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TECTONIC FRAMEWORK OF THE SÃO JOSÉ DO CAMPESTRE MASSIF, BORBOREMA PROVINCE, BASED ON NEW AEROMAGNETIC DATA

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ABSTRACT. Archean nuclei are the result of complex tectonic processes that developed during the long evolutionary history of the Earth. These units are marked by tectonic signatures that resulted from multiple deformational events, crustal reworking and tectonic reactivation at different crustal levels. The understanding of their tectonic framework requires various tools and, in this paper, geophysical data were used to improve the understanding of the Archean core located in the São José do Campestre Massif (SJCM), northeastern portion of the Rio Grande do Norte Domain, Borborema Province. Based on analysis of the radial power spectrum of the Total Magnetic Intensity (TMI), the signal was interpreted based on wavelength, which is related to different families of individual sources in different depths. This analysis allowed to separate the spectrum into four families of signals (B0, B1, B2 and B3), leading to physical limits of local crustal blocks that represent different geological units, with different ages, evolution and deformation history. It has also improved the understanding of the internal structure and the different depths of magnetic sources of the SJCM, which integrated to structural surface data, define its tectonic framework. The SJCM consists of an Archean core surrounded by Paleoproterozoic terrains. Final configuration, represented by the development of transcurrent shear zones that surround the massif, is due to the Brasiliano Orogeny. The tectonic framework of the basement high is marked by a set of magnetic lineaments representing deep transcurrent shear zones. The magnetic alignments system features structural N70° E and N30° E trends related to the João Câmara, Remígio and Brejinho shear zones and splays of the Patos Lineament. These regional structures are interpreted as boundaries of crustal blocks. The geometry of the major magnetic lineaments shows sigmoidal configuration related to the predominantly dextral EW Patos shear zone. The geophysical signatures allow establishing the limits of the Paleoproterozoic Santa Cruz, Serrinha-Pedro Velho and João Câmara complexes, which surround the Archean core. The first order magnetic features were defined in the Brasiliano Orogeny that reactivated the remaining structures and controlled the accommodation of Neoproterozoic granite intrusions, preferably along shear zones.

Keywords: aeromagnetic data, Borborema Province, geophysical and tectonic framework.

RESUMO. Núcleos arqueanos resultam de complexos processos tectônicos que se desenvolveram durante longa história evolutiva da Terra. Essas unidades são marcadas por assinaturas tectônicas complexas devidas a múltiplos eventos deformacionais, retrabalhamento crustal e reativação tectônica em diferentes níveis crustais. A compreensão do arcabouço geotectônico resultante requer a utilização de diversas ferramentas. Neste trabalho fez-se uso de dados de aerogeofísica, tendo como alvo o núcleo arqueano localizado no Maciço São José do Campestre (SJCM), porção nordeste do Domínio Rio Grande do Norte, Província Borborema. O espectro radial ponderado de potência do Campo Magnético Total (CMT) foi segmentado com relação a diferentes comprimentos de onda, produzidos pelas diferentes famílias de fontes individualizadas relativas a diferentes profundidades. A análise permitiu separar o espectro em quatro famílias de sinais (B0, B1, B2 e B3), com a individualização de limites físicos dos blocos crustais locais, que representam diferentes unidades de mapeamento geológico de distintas idades e complexa história evolutiva e deformacional. A análise melhorou a compreensão da estruturação interna e das diferentes profundidades das fontes magnéticas do SJCM e, integrada aos dados estruturais de superfície, define seu arcabouço tectônico. O SJCM é composto por núcleo central arqueano, circundado por terrenos paleoproterozoicos. A Orogenia Brasiliana, representada pelo desenvolvimento de zonas de cisalhamento transcorrentes que delimitam o maciço, foi responsável pela configuração final. A trama tectônica desse alto do embasamento é marcada por conjunto de lineamentos magnéticos que representam cisalhamentos transcorrentes profundos. O sistema de alinhamentos magnéticos apresenta tendência estrutural N70° E e N30° E, correspondentes às zonas de cisalhamento João Câmara, Remígio e Brejinho e às terminações em *splay* do Lineamento Patos. Estas estruturas regionais são interpretadas como limites de blocos crustais. A geometria dos lineamentos magnéticos principais apresenta configuração sigmoidal resultante do prolongamento da zona de cisalhamento EW de Patos, cujo sentido de movimento predominante é dextral. As assinaturas geofísicas permitem estabelecer os limites dos complexos Santa Cruz, Serrinha-Pedro Velho e João Câmara, de idade paleoproterozoica, que circundam o núcleo arqueano. As feições magnéticas de primeira ordem foram definidas na Orogenia Brasiliana, que reativou estruturas mais antigas e controlou o alojamento de corpos graníticos neoproterozoicos, preferencialmente nas zonas de cisalhamento.

Palavras-chave: aeromagnetometria, Província Borborema, blocos geofísico-tectônicos.

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INTRODUCTION

Archean cores are the result of complex tectonic processes developed over the long evolutionary history of the Earth. Often multiple tectonic signatures due to multiple deformational events, crustal reworking and tectonic reactivation at different crustal levels mark these units. A major problem when trying to understand the tectonic framework of the basement high is that they are overlapped by sediments near modern coastal regions, with scarce outcrops and no continuity of surface structures (Dantas, 1997; Stewart & Betts, 2010).

Thus, tools for integrating data from field geology, associated with enhancement techniques of geophysical anomalies, have been used to understand the geological processes dominant below the surface and to infer boundaries of tectonic blocks, defined by geophysical or geological discontinuities in depth in complex areas.

Models of tectonic partitioning obtained by 3D modeling via gravimetry and magnetometry data in Archean terrains comprising greenstone belts and TTG-type rocks present geophysical and geological peculiarities that can characterize deep sources and roots of the Archean nuclei, as in the case of the Pilbara Craton, northwestern Australia (Wellman, 2000). Geophysical characterization of Archean nuclei involves both internal configuration and defining the boundaries with adjacent Precambrian or younger units, which feature a set of inter-related crustal domains. The oldest regions encompass units composed of aluminous metasedimentary rocks, cherts, carbonates, calc-silicate rocks and TTG-type igneous rocks, which usually display low amplitude anomalies of the magnetic signal. In turn, the succession of rocks of greenstone belts, such as komatiites, tholeiitic basalts, banded iron formations and mafic intrusions, which suggest interaction with mantle plumes processes (Stewart & Betts, 2010), show large amplitude and frequency anomalies.

Boundaries of different orogenic belts formed by episodes of crustal accretion that merge around the Archean nuclei can be enhanced by integrating geological mapping and magnetometry. Holm et al. (2007), for example, improved the evolution model of these terrain types in the north-central United States by integrating geological and geophysical data.

Determination of petrophysical properties of multiple magnetic horizons, obtained through aeromagnetic data (Crawford et al., 2010), may be related to tectonic features generated in different episodes of mineralization associated with magmatism, hydrothermal processes and crustal reworking. The relationship between the structural inheritance of old events and the reactivation of pre-existing structures, generated in distinct metamorphic facies, can be evaluated. The main techniques used to associate structural studies, through refining and processing of aeromagnetic data, are Euler Deconvolution, local wavenumber and amplitude of the analytical signal of the Anomalous Magnetic Field (Bournas et al., 2003).

In the São José do Campestre Massif (SJCM), a mosaic of crustal blocks is represented by a central Archean core surrounded by Paleoproterozoic terrains. Each crustal block has a dominant tectonic regime. The aim of this study is to determine the internal architecture of this multi-deformed region, differentiating the areas where old structural patterns are preserved from the influence of the Brasiliano tectonic activity. Airborne geophysical processing and interpretation methods are used as a tool to improve and expand the geophysical and geological knowledge of the SJCM and its tectonic components.

Based on the technique developed by Grant & Spector (1970), the intensity data of the Total Magnetic Field (TMF) were separated in magnetic domains according to the depth bands interpreted in the power spectrum, thus allowing four depth components to be individualized.

The study area is located in northeastern Brazil (Fig. 1), in the eastern portion of the states of Rio Grande do Norte and Paraíba, and included in the Map of the Millionth Brazil SB-25 (Angelim et al., 2004) and the airborne geophysical Eastern Edge of the Borborema Plateau Project (CPRM, 2008).

Geological Framework of the Borborema Province

The Borborema Province – PB (Almeida et al., 1977, 1981) is defined as one of geotectonic entities that compose the set of ten structural provinces that resulted from the partitioning of the Brazilian territory. The Borborema Province is a crustal fragment, resulting from the convergence between the West Africa-São Luís and São Francisco-Congo cratons during the Brasiliano Orogeny, including ancient blocks of basement high and supracrustal mobile belts consolidated in the Neoproterozoic (Caby, 1989; Trompette, 1997; Dantas et al., 2004; Van Schmus et al., 2008). The limits of the BP are the Phanerozoic sedimentary rocks of the Parnaíba Basin, to the west; the São Francisco Craton, to the south; and the coastal sedimentary basins of the Brazilian continental margin, to the east and northeast (Brito Neves, 1975).

Caby (1989) and Van Schmus et al. (1995) suggest that the BP continues in Africa through the Trans-Saharan Fold Belt, highlighted by the continuity of large structures and lineaments.

Three geologically different subprovinces can be outlined within the province: northern, transverse (or central), and southern (Van Schmus et al., 2008, 2011; Santos et al., 2010), earlier

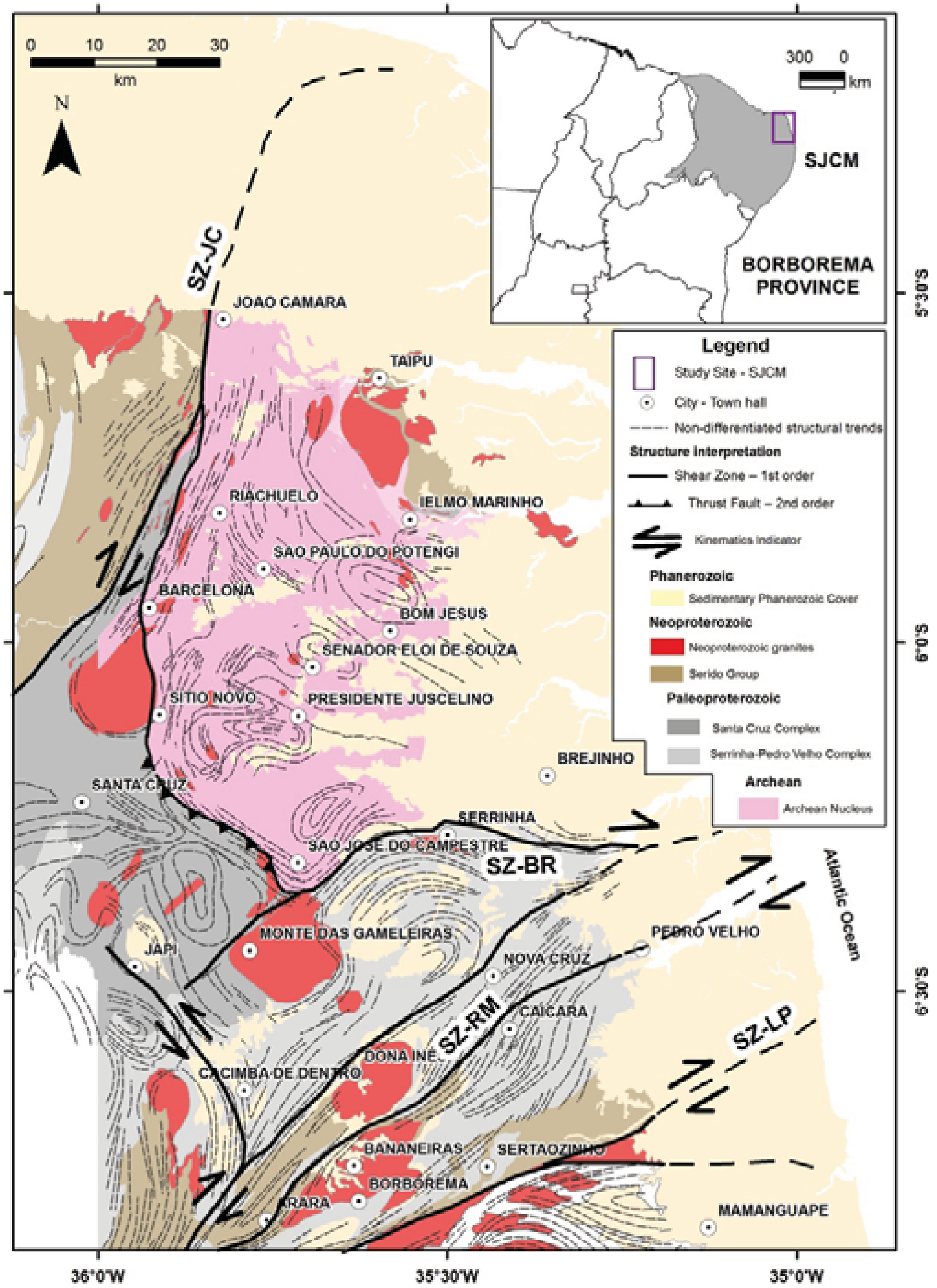


Figure 1 – São José do Campestre Massif: Main tectonostratigraphic units compiled from Angelim et al. (2007). The main structures (1st order) are delimited by the magnetic products. The dashed lines correspond to the structural trends of geological map and these are congruent with the magnetic lineaments.

on recorded as domains (Van Schmus et al., 1995; Brito Neves et al., 2000; Santos et al., 2000). They are limited by the Patos and Pernambuco continental-scale lineaments. Each subprovince comprises several domains that may be divided into subdomains, based on differences in their geology, like the Rio Grande do Norte Domain, the easternmost of the northern subprovince.

São José do Campestre Massif

The São José do Campestre Massif comprises the Precambrian basement of the easternmost Rio Grande do Norte Domain (Fig. 1), underlying an area of approximately 6,000 km^2 (Brito Neves, 1983). The massif includes the oldest fragment of sialic crust of the South American Platform (Dantas, 1997; Brito Neves et al., 2000; Dantas et al., 2004).

The SJCM essentially corresponds to a group of orthogneiss, migmatized gneisses, and syenogranites (Dantas, 1997). Recently, Dantas (2009) has identified the presence of layered mafic-ultramafic rocks and a greenstone belt-type volcanic-sedimentary sequence.

Different rock formation episodes are recorded in the Archean core. The Presidente Juscelino Complex corresponds to a tonalite-trondhjemite-granodiorite terrain (TTG suite), dated at 3.25 Ga by U-Pb in zircon. T_{DM} model age is ca. 3.6 Ga, with negative eNd values (Dantas et al., 2004). Small portions of Paleoarchean crust material, dated at ca. 3.4 Ga (U-Pb in zircon; T_{DM} ca. 3.6-3.9 Ga) are found in this TTG suite. The Brejinho Complex represents the juvenile crust of approximately 3.18 Ga.

The gabbro-anorthosite suite of 3.03 Ga (zircon U-Pb age) of Senador Eloi de Souza and Riacho da Telha complexes are represented by layered mafic-ultramafic sequences with T_{DM} age of up to 3.9 Ga (Jesus, 2011). The intrusion of 2.7 Ga syenogranite marked the last Archean igneous activity in the core.

Tectonothermal evolution between the Paleoproterozoic and Archean is suggested for the SJCM. A metamorphic event about 3.0 Ga is suggested based on dating of migmatites of the President Juscelino Complex. A Paleoproterozoic event dated at 2.0 Ga, which reached amphibolite facies conditions, can be observed due to a second phase of migmatization. The Paleoproterozoic complexes are formed of calc-alkaline granitic suites resulting from juvenile crust-forming processes and crustal reworking at the border of the Archean core. The João Câmara and Santa Cruz complexes, with U-Pb age of 2.25 Ga and T_{DM} model age of 2.5 Ga, are different from the Serrinha-Pedro Avelino Complex, which corresponds to juvenile crust of 2.2 Ga and T_{DM} 2.23. Dyke swarms of tholeiitic composition form the Inharé Suite, with U-Pb zircon ages of 2.15 Ga and 1.97 Ga (Dantas, 1997; Dantas et al., 2004).

The final configuration of the SJCM results from the Brasiliano Orogeny, represented by the development of an extensive system of transcurrent shear zones associated with granite magmatism. The granitoids were intruded between 0.62 Ga and 0.58 Ga. The Neoproterozoic tectonics in the SJCM is expressed by low angle shear systems (associated with regional D2 deformation) and the transcurrent shear systems (associated with regional D3 deformation; Jardim de Sá, 1994; Archanjo, 1987; Caby, 1989). Hackspacher et al. (1995) suggested a model including collisional tectonics associated with NW tectonic transport, followed by lateral escape tectonics that ends in NE trending transcurrent shear zones, basically a Brasiliano pattern.

The Brasiliano tectonics can be visualized by two major dextral shear zones with sigmoidal shape that define the SJCM: The Picuí-João Câmara shear zone to the west, where the basement is in contact with metasedimentary rocks of the Seridó Group, and Cacerengo-Pocinhos-Remígio shear zone to the south, resulting from the EW Patos shear zone, superimposing Paleoproterozoic terrains.

The kilometric NE dextral shear zones outline the shape of the Archean core. The curving of the lithologic trend and of the EW to NW structural elements at the boundary between the Archean and Paleoproterozoic crustal blocks is the main result of this change in orientation of deformational events and regimes. The Paleoproterozoic crust was then reworked in the Neoproterozoic during the Brasiliano Orogeny (Dantas & Hackspacher, 1997). The result is a mosaic of crustal blocks formed by the Archean central core surrounded of Paleoproterozoic terrains.

Regarding the geophysical characteristics, the SJCM presents positive gravity signature in the north-central region corresponding to the Archean core (Dantas, 1997; Dantas et al., 2004) of high density, in contrast with the metasedimentary and granitic rocks of the Seridó Belt. This density difference also suggests that the Picuí-João Câmara shear zone could be a suture between the SJCM and the Rio Piranhas Terrain (Castro et al., 1997, 1998; Jardim de Sá et al., 1997; Campelo, 1999). Oliveira (2008) used aeromagnetic data to define the boundary between the subdomains from an axis of low magnetization accompanying the north-south trend that occurs on the west and segments the northeast-southwest structuring on the east.

The main focus of this paper is to discuss the internal structure and the different depths of magnetic sources of the SJCM and its integration with surface structural data defining the tectonic framework of the area.

AIRBORNE GEOPHYSICAL DATA

High spatial density data (Jaques et al., 1997) from the Aerogeophysical Project of the eastern Edge of the Borborema Plateau were used. These data were provided by the Company for Research of Mineral Resources – CPRM, of the Ministry of Mines and Energy.

The airborne surveys had North-South production lines, spaced 500 meters from each other, east-west perpendicular control lines, spaced 10 km, and flying height of 100 meters (CPRM, 2008).

The magnetometer used Scintrex CS-2 sensor, with 0.001 nT resolution and 0.1 s measurement interval. For the approximate flight speed of 280 km/h, the magnetometer produces one reading every 8 meters (CPRM, 2008).

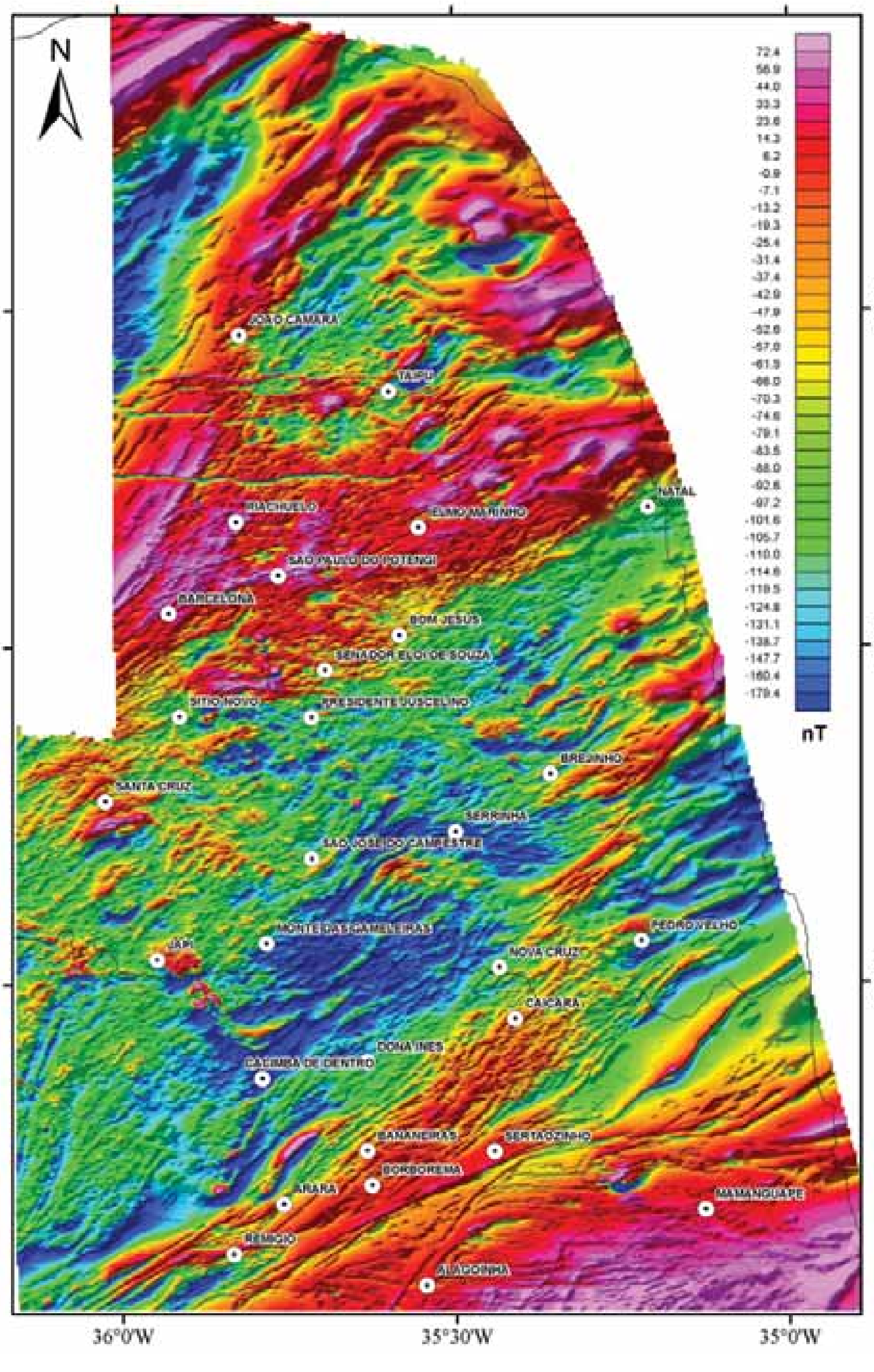


Figure 2 – Anomalous Magnetic Field (micro-leveled and shading of inclination 45° and declination of 315° Az).

DATA PROCESSING

The geophysical data were treated and processed on the Oasis montaj (v. 7) platform, by generating a regular 100-meter spacing mesh. The main product generated was the micro-leveled Anomalous Magnetic Field – AMF (Fig. 2), from which a range of products was generated and used to interpret the data.

The Spector & Grant (1970) radial weighted spectrum of the Total Magnetic Field – TMF intensity was initially used. It was then possible to separate the magnetic signal according to the depth range interpreted in that spectrum. The analysis of the radial power spectrum of the TMF (Fig. 3) allowed individualizing four components. Specifically, wave smaller than 0.09 km^{-1}

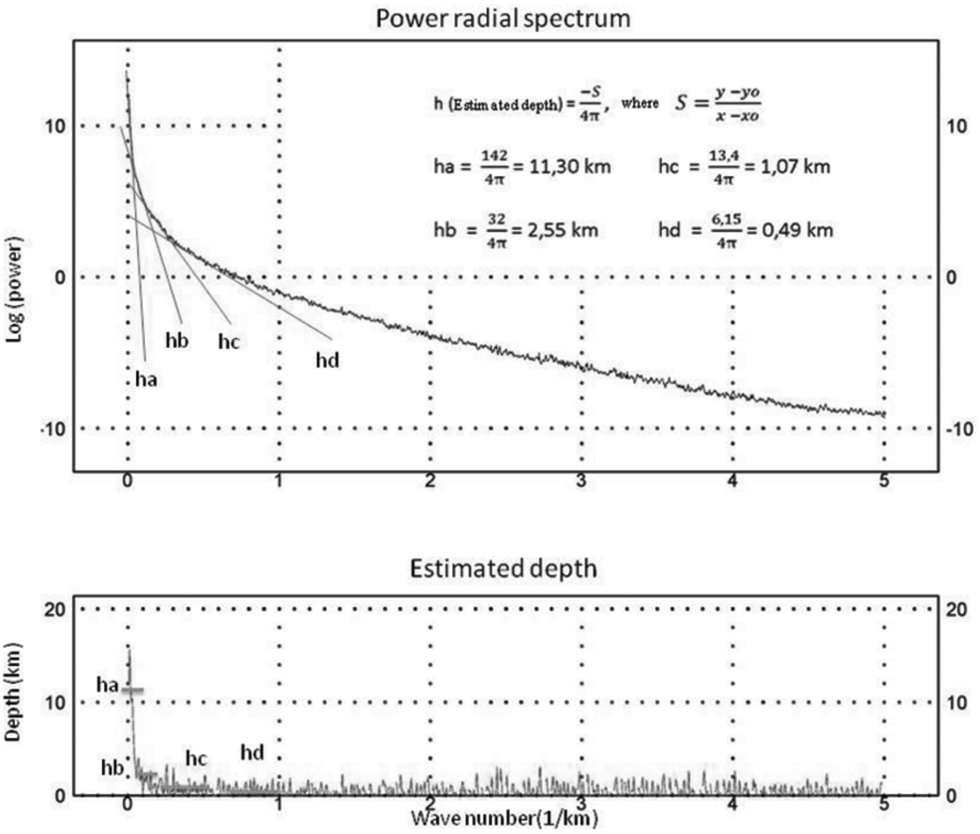


Figure 3 – Radially weighted power spectrum of the Total Magnetic Field – TMF.

represents the deep sources (h_a), with top magnetic sources between 10 and 12 km deep ($h_a = 11.3$ km). On the other hand, h_b, h_c and h_d groups characterize gradually shallower sources with wave number between 0.09 and 0.25 km^{-1} for h_b; 0.25 and 0.45 km^{-1} for h_c; and from 0.45 km^{-1} to the Nyquist frequency for h_d.

The different spatial frequency bands (h_a, h_b, h_c and h_d) that make up the spectrum of magnetic field intensity were analyzed, according to the methodology described by Blum (1999). This procedure consisted of separating different parts of the spectrum, using a *Butterworth* low pass, high pass and band pass filter, in the micro-leveled Anomalous Magnetic Field (AMF) after filtering the AMF with the *Butterworth* low pass, order 4. The result corresponds to the Anomalous Magnetic Field of the B0, B1, B2 and B3 bands (Table 1).

It is worth mentioning that magnetite loses its magnetization ability when it reaches the 580°C isotherm. Oliveira (2008) considers this occurrence reasonable at approximately 27 km depth for the Borborema Province. Thus, the estimated depth of the top of the deeper magnetic sources, 11.3 km, is compatible with real sources.

Table 1 – Characteristics of the energy spectrum bands for the region.

Band	Wave number (cycle/km)	Wavelength "λ" (m)	Depth "h" (km)
B0	0 to 0.09	$\lambda > 11{,}000$	$h_a > 11.3$
B1	0.09 to 0.25	$11{,}000 > \lambda > 4{,}000$	$11.3 > h_b > 2.55$
B2	0.25 to 0.45	$4{,}000 > \lambda > 2{,}200$	$2.55 > h_c > 1.07$
B3	0.45 to *Fn*	$\lambda < 2{,}200$	$1.07 > h_d > 0$

After separating the AMF intensity in frequency bands (Fig. 2), maps were derived for each individual band (Fig. 4) resulting in maps of Analytic Signal Amplitude (ASA) and tilt derivative for individual bands, namely B0, B1, B2 and B3 (Figs. 5 and 6).

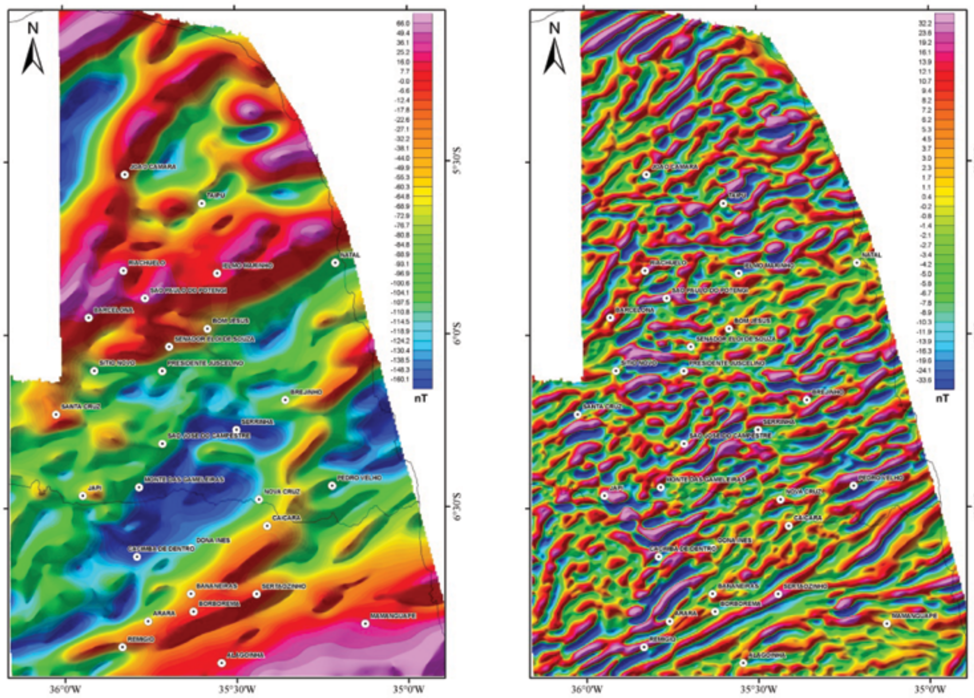
The filtering process was controlled so as not to represent degradation or distortion of measured data. To this end, the reverse operation was performed, i.e., reconstitution from the sum of the intensities for each of the spectral B0, B1, B2 and B3 bands (Fig. 4).

Thus, the result from the subtraction between the AMF and the sum of the bands must be considered as noise from the filtering process of the data:

$$\text{Noise (r)} = \text{AMF} - (\text{AMF\_B0} + \text{AMF\_B1} + \text{AMF\_B2} + \text{AMF\_B3}).$$

a) Depth 11.3 km

b) Depth 2.55 km



c) Depth 1.07 km

d) Surface

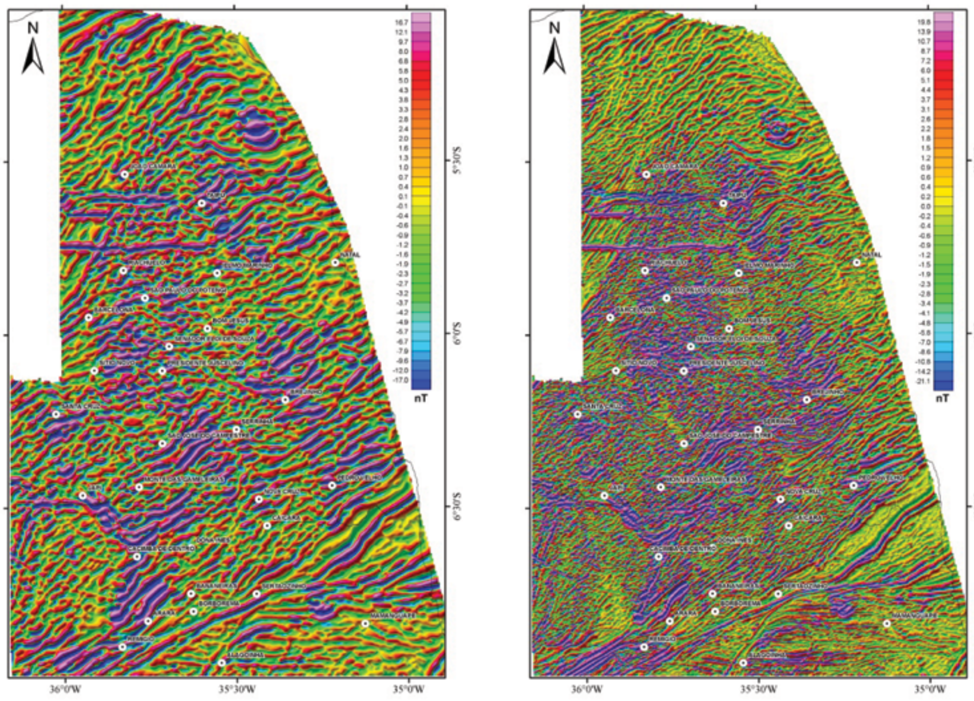
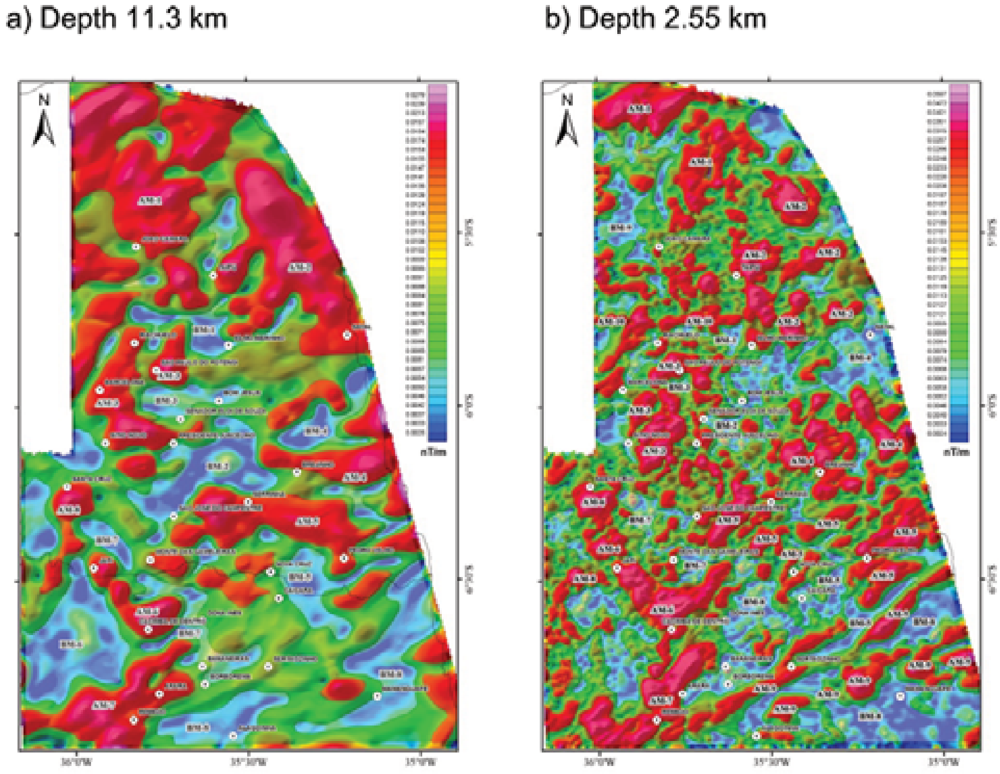
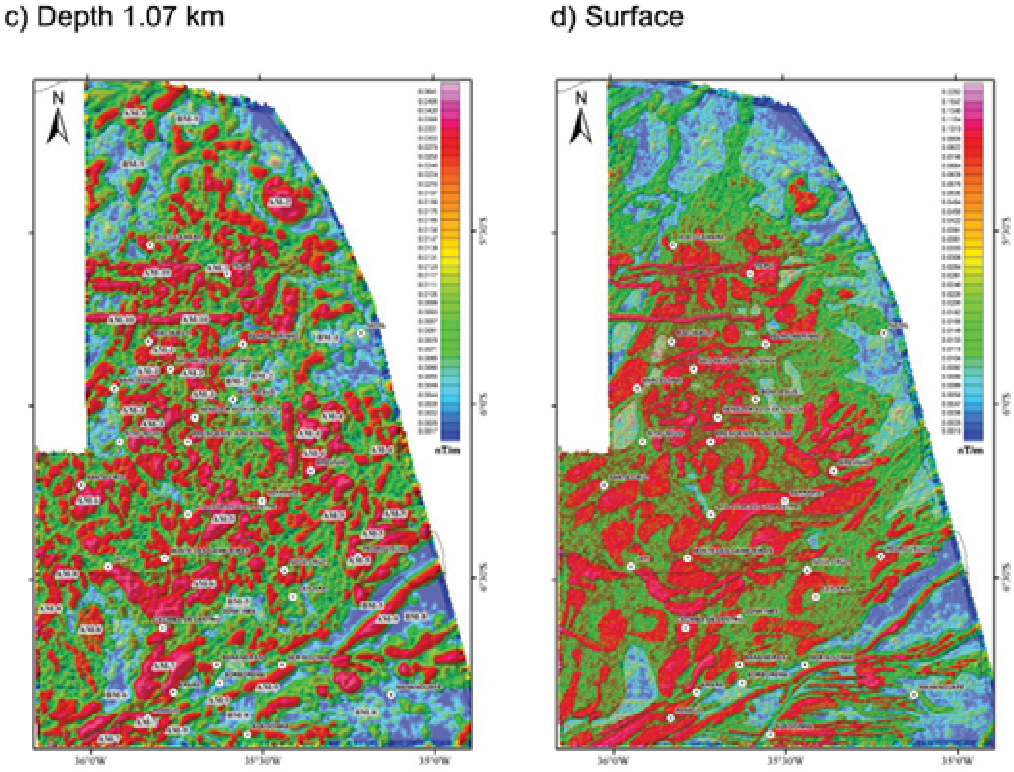


Figure 4 – Anomalous Magnetic Field (AMF) maps for the bands: a) B0 (27 km $< h <$ 11.3 km); b) B1 (11.3 km $< h <$ 2.55 km); c) B2 (2.55 km $< h <$ 1.07 km); and d) B3 (1.07 km $< h <$ 0 km).



a) Depth 11.3 km

b) Depth 2.55 km



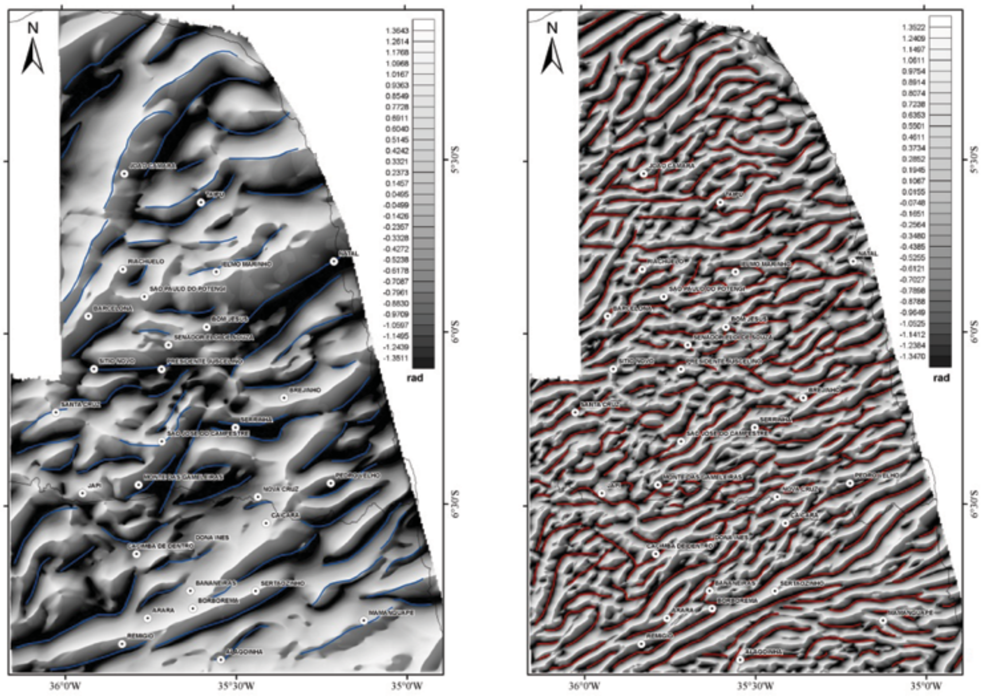
c) Depth 1.07 km

d) Surface

Figure 5 – Analytic Signal Amplitude overlapping with the interpretation of the bands: a) B0 (27 km < h < 11.3 km); b) B1 (11.3 km < h < 2.55 km); c) B2 (2.55 km < h < 1.07 km); and d) B3 (1.07 km < h < 0 km).

a) Depth 11.3 km

b) Depth 2.55 km



c) Depth 1.07 km

d) Surface

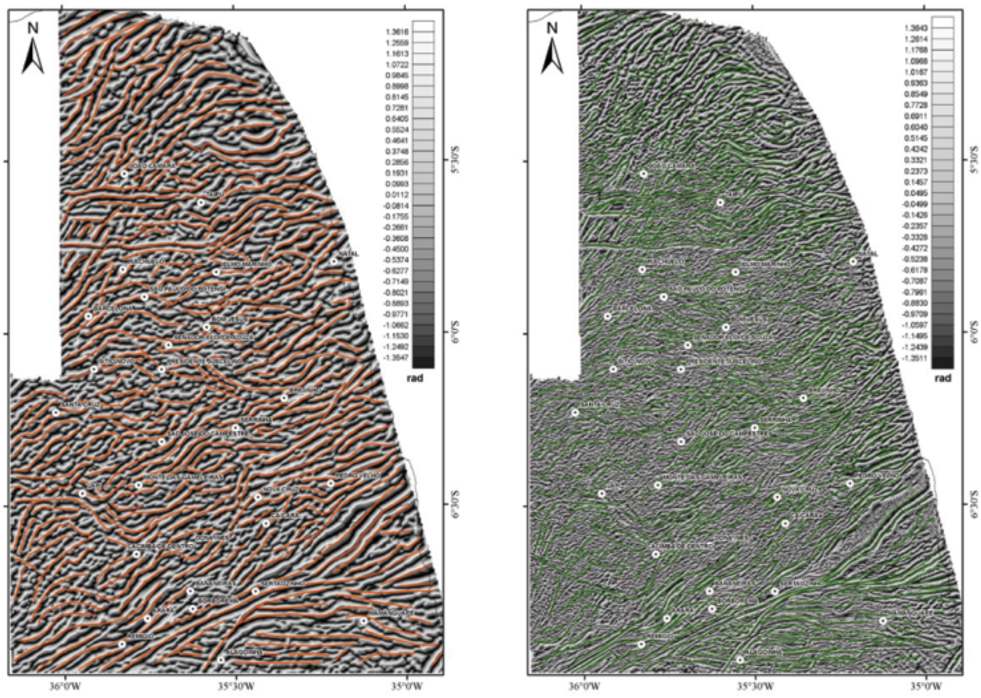


Figure 6 – Tilt derivative maps for bands: a) B0 (27 km < h < 11.3 km); b) B1 (11.3 km < h < 2.55 km); c) B2 (2.55 km < h < 1.07 km); and d) B3 (1.07 km < h < 0 km) and interpretations of the magnetic lineaments.

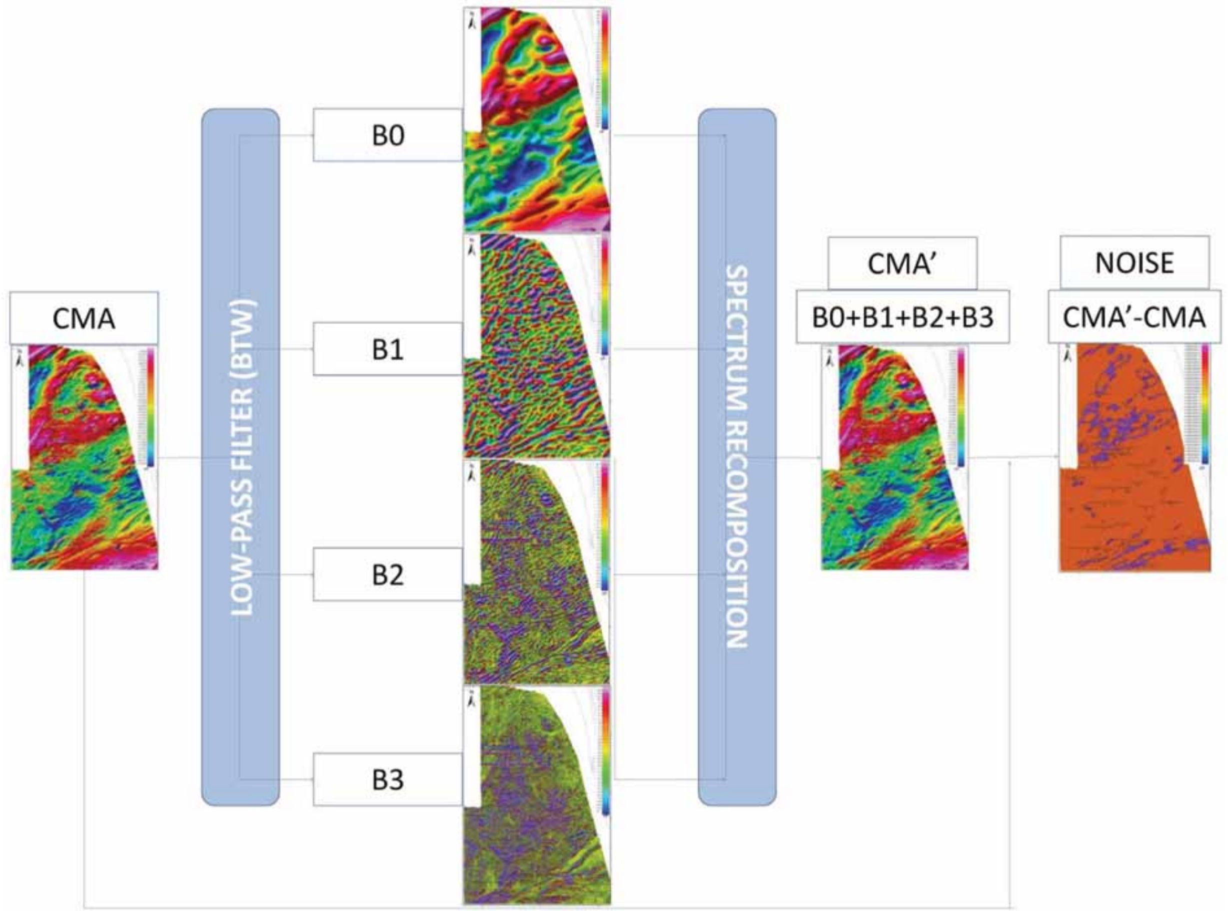


Figure 7 – Flowchart of spectrum segregation and recomposition processes of AMF according to the power spectrum. The reverse operation shown in the figure corresponds to: dividing the Anomalous Magnetic Field in four bands (B0, B1, B2 and B3) according to the power spectrum parameters (Table 1); applying the signal attenuation filter; restoring the power spectrum signal by summing the components resulting from the previous process. The noise is the difference between the original magnetic signal and the sum of the four components of the magnetic field (AMF). Note that the noise generated is of the order of 10^{-9} nT.

It is inferred that the processing maintained the signature of the initial data – AMF (Fig. 7). Anyhow, this noise can be considered the product of level four smoothing of the *Butterworth* low-pass filter, order 4.

Magnetic Data Interpretation

The magnetic domains were interpreted from the Analytic Signal Amplitude – ASA and magnetic lineaments were based on Analytic Signal Tilt – AST, both products generated from the Anomalous Magnetic Field for each band separately. More specifically, they used the bands B0 (depth greater than 11.3 km), and shallow components, B1 (depths between 11.3 and 2.55 km), B2 (depths between 2.55 and 1.07 km) and B3 (depths less than 1.07 km), according to depth intervals estimated (Table 1). Domains and lineaments (Figs. 5 and 6) can be observed for each depth interval.

Different maps for deep (>11 km) to shallow (<2 km) sources were prepared for the area. The deeper sources, located in the region between Santa Cruz and João Câmara correspond to AM-1 and AM-8 (Fig. 5a) domains and present a set of elongated NE-SW anomalies, this trend being more evident in the second domain due to steep N30°E elongation.

Other deep anomalies can be identified (Fig. 5a) between Sítio Novo and Presidente Juscelino (AM-04), and in Barcelona (AM-03). All these anomalies of the analytic signal represent an abrupt geophysical discontinuity segmented by the BM-2 domain, between Lagoa Santa and São José do Campestre, with N30°E trend. A N30°W high amplitude anomaly of the analytic signal is recognized next to Japi (AM-6). The domain of N70°E anomalies (AM-7) corresponds to a directional gradient in elongated strip that defines the boundary between different geophysical blocks between Remígio and Pedro Velho (Fig. 5a). The shallower sources (h<2 km) are represented by B1, B2 and B3 bands (Figs. 5b, 5c and 5d) from which the AM-2 domain can be extracted. This domain represents a semicircular anomaly on the surface with high amplitude anomaly and sharp drop of magnetic relief.

Similarly to the magnetic domains, the structures corresponding to the magnetic lineaments are segmented in deep components (>11 km), which correspond to magnetic lineaments extracted from the AST, more specifically from the B0 band (Fig. 6a) and shallow components (<2 km) of the B1, B2 and B3 bands (Figs. 6b, 6c and 6d). The main structures depicted in this work are the NE-SW components represented by penetrative strong magnetic gradient that should, certainly, be linked to the deep physical discontinuities limiting large magnetic fields (Fig. 6a). NW features are more evident in shallow components of magnetometry (Figs. 6b, 6c and 6d), especially in the central region, which are NE-SW bent by sinistral motion. EW linear structures are shallow and do not affect the remaining structures in the southern portion.

Geophysical-tectonic Framework of São José do Campestre Domain

In SJCM, a mosaic of crustal blocks is depicted as a central Archean core surrounded by Paleoproterozoic terrains. The analysis of the anomalies allowed differentiating a set of domains or tectonic-geophysical homogeneous blocks (Fig. 8), segmented by the structural frame of large shear zones, which represent discontinuities of the crust magnetic signal observed at greater depths, approximately 10 km, in the B0 band. These blocks correspond to different geological terrains and can be defined in terms of geophysical signature:

- Seridó Belt (Seridó block): Displays magnetic lineaments with preferred N30°E trend and magnetic character at the depth greater than 11.3 km (B0);

- João Câmara Terrain: represents the elliptical magnetic body with N30°W trend in the B0 band, representing depth greater than 11.3 km, and acquires semicircular shape in the shallow portions (B1, B2 and B3);

- São José do Campestre Terrain: the magnetic anomalies are preferentially N30°W and N70°E oriented, with magnetic character of heterogeneous internal distribution (high magnetism zones). The blocks in question are segmented by N30°E magnetic lineament;

- Santa Cruz and Serrinha-Pedro Velho terrains (north of SZ-LP): physical blocks with medium to low anomaly of the Analytic Signal Amplitude with preferentially N30°E and N70°E trending magnetic lineaments;

- Santa Cruz and Serrinha-Pedro Velho terrains (south of SZ-LP): correspond to low anomaly of the Analytic Signal Amplitude with internal homogeneous distribution and preferentially N70°E trending.

The coherence of each crustal block magnetic structures may be related to a dominant tectonic regime, and will be considered as different structural domains, defined in field work and basic geological mapping. Each homogeneous structural domain is individualized by the predominant behavior of structural elements in a given geographical area (Jardim de Sá & Hackspacher, 1982). The time factor, considering the time of the development of geometry and kinematics of a tectonic regime imprinted in a particular structural domain, will be the main element tying the discussion.

The nomenclature consists of identifying different phases of deformation generated in a polycyclic history. D1 corresponds to the earlier deformation described in the area (Hackspacher et al., 1986; Archanjo et al., 1991; Jardim de Sá, 1994), while D3 corresponds to the superimposed youngest event. Identification of the older structural framework preserved from the superposition of the Brasiliano tectonic defines the earliest structural domains of the SJCM.

The main criterion to recognize homogeneous structural domains in the Paleoproterozoic terrains of the SJCM, adjacent to the Archean core is the presence of textural features indicative of magmatic and tectonic history preserved in migmatites and granitoids that make up these terrains. In these terrains, the structural elements are associated with a general NW low angle structural trend (foliation and stretching lineation). Generally, the older structures of tangential tectonics are preserved in low strain zones between pairs of dextral and sinistral strike-slip shear zones associated with the D3 event, regionally considered to be related with the Brasiliano Orogeny. In this case, isoclinal recumbent folds showing NS axes are recognized on the flanks of NE shear zones. The axes of the folds are reoriented, creating SSW and NE verging folds.

The geometry of the central Archean core is defined by an antiform dome whose structural elements follow the elliptical shape of the block with NE-SW and NW dips, limited to the south by the Brejinho Shear Zone (SZ-BR, Fig. 9). Internally, this dome displays small oval shapes 5-10 km in diameter, regularly distributed in the massif, which can be considered as crustal

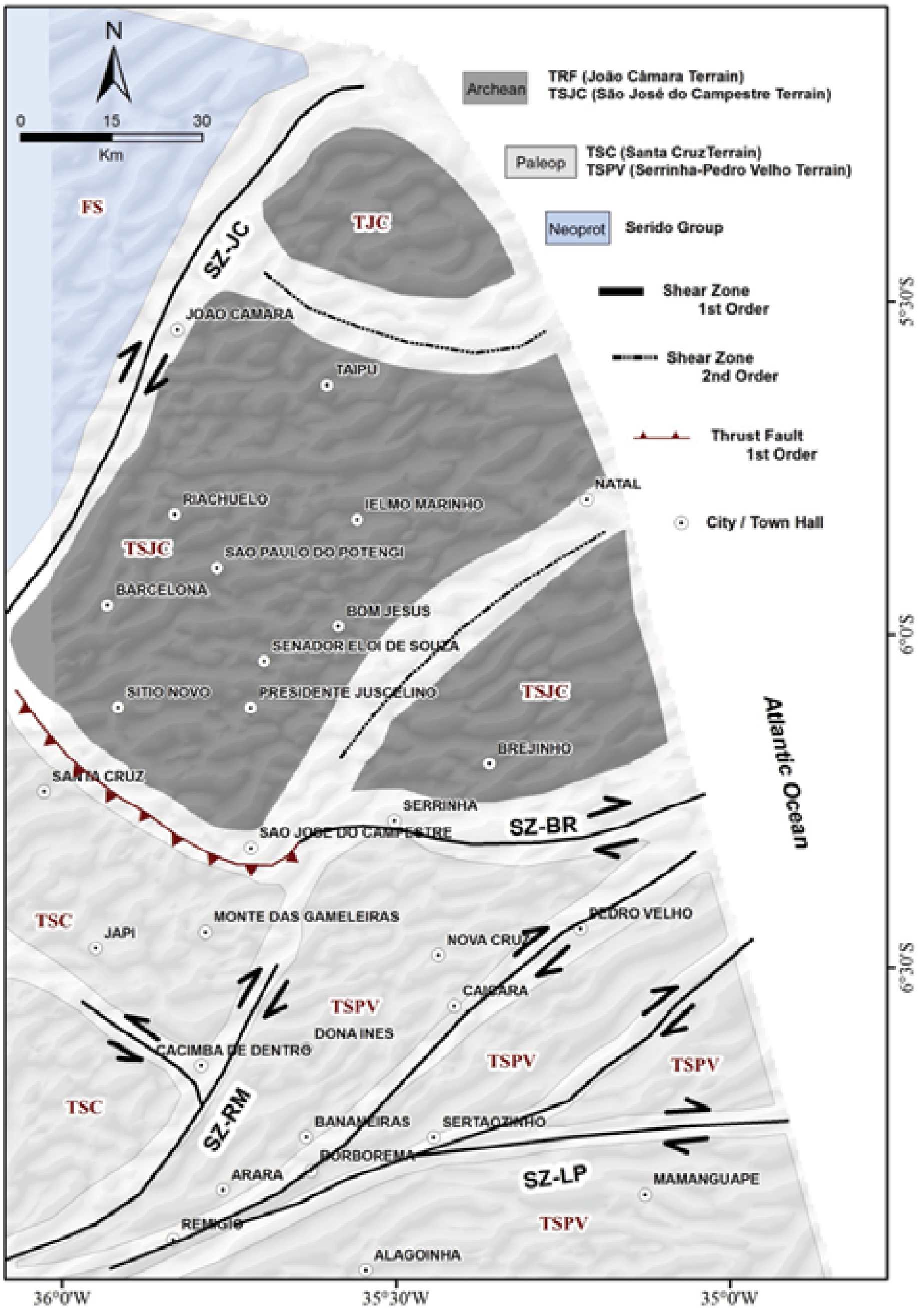


Figure 8 – Physical and geological model. Santa Cruz (TSC), Serrinha-Pedro Velho (TSPV), São José do Campestre (TSJC), João Câmara (TJC) terrains; and Seridó Group (FS); Splay Fault of Patos Lineament (SZ-LP), Remígio (SZ-RM), Brejinho (SZ-BR) and João Câmara (SZ-JC) shear zones.

segments in the structure of the central Archean block (Dantas, 1997). The well preserved deformation inside the Archean block is characterized by the development of a low angle Paleoproterozoic foliation (Hackspacher et al., 1995), bearing kinematic indicators suggesting SE to NW tectonic transport. The high foliation dips in many parts of the core suggest lateral ramps associated with NW thrusting.

The Senador Eloi de Souza area is characterized by a system of left lateral strike-slip shear, which can be considered as a homogeneous structural domain with NW-SE trending linear and planar elements. The subvertical foliation is usually represented by L-type tectonites, in which the associated stretching lineation can be horizontal or of high rake. The location of this strike-slip system associated with high-grade metamorphic rocks (heden-

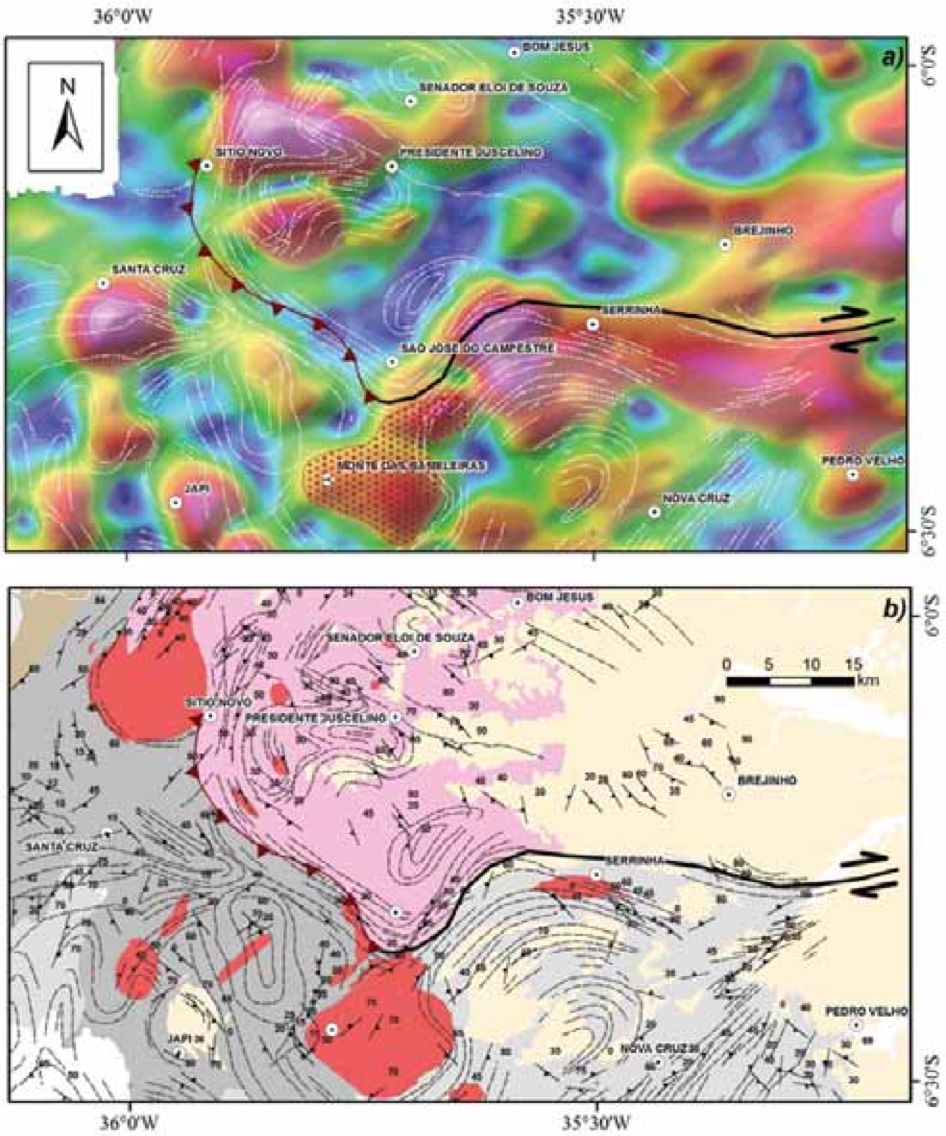


Figure 9 – Brejinho Shear Zone (SZ-BR) represents the boundary between the Archean nucleus and the Paleoproterozoic complex. In a) there is consistency between the trends of surface features shown in white dotted lines, and the magnetic signal behavior in depth (Analytic Signal Amplitude of AMF for the B0 band, deeper than 11.3 km). The accommodation of the Neoproterozoic granitic bodies (red in b) occurs preferentially in the spaces generated by the reactivation of older structures, such as SZ-BR, at the boundary between the crustal blocks. The symbols in this figure are described in Figure 1.

bergite gneisses of the Senador Eloi de Souza Complex) between two Archean ovals suggest an old structure, reactivated and reworked during the Brasiliano Orogeny, as evidenced by garnet meta-anorthosites and a large amount of mafic rocks in this area. EW trending folding, with closed-like folds and locally verticalized axes are recorded, while interference patterns of the coaxial type are common.

Between São José do Campestre and Brejinho, the main structural feature is the NW to EW curving trend of the rocks at the boundary between the Archean blocks and the Paleoproterozoic Serrinha-Pedro Velho Terrain. The main penetrative foliation in the rocks of this area trends NW and plunges gently to SW-SSE inside the dome, and is truncated by a dextral NE trending strike-slip shear zone, considered as Brasiliano-related, which inflects to EW towards the coast.

A particular structural domain can be individualized in the area of Lages Pintadas, Picuí and Barra de Santa Rosa. The structural elements (foliation and lineation) present in this domain are sub-horizontal, with kinematic indicators suggesting main S-SW thrusting and NW secondary thrusts.

The main features of the structural domain between the Brejinho, Pedro Velho and Santo Antônio do Salto da Onça are the EW trend of the main foliation and a sinistral N50°E strike-slip system between the two major dextral shear zones. The stretching lineation associated with NE sinistral strike-slip shows 50°SE rake.

In Nova Cruz, the rocks show a prevailing N40°E trend, controlled by a dextral strike-slip system (Figs. 8 and 9). The contact between the Archean core and the Paleoproterozoic rocks is marked by mylonites. The best exposure of this contact occurs in the Trairi dam, where mylonites are exposed in a 500-1000 m wide NW sinistral strike-slip shear zone. Sheath folds show NW curved axis, parallel to the shear zones, characterizing lateral escape tectonics. Both blocks dip gently to the SW, with the Paleoproterozoic block thrusting over the Archean block (Fig. 9).

The transpressive strike-slip structural domain of Picuí-João Câmara, which affects the metasedimentary Seridó Belt, is due to the Picuí-João Câmara shear zone. This shear zone developed at the contact between the metasedimentary rocks of the Seridó Group and Paleoproterozoic basement granitoids. Thrusts associated with strike-slip shear characterize this as a transpressional system, in which the supracrustal metasedimentary rocks are thrown eastwards onto the basement (Jardim de Sá, 1994), and to the west in the Lages area, defining a positive flower structure in this region. The structure shows a preferred N30°E trend, curving to EW in its northern end (Fig. 10).

In terms of magnetic signature, the João Câmara shear zone comprises a set of anomalies of the Analytical Signal Amplitude with low relief magnetic field (AM-1, Fig. 5a) at depths represented in B0. On the other hand, the anomaly of low amplitude of the analytic signal occurs only in shallow parts of the crust and it is most striking up to 1 km deep, corresponding to the B2 band (BM-9, Fig. 5c), which contrasts with the high magnetic fields of the Archean core to the east.

In contrast, in the region of Taipu, Ielmo Marinho and Barra de Santa Rosa predominates a transtractive structural domain, where a small strip of metasedimentary rocks of the Seridó Group displays low angle structures (D2), where associated kinematic indicators show NE trending transport. Structural elements indicate a low angle extensional component, showing the sliding of metasedimentary rocks on the basement rocks (Dantas, 1997). The tangential tectonics is followed by the development of NS and NE strike-slip shear zones (D3).

Thus, the geophysical architecture allows suggesting geophysical structures of first order that correspond to well-known regional shear zones, e.g. João Câmara shear zone, reaching deeper than 11 km, and Brejinho shear zone, whose depth could not be well defined by the magnetometric data (Fig. 8).

The splay termination of the Patos Lineament (Fig. 11) is a first-order structure, affecting a large part of the Borborema province, over 100 km, forming a band of more than 25 km of mylonites. This EW to N70°E structural feature is represented by the analytical signal anomaly (AM-9, Fig. 5), a feature that reaches the base of the continental crust (deeper than 11 km), with reactivation of the shallow structures (above 2 km deep) observed in B1, B2 and B3 bands.

DISCUSSION AND CONCLUSIONS

Integration of structural geology and geophysics data, based on the results of power spectrum segmentation and their interpretation, and analysis of different wavelengths indicate that the principal limits between crustal blocks of the study area and the spatial segregation in depth can be established.

The deep components found ($h_a = 11.3$ km) can be correlated with crustal heterogeneities. Specifically in the Archean block, the depths between 10 km and 12 km represent the root of old nuclei, which leads to inferring the discontinuity of the SJCM rooting at this depth. On the other hand, the components h_b, h_c and h_d correlate with shallower sources of the continental crust, with wave number above 0.1 km^{-1}, with a theoretical limit in *Fn*.

The deeper anomalies in the Archean core (AM-3) suggest the continuity of the Greenstone Belt of Serra Caiada to a depth of 10 km.

The final tectonic setting of SJCM is due to the Brasiliano Orogeny, represented by the development of an important system of transcurrent shear zones, surrounding the older core. Two major dextral shear zones with sigmoidal shape (Fig. 12) define the limits of SJCM: i) the Picuí-João Câmara shear zone to the west, where the basement rocks are in contact with the metasedimentary rocks of the Seridó Group and; ii) Cacerengo-Pocinhos-Remígio shear zone to the south, resulting from the extended EW Patos lineament, superimposing on Paleoproterozoic terrains.

Regarding the Seridó block, to the west of João Câmara, the Seridó Group correlates with low amplitude anomalies of the analytical signal and is limited to depths of about 2 km, consistent with the top of the magnetic source marked by the spectral component h_b (Fig. 3 and Table 1), superimposed on the Paleoproterozoic basement of magnetic character (AM-1, Fig. 5).

The João Câmara Terrain, in the Taipu region, which is covered by Phanerozoic sediments in the far northeast, is characterized by anomalous Analytic Signal Amplitude (AM-2, Figs. 5a,

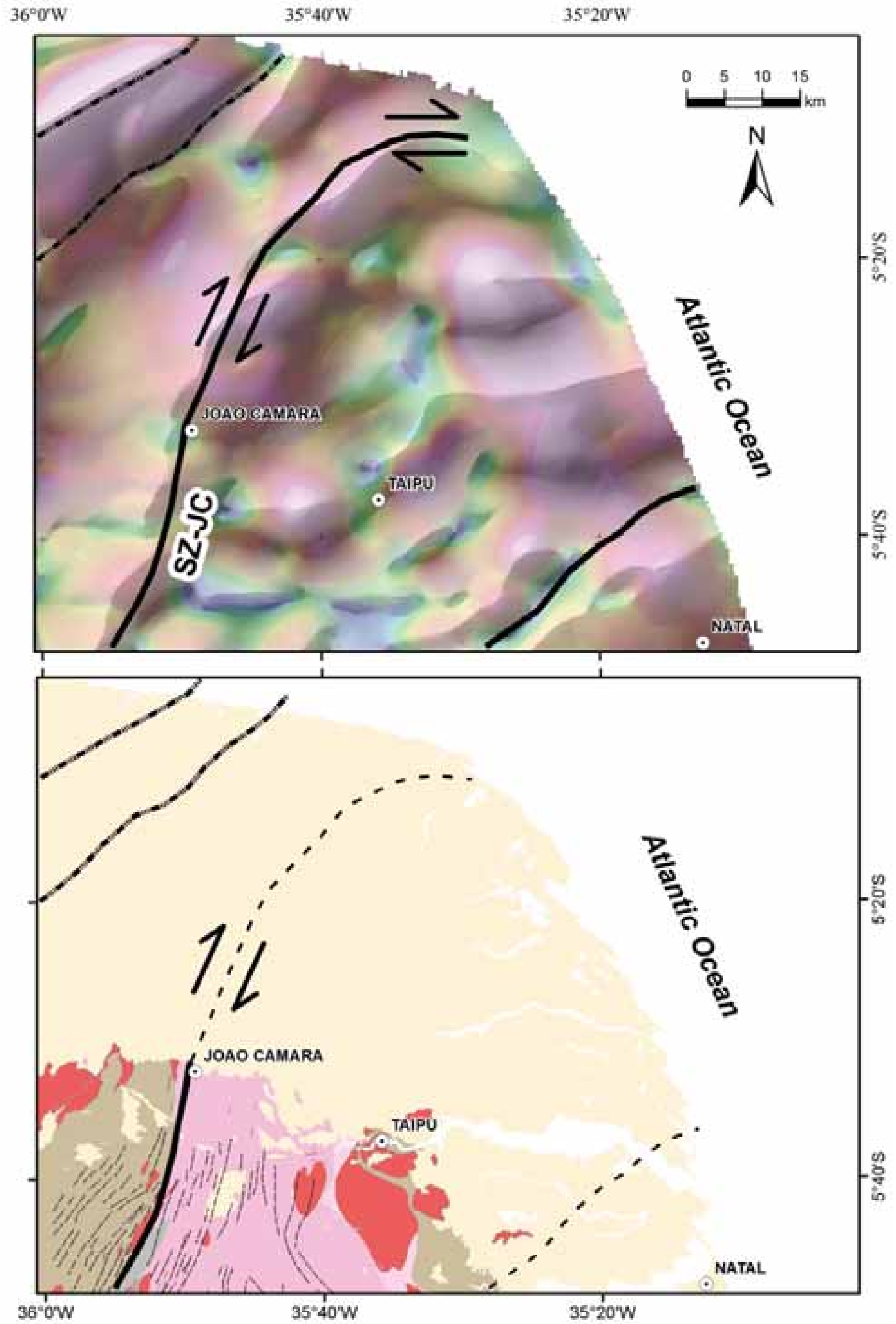


Figure 10 – Detail of the N30°E to N90°E curving in the João Câmara Shear Zone that extends to the limit of the coastal zone (basement of Potiguar Basin). (a) ASA of B0 overlapping with the B0 Tilt derivative. (b) Detail of Figure 1 for the analogy of the data interpreted from geophysics with the surface geology.

5b and 5c), with semicircular geometry, reaching depths of about 10 km, and can be correlated to the João Câmara Complex.

A tectonic model for the evolution of SJCM may be suggested by the relationship between the systems of NE dextral shear zones. Between two parallel zones, a group of parallel NW trending shear zones form a mosaic of small rectangular blocks. This shear system has sinistral displacement and suggests that domains between larger areas were rotated clockwise to establish the current

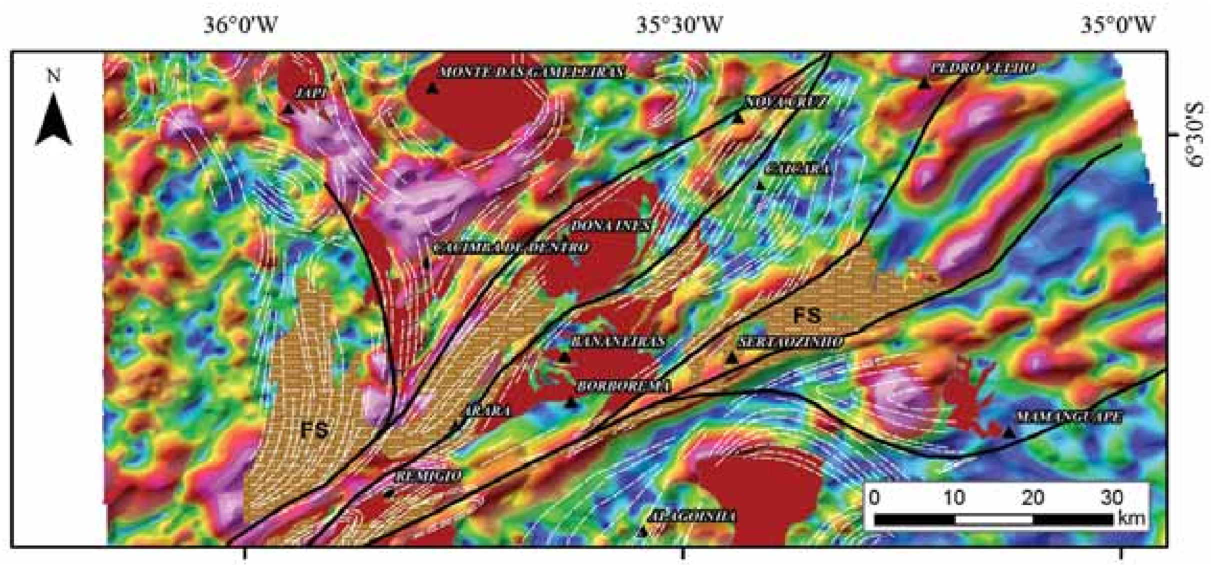


Figure 11 – Splay Fault of Patos Lineament (LP), dextral structure marked by the lineaments in black. The SZ-LP structure is the preferred structure for Seridó Belt's (FS) accommodation and Neoproterozoic intrusions defined in the B1 band, in red. In the background, the analytical signal map is superimposed by tectonostratigraphic features of Figure 1.

configuration. The rotation of blocks is only related to the lateral displacement caused by the motion compensation of major dextral faults. It also suggests that these blocks became rigid during rotation and were only rotated, showing no large displacement rates.

NW-trending sinistral shear zones can be considered as antithetic faults in a conjugate system with predominantly EW and NE shear zones in the PB. This progression suggests contemporaneity between the Riedel transcurrent systems in different shear directions and the development of this type of tectonics in deep crustal levels.

The rotation of blocks creates spaces for the accommodation of the Brasiliano granites, always between different crustal blocks. The granites intruded using the old structural framework. This analysis leads to the conclusion that the magnetic field anomalies AM-01 and BM-09 (Fig. 5) represent a favorable system to accommodate the granites in the Picuí-João Câmara shear zone while the AM-04 and AM-05 anomalies, which are positioned at the boundary between the Archean core and the Paleoproterozoic complex (Brejinho shear zone, Fig. 9), represent the accommodation zone of Neoproterozoic granite intrusions.

As stated above, when the Curie temperature (about 580°) is reached, the magnetization ability of minerals that make up the crust is lost. Oliveira (2008) considers reasonable that the Borborema Province reaches the Curie temperature at approximately 27 km. Thus, the estimated depth to the top of the deeper magnetic sources, h_a for the studied area is compatible with real sources. The presence of mafic rocks, such as gabbros, anorthosites and diorites associated with granites in these major shear zones is evidence that the major structures have reached basal portions of the continental crust, with the presence of magmatism of mantle partial melting. Thus, it is argued that these faulting systems reached depths below h_a (11 km).

The different tectonic regimes in each of the crustal blocks reflect existing change in the field of stress with increasing overall shear strain during the development of transcurrent shear systems, as demonstrated experimentally by Schreurs (1994). Zones of low strain are accompanied by the development of synthetic faults, while areas of high strain are accompanied by antithetic and synthetic faults that develop between major shear zones. Parallel spaced zones develop forming building blocks (domains) that rotate around a vertical axis. An important point is that as deformation progresses, old faults remain active while new faults are formed.

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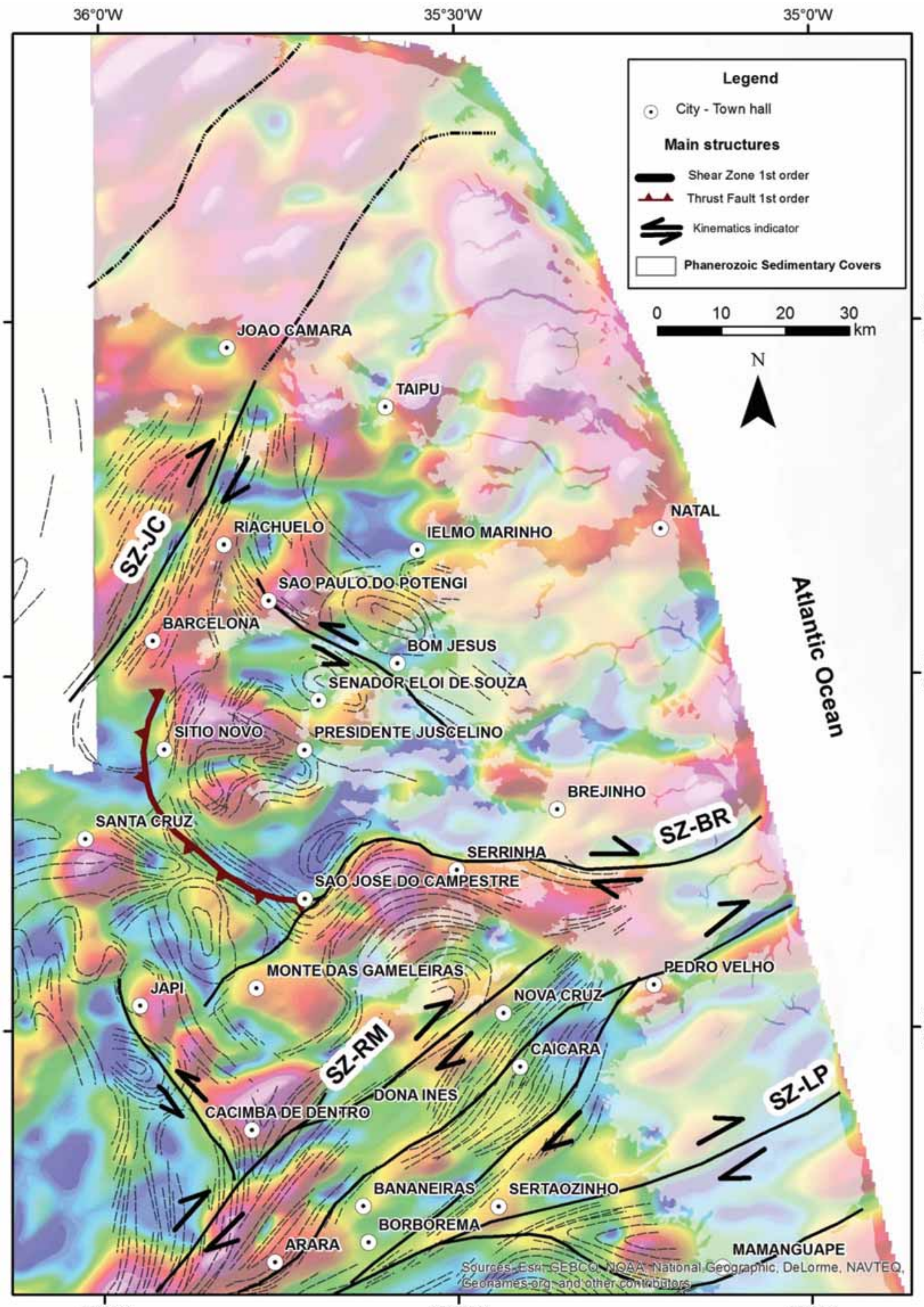

Sources: Esri, GEBCO, NOAA, National Geographic, DeLorme, NAVTEQ, Geonames.org, and other contributors

Figure 12 – Analytic Signal Amplitude map for B0 band (11.3 km depth) overlapping with the structural interpretation and surface lineaments. The top of the figure illustrates the kinematic model for the SJCM, whereby the shear zones of Cacerengo-Pocinhos-Remígio (SZ-RM) and Picuí-João Câmara mark the sigmoidal structure of the SJCM, enveloped by the Splay Fault of Patos Lineament (SZ-LP).

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