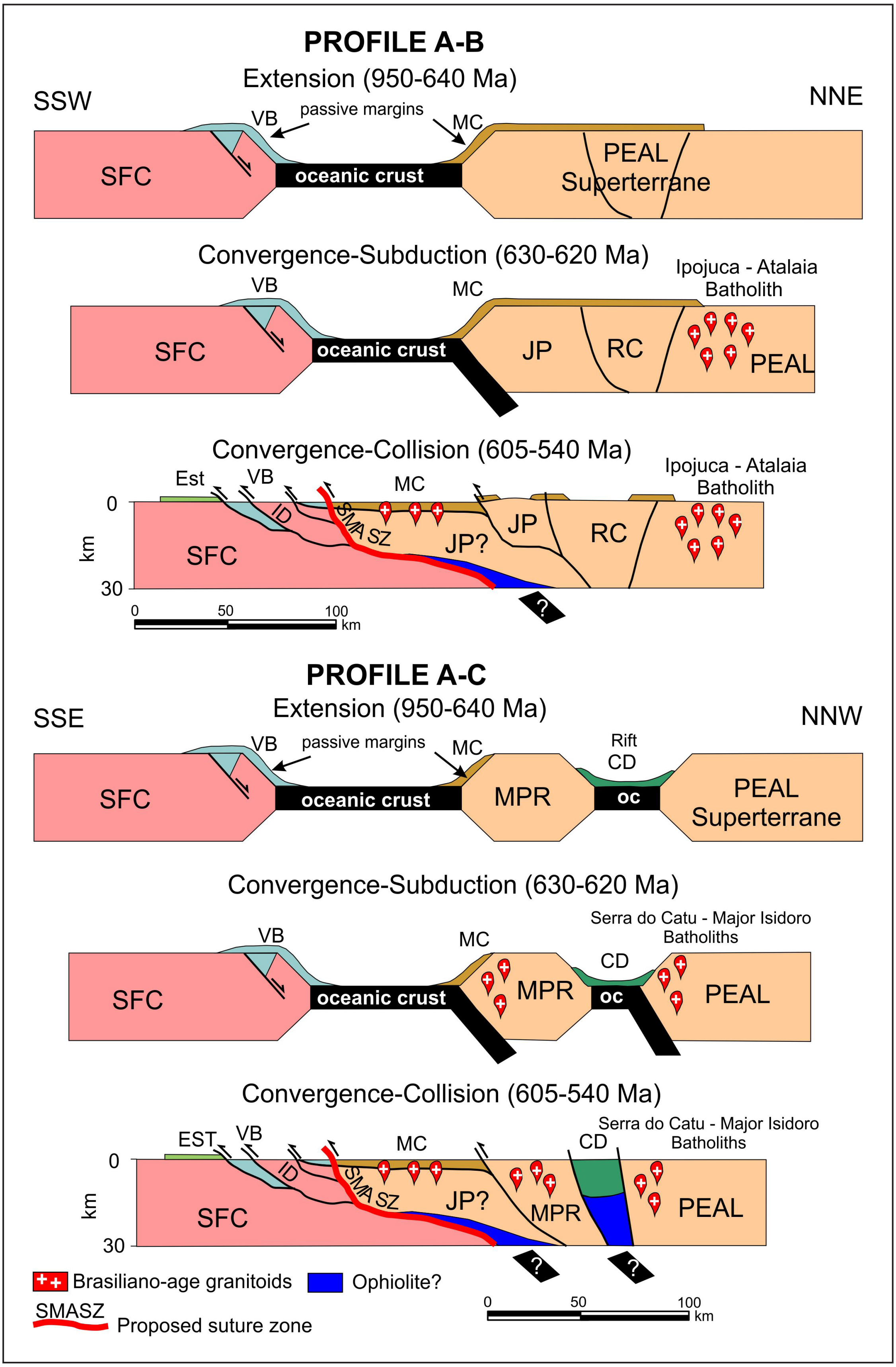

FIGURE 9– Simplified evolution of the Sergipe Belt in three stages during the Neoproterozoic for profiles A-B and A-C: extension, convergence-subduction and convergence-collision. Models based on the results of this study and on the geological sections of D'el-Rey Silva (1995a), D'el-Rey Silva (1999), Oliveira et al. (2010), Lima et al. (2018), Brito Neves and Silva Filho (2019) and Passos et al. (2021). The ages for each evolutionary stage are based on Oliveira et al. (2010). An uniform crust thickness of 30 km has been stipulated for simplicity purposes only. The geological domains are identified by the following abbreviations: EST - Estância, ID - Itabaina Dome, VB - Vaza Barris, MC - Macururé, MPR - Marancó - Poço Redondo, CD - Canindé, JP - Jirau do Ponciano, RC - Rio Coruripe, PEAL - Pernambuco - Alagoas Superterrane., SFC - São Francisco Craton.

crust as a place of weakness that could trigger the obduction process by means of inverse faults.

To the south of the Itaporanga Shear Zone, on the crust of the São Francisco Craton, there is a plane-parallel sedimentary stacking composed of continental siliciclastic-carbonatic deposits called the Estância Group (Figure 1). The sedimentary units of this group, little deformed and with low metamorphic degree, were interpreted as late-orogenic deposits of a foreland basin (Brito Neves et al. 1977; Silva Filho et al. 1978). The results of the modeling associate the Estância Group with a tabular block with no correlation with negative gravimetric anomaly, with a density of around 2,800 kg/m^3 and a thickness of less than 3 km (EST in Figures 5 and 6). These results indicate that the development of the basin did not produce great sedimentary thickness and sufficient weight to flexure the São Francisco paleoplate, as occurred with the sedimentation of foreland of the Araguaia (Ussami and Molina 1999) and Brasília (Reis et al. 2020) belts. The most likely explanation may be attributed to the elastic properties of the São Francisco Craton lithosphere involved in the collision with the Sergipano Belt. Probably, the lithosphere behaved rigidly, preventing the thrust of the Sergipano Belt rocks from producing important lithospheric flexure. Therefore, there was no generation of an expressive foreland basin; as well, there was also no South penetration of compressive deformation in the interior of São Francisco Craton, as it happened in the Riacho do Pontal Belt, where the deformation of the thin-skined tectonic is recorded 500 km south inside the craton (Danderfer Filho et al. 1993).

In the Vaza Barris Domain, although the data indicated an expressive magnetic signature for the Itabaiana Dome (Figure 3), the modeling was adjusted by a block with low magnetization (ID in Figures 5 and 6). Possibly, this is because the magnetic data profile did not adequately sample the rocks of the Itabaiana Dome. However, the interpretation of the data on map (Figure 3) reveals that the substrate of the metasediments is magnetic. Also, it is evident the continuation of these magnetic rocks under the sediments of the Sergipe-Alagoas Basin (Figure 3). On the contrary, it is not clear in geophysical data its continuation below the many thick sediments of the Tucano Basin; possibly because of the strong attenuation of the geophysical signal produced by increasing the distance between the sensor and the signal source. On the other hand, it may be that the rocks observed in the Itabaiana Dome do not have continuity below the sediments of the Tucano Basin.

The limit between the Vaza Barris Domain and the Macururé Domain is the São Miguel do Aleixo Shear Zone. The interpretation of the modeling results also indicates that this shear zone separates blocks of crusts with different densities and susceptibility (Figures 5 to 8). In addition, it was possible to interpret the continuity of the Salvador-Esplanada-Boquim Belt in the subduction interface of the São Francisco Craton crust to the north (Figure 7). Based on this model, the São Miguel do Aleixo Shear Zone represents the most important crustal boundary of the Sergipano Belt (Figure 9), confirming the interpretations of Oliveira et al. (2010) and Oliveira and Medeiros (2018). At this point, it is important to consider that in the seismological data of Rocha et al. (2019), a horizontal section at a depth of 150 km suggests that the São Francisco lithosphere extends to the proximity of the Pernambuco Lineament. The conclusions of Rocha et al. (2019) do not clarify whether the Pernambuco - Alagoas Superterrane is a part of the ancient São Francisco paleoplate or whether the data record the preservation of the lithosphere of the São Francisco Craton that were subducted to the north. Some discussions regarding the links between the craton and the Borborema Province before the Brasiliano Orogeny defend a model of intracontinental orogenesis for the province (e.g., Neves 2003; Ganade et al. 2021). In the specific case of the Sergipano Belt, the data show an evolution model that points to the opening and closing of oceans with culmination in an accretionary collision (Oliveira et al., 2010; Passos et al., 2021; Almeida et al., 2021). The question, whether or not the Pernambuco - Alagoas Superterrane had inheritance in the São Francisco Craton, has no important implications for this geotectonic model of the Sergipano Belt; as, even if they have composed a single plate in the past, it may have been opened with oceanic crust formation, subducted and finally collided (Figure 9).

In the Macururé Domain, the geometry and geophysical parameters of the models (Figures 5 to 8) suggest a detachment and thrust to the south of the lower crust in the process of the crust shortening during the collision. In the model there also non-magnetic small bodies with a density of 2,650 kg/m^3 (Figures 5 and 6) that are interpreted as granitic stocks (Figures 7 and 8). The size of these bodies and the absence of negative gravity anomalies with expressive amplitude, indicate that the granitic magmatism that intruded the Macururé Domain was of small volume, without formation of batholiths, even in depth.

In the Marancó - Poço Redondo Domain, the model geometry is in agreement with the low-angle tectonic with vergence to the south of the Belo Monte - Jeremoabo Shear Zone (Figures 6 and 8). The model indicates that the crust has a lower density (~2,750 kg/m^3) than that of the Macururé Domain. This density contrast between the two blocks is well marked by the decrease in the positive intensity of the gravity anomaly to the north from the Belo Monte - Jeremoabo Shear Zone. The tectonic history of the Marancó - Poço Redondo Domain indicates that its crust was intensely penetrated by acid magmatism twice along the Neoproterozoic (Oliveira et al., 2010). This intense granitization of the crust can be the cause of the decrease in the density observed in the modeling results.

In the Canindé Domain, the result of the modeling, despite being a frozen record of the tectonic process, allows to analyze the geological models proposed by Oliveira et al. (2010) and Passos et al. (2021). The block modeled in section 2D and its correlation in map indicate that originally the Canindé Domain was long and narrow, which is a more suitable configuration for a rift type basin. However, the result demonstrates the existence of a lower layer with high density (3,100 kg/m^3), which supports the hypothesis of an extension of the lithosphere to the point of forming oceanic crust. In this case, the model favors the interpretation of the Canindé Domain as a back-arc basin that opened enough to form oceanic crust, as proposed by Passos et al. (2021). The oceanic crust formed must have subducted under the Pernambuco - Alagoas Superterrane, generating a magmatic arc in its edge (Figure 9), as witnessed by the intrusions of the batholiths of Serra do Catu (Brito et al., 2009; Soares et al., 2022) e Major Isidoro (Silva et al., 2015).

The models of density and magnetic susceptibility distinguish the infrastructure of the Jirau do Ponciano Domain (Dome) from that observed in the Rio Coruripe Domain (Figures 5 and 7). However, geological mapping data indicate that the two blocks are covered by the rocks of the Macururé Group, whose quartzites of the base of the metasedimentary stacking make unconformity contact with the basement (Jirau do Ponciano and Rio Coruripe domains) without participation of faults (Mendes et al., 2009; Mendes and Brito, 2016). Since the two blocks are partially covered by the metasediments of the Macururé Group, the modeling results and the geological data (geological map of Mendes et al., 2009) they suggest that the Jirau do Ponciano and Rio Coruripe domains were agglutinated in tectonic events prior to the deposition of the passive margin Neoproterozoic sedimentary basin formed by sediments from the rocks erosion of the Pernambuco-Alagoas Superterrane (e.g., Oliveira et al., 2015b).

The geological and tectonic peculiarities of the Rio Coruripe Domain led some researchers to adopt the designation of Sul Alagoana Belt (Silva Filho and Torres, 2002), an interpretation that was accompanied by other researchers in more recent works (e.g., Brito Neves and Silva Filho, 2019; Almeida et al., 2021). As the geophysical models (Figures 5 and 7) and geological data demonstrate (Mendes et al., 2009; Mendes e Brito, 2016; Tesser et al., 2022), the gravity and magnetic signatures of the Rio Coruripe Domain are a consequence of its lithological composition (iron formations, mafic rocks, dense and magnetic granulites). This result brings difficulties to the interpretation of Almeida et al. (2021) that the High-Intensity Magnetic Zone (HIMZ), which is coincident with the Rio Coruripe Domain, indicates the location of a Brasiliano suture between the São Francisco Craton and the Pernambuco - Alagoas Superterrane. The northern boundary of the Rio Coruripe Domain presents a subvertical configuration compatible with a transcurrent deformation at a high angle and associated with a decrease in the intensity of the gravity anomaly to the north (Figures 5 and 7). This conformation is different from that of Mendes et al. (2009) that established low angle and vergence to the north in the Palmeira dos Índios Shear Zone. However, Neves et al. (2016) disagreed with the results presented by Mendes et al. (2009) and reported not having found a shear zone in their field work at this location. In addition, they identified a Neoproterozoic sedimentation (~670 Ma), which crops out between windows of the Paleoproterozoic basement, to the north and south of the Palmeira dos Índios Shear Zone. The modeling results are evident as to the existence of a subvertical structure in the northern boundary of the Rio Coruripe Domain, which corresponds to the geographical position of the Palmeira dos Índios Shear Zone (Figures 5 and 7). However, the modeling results also suggest the possibility that the shear zone is concealed under a layer of rocks (blue color layer in Figure 7). Therefore, if this layer is composed of Neoproterozoic metasediments mapped and dated by Neves et al. (2016), the Palmeira dos Índios Shear Zone does not outcrop, at least in the region of the geophysical profile. Thus, we interpret that the Jirau do Ponciano and Rio Coruripe domains were already together before the Neoproterozoic sedimentation (being part of the Pernambuco - Alagoas Superterrane) and, therefore, before the Brasiliano Orogeny. Since they are geologically and geophysically unequal, possibly with different origins, the junction between them must have occurred through the shear zones that delimit them, and that were reactivated during the Brasiliano Orogeny.

The placement of a dense layer (3,100 kg/m^3) on the base of the crust, correlated on the surface with the elevated topography of the Borborema Plateau (e.g., Oliveira and Medeiros, 2012), was necessary for the better adjustment of the model of densities in the Pernambuco-Alagoas Superterrane (Figures 5 and 6). Regarding this aspect of the results, we verified that the geological models proposed by Silva Filho et al. (2021) suggest the installation of basalt layers (basaltic underplate) at the base of the crust, in an environment of Brasiliano pre-collision extension, as one of the triggers for the production of voluminous acid magmatism. However, the evolution model of the Borborema Plateau proposed by Oliveira and Medeiros (2012) also suggests magmatic underplating as an engine for the uplifting of the Borborema Plateau in the Cenozoic. In the latter case, the magmatism installed at the base of the crust would be associated with events of alteration of the mantle thermal properties in the Mesozoic-Cenozoic. The clues for melting events of the subcontinental mantle during this period in the Borborema Province are: i) the Mesozoic Equatorial Atlantic Magmatic Province - EQUAMP (Hollanda et al. 2019; Melo et al. 2022), a Large Igneous Province (LIP) formed in the pre-rift phase of the opening of the South Atlantic; and ii) Macau magmatism (e.g., Sial 1976; Mizusaki et al. 2002) occurred in the post-Atlantic opening stages. According to the proposal of Oliveira and Medeiros (2012), the Macau magmatism in the Cenozoic has a more evident temporal correlation with the uplifting of the Borborema Plateau. In addition, Lima (2008) and Morais Neto et al. (2009) also identified denudation and uplifting events in Cenozoic in this region of the Borborema Province. However, in the area proposed in this paper for the occurrence of a possible magmatic underplating, Hollanda et al. (2019) dated the Canindé - Riacho do Cordeiro dike swarm at 119 ± 2 Ma (K–Ar) (Figure 3), which has spatial correlation with the south of the Borborema Plateau. Therefore, if the modeled dense layer represents magma underplating and is associated with the Canindé-Riacho do Cordeiro dike swarm, then the uplift of the plateau could have already started in the Aptian.

7. Conclusions

The joint forward modeling of gravity and magnetic data revealed the deep crustal structure of the Sergipano Belt through the interpretation of the density distribution and magnetic susceptibility of the rocks. This interpretation was supported by the use of geological data during modeling and correlation of results with published geological sections. The results allowed the identification of the geometry of the main geological domains to the depth of Moho discontinuity and provided a consistent view of the crust configuration of the Sergipano Belt at the end of the Brasiliano Orogeny.

The results showed the predominance of low-angle interfaces in the south of the Sergipano Belt and high-angle in the north, indicating that the folds and thrusts toward the São Francisco Craton observed on the surface are a persistent and deep feature in the Southern crust of the Sergipano Belt; while in the north, the subvertical interfaces suggest the high-angle transcurrent tectonic action. The general tectonic context of the models is compatible with the subduction and collision of the São Francisco paleoplate under the Pernambuco-Alagoas Superterrane, sutured in the São Miguel do Aleixo Shear Zone. The presence of dense blocks at the base of the crust was interpreted as record of obduction of an oceanic crust that existed before the collision. However, the configuration of regional gravity anomaly and the small thickness of foreland sediments (Estância Group) indicate that the collision process was not accompanied by expressive flexures of the São Francisco paleoplate in the region of the Sergipano Belt, unlike what occurred in the Riacho do Pontal and Brasilia belts.

The metasediments of the Vaza Barris and Macururé domains were modeled as tabular blocks of thickness less than 5 km, which dip at low angle on the shear zones flanks. Small vertical bodies of lower density in the Macururé Domain were interpreted as granitic intrusions. The absence of expressive negative gravity anomalies indicates that intrusions have small volume (stocks), not constituting batholiths, even in depth. In the Canindé Domain, the presence of mafic rocks is well recorded by gravity and magnetic anomalies. The existence of a denser than normal block in the lower crust was interpreted as an ophiolite, which records the oceanic crust that based a possible back-arc basin before the collision. Possibly, the subduction of this crust to the north produced granitic magmatism with record in the Serra do Catu and Major Isidoro batholiths.

The data and models revealed geophysical differences between the Jirau do Ponciano and Rio Coruripe domains in relation to the crust of the Pernambuco-Alagoas Superterrane located north of the Palmeira dos Índios Shear Zone. Among them, the Rio Coruripe Domain presents a unique geophysical configuration, with the upper crust very magnetic and the lower crust very dense. The Jirau do Ponciano Domain, which by geological and geophysical data has different origin from the Rio Coruripe Domain, possibly constitutes the infracrust of the Macururé Domain south of the Porto da Folha Shear Zone. These domains are separated by shear zones with evident expression in gravity and magnetic data, but the existence of Neoproterozoic metasedimentary supracrustal rocks partially covering the three domains and the boundary shear zones indicates that the junctions among these blocks were formed before the deposition of the Neoproterozoic sediments.

The high density block inserted in the base of the crust of Pernambuco - Alagoas Superterrane was interpreted as a layer of magmatic underplating produced by fusions in the mantle of Borborema Province during the Mesozoic-Cenozoic, which provided dike swarms and volcanic plugs and raised the Borborema Plateau. Finally, the results presented in this work, in addition to its relevance regarding the understanding of the deep crustal structure of the Sergipano Belt, also provide key points for the understanding of the Borborema Province formation and, as a consequence, the evolution of the Gondwana Supercontinent.

Authorship credits

Author	A	B	C	D	E	F
RGO	X	X	X	X	X	X
NRRD			X	X	X	
WEM			X	X	X	

A - Study design/Conceptualization **B** - Investigation/Data acquisition
C - Data Interpretation/Validation **D** - Writing
E - Review/Editing **F** - Supervision/Project administration

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