Using airborne gravity and magnetic data to recognize crustal domains concealed underneath the Parnaíba basin

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Abstract

This paper presents a new geophysical study to map the crustal domains beneath the Paleozoic Parnaíba basin (NE Brazil), based on airborne gravity and magnetic data. Several aeromagnetic surveys and gravity data derived from satellite altimeters were processed and merged with the Aerogeophysical Project Parnaíba Basin in order to cover an area beyond the basin boundaries. The resulting datasets are here used as a tool in the recognition and interpretation of geological structures in a large basement area occupied mainly by several Precambrian crustal blocks, amalgamated during overall collisional tectonics and later on affected by an aborted rifting process, which culminated with the Parnaíba basin formation. The hidden crustal domains have been identified based on their gravity and magnetic signatures.

Introduction

The Parnaíba basin is a Paleozoic cratonic sag that occupies a 0.6 Million km^2 nearly circular shaped area in NE Brazil (Cordani et al., 1984) (Fig. 1). This structural framework is a key region to understand the Neoproterozoic-Eopaleozoic Brasiliano-Pan African orogenic collage in South America (Fuck et al., 2008). The Precambrian basement comprises three cratonic areas (Amazonian, São Luís/West Africa and São Francisco/Congo) and surrounding fold belts (Gurupi belt, Tocantins and Borborema provinces), as well as a completely concealed basement inlier (Parnaíba block). Several tectonic relations between these crustal segments remain unknown due to the lack of direct information from surface mapping. Nunes (1993) proposed an initial tectonic subdivision, which is now revised and detailed.

Another aim of the present work is to map the main shear zones of the Brasiliano-Pan African orogen (0.75-0.5 Ga) and the Cambrian graben-like features in the eastern part of the Parnaíba basin (Fig. 1). Their gravity and magnetic signatures were properly recognized in the geophysical maps. This allowed correlations between the Precambrian structural framework and the graben in an attempt to show that Eopaleozoic brittle reactivation led to the generation of rift basins preceding the sag formation in NE Brazil.

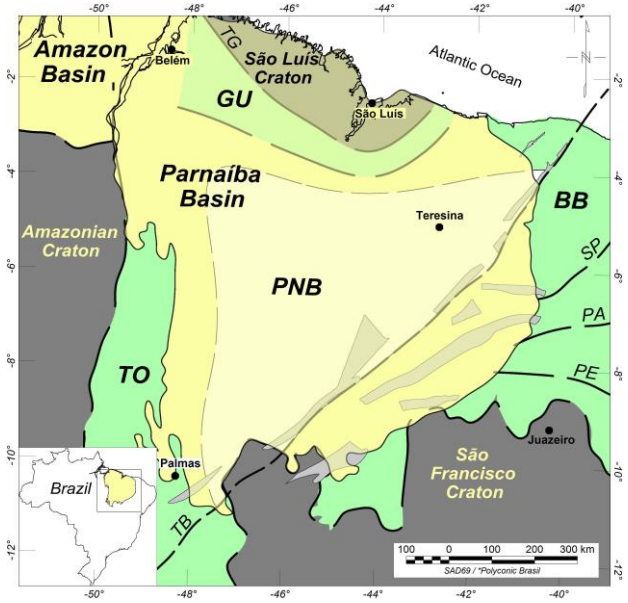

Fig. 1. Tectonic sketch of the Parnaíba Basin basement inferred from geophysical survey (Nunes, 1993) and previous geological mapping (adapted from Cordani et al., 1984, 2009; Bizzi et al., 2003). Hidden basement inlier: PNB – Parnaíba Block. Neoproterozoic tectonic provinces: BB – Borborema; TO – Tocantins; GU – Gurupi belt. Shear zones: TB – Transbrasiliano, SP – Senador Pompeu, PA – Patos, PE – Pernambuco.

Geophysical Datasets

In this work we use new airborne gravity and magnetic data (Parnaíba Basin Project), previous magnetic airborne surveys and gravity data derived from the geodetic satellite GRACE (Fig. 2). The aerogeophysical surveys are derived from the Brazilian Petroleum Agency (ANP) and Brazilian Geological Survey (CPRM) data banks, undertaken from 1970 until 2010 with different flight elevations and directions, and spacing between lines.

Each magnetic data set was interpolated onto a grid, using the bi-directional method. A decorrugation filter, combined with a directional cosine filter, was applied to eliminate high frequency noise along the fly direction. Then, each project was upward continued to the same height (3000 m) and reduced to the pole, using a pseudo-inclination factor to suppress the amplitude and power in near the declination direction, over-corrected at low magnetic latitudes (Blakely, 1996). The magnetic projects were then merged, using a grid-knitting tool to smooth the transition between adjacent grids.

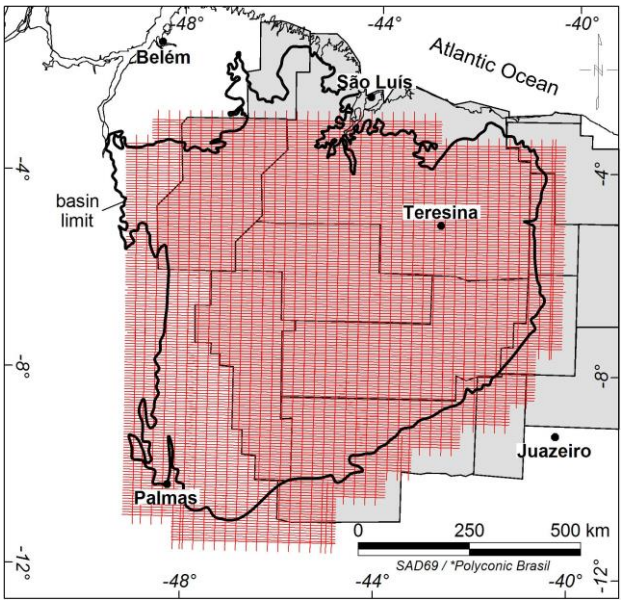

Fig. 2. Airborne magnetic and gravity data of the Parnaíba Basin Project (red lines) and other aeromagnetic surveys (gray areas).

The final magnetic anomaly map of the basin is shown in Figure 3a. A Gaussian filter was applied in order to separate the regional (Fig. 3b) and residual (Fig. 3c) components of the magnetic field, allowing interpreting shallow and deep magnetic sources separately. The tilt derivative filter was applied to the residual data to depict the edges of deep and shallow magnetic sources equally, enhancing geological contacts and structural features. In addition, the pseudo-gravity transformation was applied to enhance anomalies associated with deeper magnetic sources in the bottom of the Parnaíba Basin, namely the Cambrian rifts (Fig. 3d).

Gravity data derived from GRACE satellite Mission were incorporated to extend the airborne survey area and allow a regional analysis of the Moho relief beneath the Parnaíba Basin. Both airborne and satellite datasets were interpolated using a cell size of 1500 m. The resulting grids were merged using the same grid-knitting tool applied to magnetic data (Fig. 4a). The regional and residual gravity components were separated using a Gaussian filter by a cut-off frequency of 0.8 cycles/m (Figs. 4b and 4c). Several gravity domains could be identified in the basement, based on distinctive gravity patterns and lineaments, which were depicted by applying a tilt derivative filter to the residual anomaly map (Fig. 4c). Finally, Figure 4d shows NNW-SSE trending gravity minima highlighted in the residual map. Their meaning is discussed below.

Results

Magnetic Response

The magnetic anomalies in the Parnaíba Basin show an overall NE-SW trend roughly parallel to the Transbrasiliano Lineament (Fig. 3), which crops out beyond the NE and SW borders of the basin. Secondarily, E-W and NW-SE oriented magnetic alignments occur in the central and NW parts of the basin. The E-W magnetic trend separates the basin in two regional domains, with positive anomalies to the north and negative anomalies to the south (Fig. 3b). A major axis of the cratonic arch (Xambioá arch – Cordani et al., 1984) is associated with this magnetic alignment. In the southern portion, large magnetic minima (A to E in Fig. 3b) should be related to deeper basement structures, which probably controlled the Cambrian rifting and the Mesozoic volcanic activities.

The deep character of this structural trend can be seen by the significant attenuation of the regional magnetic minima in the residual anomalies map (Fig. 3c). In this map, the short to medium wavelength anomalies are elongated in the NE-SW direction, mainly close to the Transbrasiliano Lineament. To the east (São Francisco, Borborema S and Borborema N domains – Fig. 3c), the magnetic lineaments bend to the E-W direction, following the main shear zones of the Borborema Province, namely the Senador Pompeu, Patos and Pernambuco shear zones. In the western flank of the Transbrasiliano Lineament (Parnaíba S and Parnaíba N domains), the magnetic anomalies tend to align along the N-S direction, following the overall tectonic fabric of the Tocantins Province (Goiás Magmatic Arc and Araguaia basement domains). To the north, the magnetic anomalies are essentially oriented in the ENE-WSW direction, allowing to discriminate the Médio Coreaú, Gurupi and São Luís domains (Fig. 3c), roughly parallel to the Tentugal Shear Zone. Finally, the Teresina domain can be recognized in the magnetic maps between the Transbrasiliano Lineament and Parnaíba domains by presenting high-frequency anomalies, which trend either E-W or NE-SW, close to the Transbrasiliano Lineament (Fig. 3c).

Figure 3d shows the locations of Cambrian rifts and volcanic rocks, superimposed to the pseudo-gravity map of the Parnaíba Basin. These rifts partially crop out at the basin edges and their supposed extensions beneath the basin were defined by Brito Neves et al. (1984) and Nunes (1993), based on aeromagnetic, seismic reflection and well log data. It is worthy to note that NE-SW and E-W trending, elongated pseudo-gravity minima are geographically coincident with those rifts and the principal volcanic exposures. It is also clear that the Precambrian tectonic heritage controlled the rifting process, specially the extensive Brasiliano shear zones. In addition, some other pseudo-gravity anomalies were highlighted in order to propose new buried rifts beneath the basin.

Gravity Response

Several gravity domains could be identified in the Precambrian basement (Fig. 4c), based on distinctive gravity patterns and lineaments, which were depicted by applying a tilt derivative filter to the residual anomaly map. At the western border of the Parnaíba Basin, the N-S trending gravity domains akin the crustal domains, alternating positive (Amazonian Craton, Araguaia basement and Goiás Magmatic Arc domains) and negative (Araguaia supracrustal domain) anomalies, in both regional and residual maps (Figs. 4b and 4c). This geophysical pattern is repeated in the eastern (south border and São Francisco craton domains) and northern (Médio Coreaú, Gurupi and São Luís domains) edges of the basin.

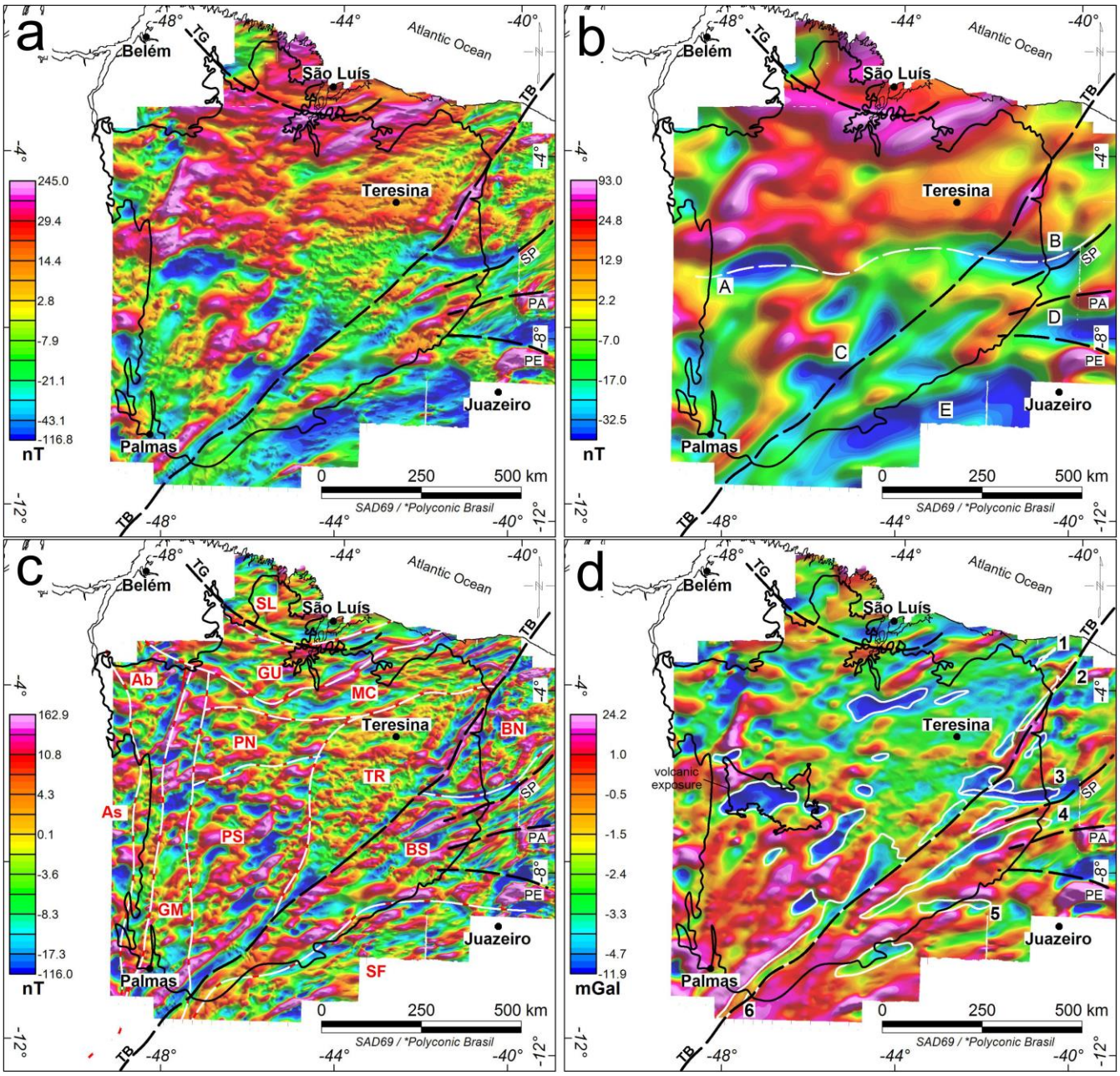

Fig. 3. (a) Reduced to pole magnetic anomalies map of the Parnaíba Basin. (b) Regional and (c) residual components of the reduced to pole magnetic field. Labeled anomalies are discussed in the text. (d) Pseudo-gravity anomalies map with location of possible Cambrian rifts (white contoured areas) and volcanic exposures (black contoured area). 1 to 6: Outcropping Cambrian rifts. Magnetic domains: SF - São Francisco; SL - São Luís; BN - Borborema N; BS - Borborema S; TR - Teresina; GU - Gurupi; PN - Parnaíba N; PS - Parnaíba S; MC - Médio Coreaú; GM - Goiás Magmatic Arc; Ab - Araguaia basement. Shear Zones: TB - Transbrasiliano; TG - Tentugal. Shear zones: TB – Transbrasiliano, SP – Senador Pom-peu, PA – Patos, PE – Pernambuco.

The central Teresina and Parnaíba domains are distinguished by a broad negative regional anomaly oriented both in NE-SW and N-S, parallel to principal structural trends (Fig. 4d). On the other hand, the residual map shows a series of elongated positive and negative anomalies with a preferential N-S direction and slightly arcuate to E-W (Parnaíba domain). This trend alters to the NE-SW orientation eastwards in the Teresina domain.

Nunes (1993) interpreted the large gravity minimum in the central sector of the basin and orthogonal to the Transbrasiliano Lineament as a NW-SE oriented rifting system. She speculated a Proterozoic age for its origin, however no direct information is available to confirm this assertion. In any case, this trend is also evident in the residual gravity anomalies map (Fig. 4c), indicating a broad low-density gravity source within the Parnaíba and Teresina domains.

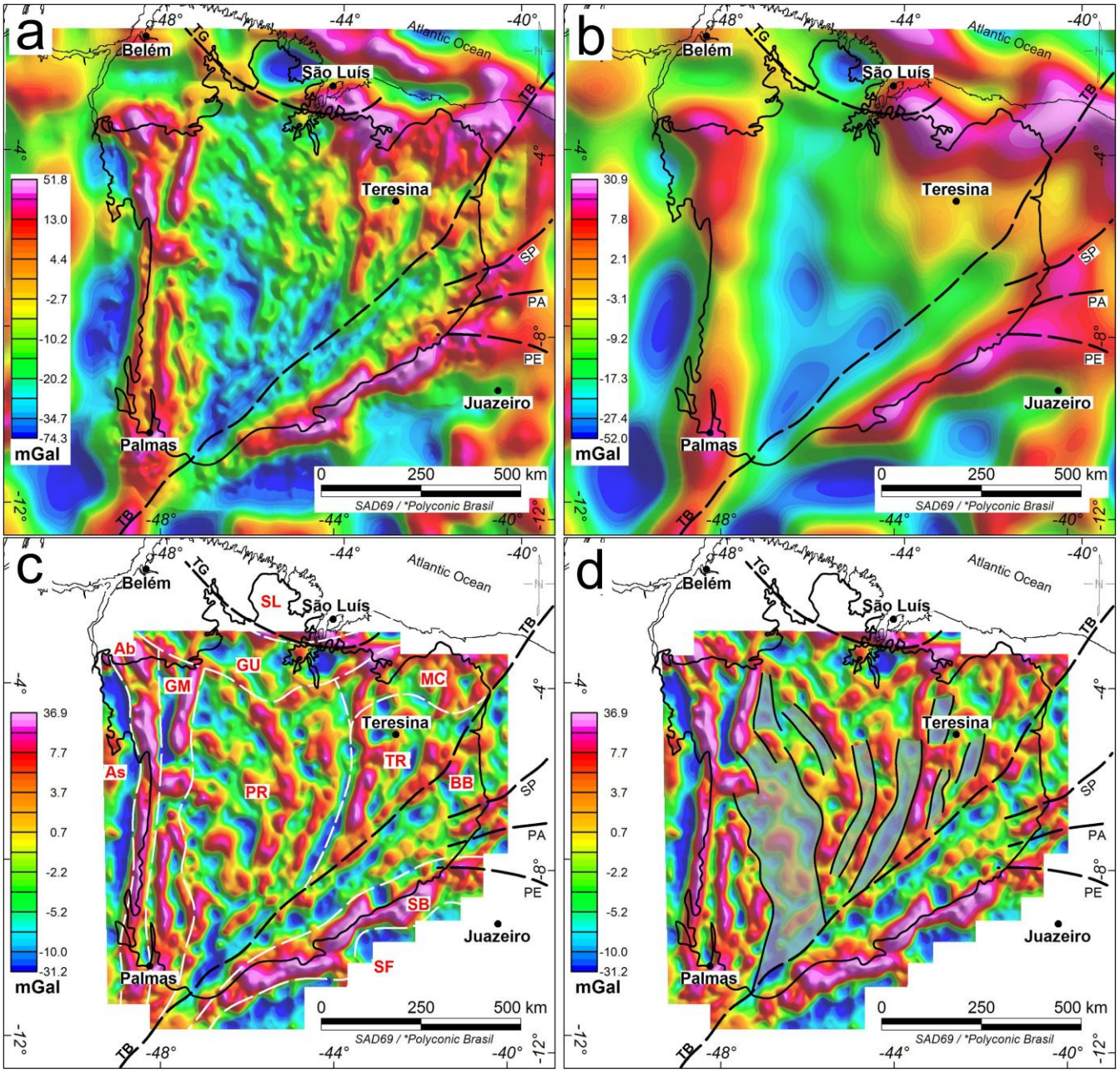

Fig. 4. (a) Gravity anomalies map of the Parnaíba Project merged with GRACE gravity model. (b) Regional and (c) residual components of the gravity field. (d) Residual gravity anomalies with location of possible Proterozoic-Phanerozoic rifts (gray areas). Gravity domains: SF - São Francisco; SB - South Border; SL - São Luís; BB - Borborema; TR - Teresina; GU - Gurupi; PR - Parnaíba; MC - Médio Coreaú; GM - Goiás Magmatic Arc; BR - Brasília; Ab - Araguaia basement; As - Araguaia Supracrustal.

This NW-SE gravity trend is not observed in the magnetic maps (Fig. 3). It suggests that the geological units that generate the gravity anomalies do not exhibit enough lateral contrasts of the magnetic susceptibility to yield magnetic anomalies with the NW-SE direction. In contrast, the NE-SW trend of negative magnetic and pseudo-gravity anomalies, which are coincident with the Cambrian rifts underlying the Parnaíba Basin (Fig. 3d), is not evident in the gravity maps (Fig. 4d). Apparently, the volume of sedimentary material that fills most of these graben-like structures is not sufficient to provide gravity anomalies, which superimpose the response of the gravity sources in the Precambrian basement.

Conclusions

New airborne gravity and magnetic survey has been used together with previous aerogeophysical and satellite data to map the structural framework of the Parnaíba Basin and its complex Precambrian basement. The main improvements of this research consist in detailing of the basement inliers (Parnaíba and Teresina blocks), its in-

ternal structure and contacts with the surrounding fold belts. This triangle-shaped and thicker crustal fragment is emplaced in the central region of an overall Neoproterozoic-Eopaleozoic collisional event in NE Brazil, where the Amazonian, São Francisco and São Luís cratons converged during West Gondwana amalgamation. The peripheral fold belts (Tocantins and Borborema provinces and Gurupi Belt) made up of supracrustal and basement domains were strongly deformed and metamorphosed during the Brasiliano-Pan African orogeny. Especially at the western and SE basin edges, extensive gravity highs reflect remarkable crustal boundaries, possibly related to subduction magmatism deep in the crust or upper mantle and crustal shortening. These limits are coincident with the major structural trends, represented by large N-S and NE-SW oriented shear zones in the Tocantins and Borborema provinces, respectively. Similarly, an arcuate positive gravity anomaly reflects the concealed suture zone between the São Luís Craton and the Gurupi Belt. On the other hand, the contact between the Gurupi Belt and the basement inliers is not so easy to identify in the potential field maps. It suggests that rocks of both crustal blocks have been reworked during the Neoproterozoic orogenic event, masking any lateral contrast between them.

Two generations of rifting are proposed, which precede the major intracratonic sag formation. The oldest one is revealed by weakly arcuate negative gravity anomalies, located in the Parnaíba and Teresina blocks. Their overall N-S orientation shows a progressive bending to NE-SW eastwards, suggesting that E-W trending extensional efforts took place at the final stages of the Brasiliano/Pan-African orogeny. In the central sector of the basin, an E-W structural trend is well recorded by regional magnetic lineaments and principal axes of graben-like features and volcanic exposures. Negative residual magnetic and pseudo-gravity anomalies display many NE-SW elongated graben related to the second rifting process. This series of Cambrian-Ordovician troughs partially crop out at the eastern and southern edges of the Parnaíba Basin and their concealed portions can be mapped in the geophysical maps. They mainly occur along the Neoproterozoic shear zones, especially the Transbrasiliano Lineament, exposing the structural control of the Precambrian tectonic heritage in the rifting process. In a jointly gravity and magnetic modeled profile, these graben-like features reach a maximum thickness of 1.5 km beneath the up to 2.5 km thick sag infill.

Acknowledgments

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