The rifting evolution of the Santos Basin: A Geophysical view

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Abstract

This study investigates the rifting architecture and tectonic evolution of Santos Basin at Southeastern Brazilian Margin, based on integrated geophysical data. A high resolution aeromagnetic grid is correlated with gravity anomalies and published seismic lines, in order to provide a regional view of the Santos Basin. We calculate the magnetic basement using the power spectrum analysis, which enabled us to constrain the basement geometry at the proximal and necking domains at Santos Basin. Our results suggest a tectono-structural transition from proximal to distal parts of the margin. Each domain is characterized by intrinsic rifting structures, where continental inheritance seems to predominate at the proximal domain while towards the distal margin, increasing oceanic parallel structures can be observed, suggesting the predominance of mantle dynamics on rifting evolution. We propose that the northern Santos Basin consists of an intensely deformed zone where rifting evolved under oblique extension adjacent to a transform plate boundary.

Introduction

The Santos Basin at the Southeastern Brazilian margin (Fig. 1) has been intensely surveyed in the last decades. The tectono-magmatic history of the basin is highly complex, with several phases of magmatism and intense tectonic activity since the pre-rift stage (Ponte and Asmus, 1976; Macedo, 1989; Almeida et al., 1996, Zalan and Oliveira, 2005.

Despite the increasing work developed at the Santos Basin, there are still several remaining unanswered questions regarding the nature of the basement, the existence of a hyper-extended domain and its characteristics and the location of the continent-ocean boundary.

In the present study we investigate the Santos Basin basement and rifting evolution using an integrated geophysical approach. We applied statistical analysis of the power spectrum of the magnetic field, which is related to the depth of the magnetic basement to investigate the geometry of the basement at the proximal margin (Stanton et al., submitted). The integrated geophysical results provide a regional view of the margin architecture and the intrinsic tectono-structural characteristics of its domains.

Geological Background

The Santos Basin is the largest offshore sedimentary basin of the Brazilian Margin and was formed during Gondwana disruption at Early Cretaceous (Fig. 1) The crystalline basement is composed by the Ribeira Belt granites, gneisses and orthoamphibolites that compose several collisional terranes extending for more than 1400 km along the continent. They formed during the Pan-African-Brazilian orogenic events that evolved from Late Neoproterozoic (Heilbron et al., 2000), until the Ordocivician (Schmitt et al., 2004). In general, the Central Ribeira Belt basement is characterized by NE-SW and ENE faults, suture and shear zones (Fig. 1) with minor NW-SE oriented structures. The rifting at Santos started in the Hauterivian (Neocomian) (Moreira et al., 2007), through which the margin underwent an important tectono-magmatic event, with the formation of onshore and offshore magmatism. The rifting structures formed are mainly NE-SW oriented, with faults bounding horsts and grabens, intruded by syn rift magmatic rocks. The São Paulo Plateau that lies at the distal part of the basin constitutes one of the most important features of the Brazilian margin. The nature of its basement is still debated and possibly is constituted by extended/attenuated continental crust highly magmatically intruded (Chang and Knowsman, 1984; Macedo, 1989, Zalan et al., 2011).

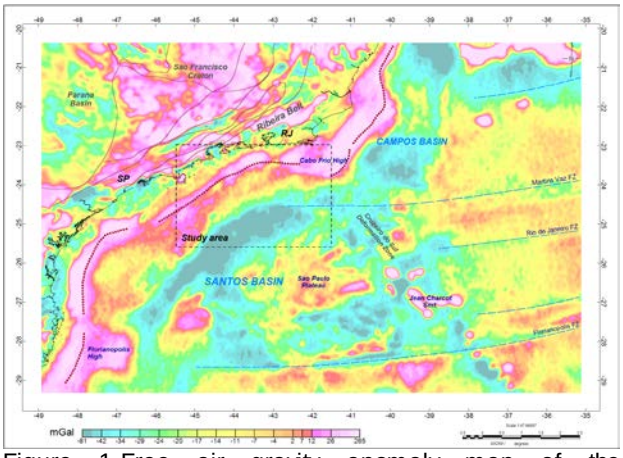

Figure 1-Free air gravity anomaly map of the Southeastern Brazilian Margin, with the main continental and offshore features. The dotted line rectangle shows the study area.

Data and Method

We construct a magnetic grid based on 4 aeromagnetic surveys. The line spacing is 1 km interval with controll lines at 1 and 4 km. The final grid was obtained unifying the individual grids using the blend method, through a cosine function to determine the weighting on the overlap region. The correction for the Regional Field was obtained subtracting the IGRF from the total field for each survey individually, due to their different epochs of acquisition.

The magnetic basement (Fig. 2) was calculated based on the local functions method, which may be used to obtain analytic approximations for local magnetic anomaly maps (Alldredge (1980). We statistically estimate the depth to magnetic sources using the power spectrum analysis (Bhattacharyya, 1966; Spector and Grant, 1970). The area is subdivided in blocks of 60 x 60 kms and the depth estimates are calculated at the center of each equally-spaced gridded block. This overlapping technique increases the resolution and reduce the edges artifacts.

Results

The aeromagnetic anomaly map displays NE-SW oriented high amplitude (200-500nT) lineaments along the proximal margin of Santos Basin, intercepted by some NW-SE negative lineaments (Fig. 2). The prolongation of the NW-SE lineaments is well correlated with some basement morphostructures, like the Paranapanema Fault (Fulfaro, 1974), the Taxaquara Fault (Rideg, 1974), Tingua-Tijuca Transfer Zone (Zalan and Oliveira, 2005). At the northeastern portion of the basin, the lineaments show an E-W inflection, accompanying the change in orientation of the coast and basin structures. At Cabo Frio the magnetic lineaments assume a NE-SE orientation until the north of Brazil. The most intense anomaly occurs at the boundary between Santos and Campos Basins, offshore of Rio de Janeiro, where it reaches 700 nT and corresponds to the stronger anomaly of the southeastern Brazilian margin (Stanton et al., 2010).

The necking domain of Santos was interpreted based on the gravity anomaly analysis (Stanton et al., submitted), corresponding to a strong gradient zone. This pattern is directly associated with a negative gradient on the magnetic anomaly pattern (Fig. 2) and a general change in the pattern of the anomalies at the distal margin. Though the distal margin is only partially imaged from the magnetic map, it is characterized by large and smooth positive anomalies, which amplitudes are reduced due to the distance of the source, since the basement in the area is deeper (> 3000m). It displays NE-SW and the gradual increasing presence of E-W lineaments, which are intercepted by minor NW-SE negative zones. The presence of magmatism is especially evident along the proximal and necking domain, represented by high amplitude and short wavelength magnetic and associated gravity highs

The magnetic basement map shows the regional basement architecture of the proximal and necking domains of Santos Basin (Fig. 3).

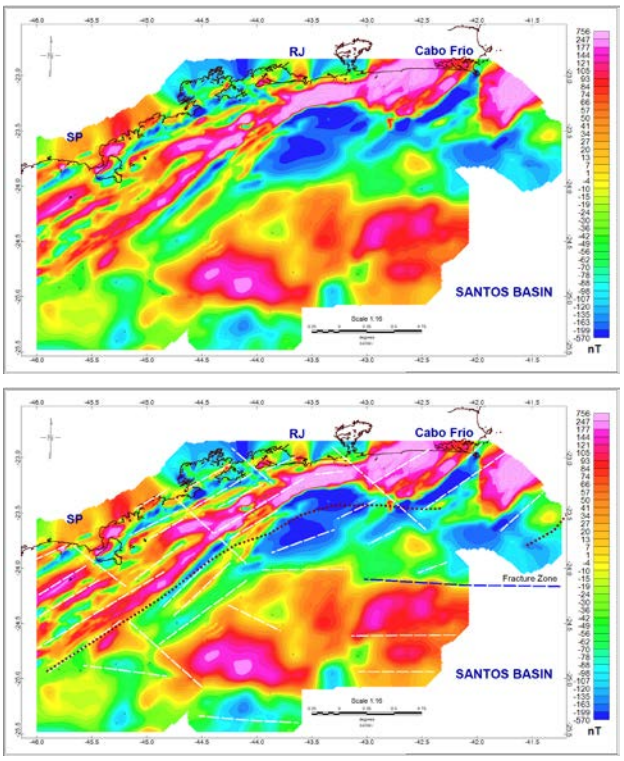

Figure 2- Aeromagnetic anomaly map of Santos Basin. B) The same map interpreted. The white lines correspond to magnetic lineaments; the blue dotted lines is fracture zones and red dotted line is the necking zone interpreted from the gravity anomalies (Stanton et al., submitted)

The magnetic basement map displays blocks following a NE-SW orientation on the proximal margin, assuming a E-W direction at northern Santos Basin, which are separated by basins NW-SE oriented. Towards offshore occurs a rapid deepening of the basement (~6-8 km) along the area of the continental slope, corresponding to the necking zone. An important low zone that bounds to the north the NW-SE basement highs corresponds in location with the Santos Fault.

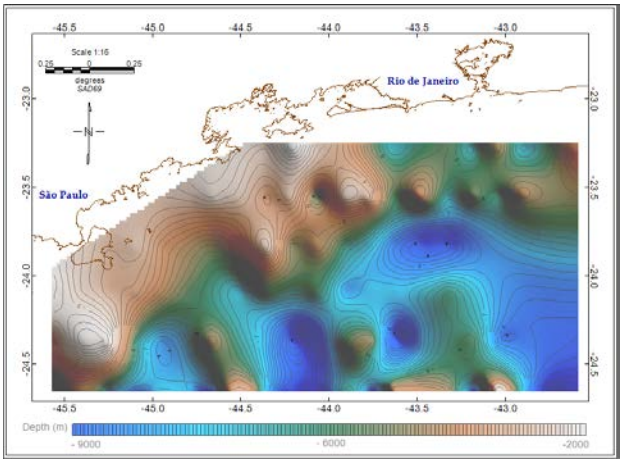

Figure 3- Magnetic basement map of central Santos Basin. Values are in meters.

Discussion

In a general way, the gravity and magnetic anomalies show a good correlation. The main rifting structural systems interpreted in previous studies are well correlated with the linear magnetic anomalies and the gravity gradient, representing a region of extended crust that marks the contact between the Sao Paulo Plateau and the necking domain and the transition to the hyper-extended domain of Santos Basin

The magnetic basement map shows in general a good correlation with the gravity pattern. They show a transition from NE-SW and E-W blocks disposition along the proximal domain, corresponding to the Tectonic corridor (Stanton et al., submitted). The magnetic basement shows in detail the pattern of the rifting structures along the necking zone of the margin, where the crust abruptly thins and provides additional on its morphostructure. The proximal NE-SW disposition of rifted blocks give place to NW-SE basement highs and lows, resulting from a continental extension under oblique direction and adjacent to a transform plate boundary (Basile and Brun, 1999).

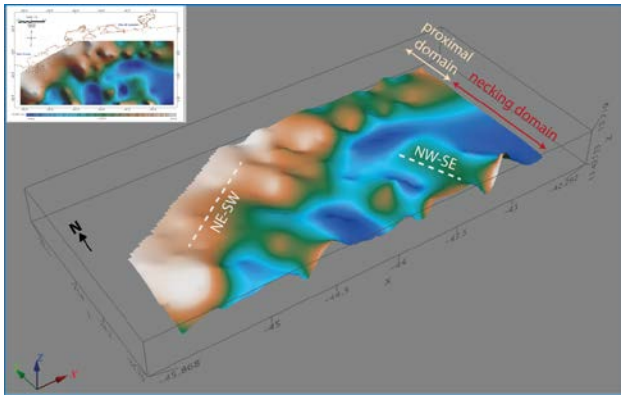

Figure 4-A 3D view of the magnetic basement at central Santos Basin (for location see figure 1). The main structural trends are represented by white dashed lines and the boundaries between the margin domains are indicated.

Our results are supported by seismic reflection data. The mean depth values for the magnetic basement and the regional architecture is well correlated with the results of Souza et al., (2007).

The role of transfer zones in segmenting the margin is evident from the magnetic basement map, as has been previously suggested by several authors (Cobbold et al., 2001; Zalan et al., 2005; Souza et al., 2007; Oreiro et al., 2008). Our gravity, magnetic and basement maps show mainly NE-SW blocks at the proximal domain and the NW-SE discontinuities segmenting them. The necking domain at northern Santos Basin display a distinct pattern, characterized by orthogonal NW-SE basement blocks and interbasinal highs, which we propose constitute a zone of tectono-structural transition between two distinct segments along the Southeastern Brazilian Margin - Santos and Campos. Along the necking domain, the crust abruptly thins, as suggested by the strong gravity and magnetic gradients, possibly accompanied by magmatism. Towards the distal margin, the continental structural inheritance diminishes and eventually stops, as shown by the increasing presence of E-W lineaments which are sub parallel to Oceanic Fracture Zones suggesting the influence of the astenosphere on the rifting process at the most distal portions of the margin.

The northern Santos Basin, along the area close to the Cruzeiro do Sul Deformation Zone (Souza, 1991) seems to have behaved as a transfer zone, which accommodated/localized the deformation between the Campos and Santos basins.

Conclusions

The Santos Basin general gravity and magnetic pattern is characterized by NE-SW trends, interrupted by NW-SE oriented negative zones at the proximal domain and at the necking domains. These first order trends are subparallel to continental structures. They show an inflexion at its northern limit, following the Tectonic Corridor area, proposed by Hasui (2010). These evidences suggest a basement inheritance control on the tectonic evolution of the margin along the proximal domain.

The passage from proximal to distal domains is characterized by a transition on the tectono-structural pattern, evidenced by the rifted blocks architecture. This evidence has an important tectonic meaning in the context of the rifting evolution of Santos. Inheritance may control the rift structures at the proximal and the necking domains of Santos, where previous continental structures seem to be reactivated. However the inherited trends predominance diminishes and eventually stops on the hyper-extended domain at the distal margin,. In areas that underwent highly oblique extension, transtensional structures may prevalence. However, the distal domain display a tectono-structural pattern that suggests the presence of oceanic fracture zones, what may be related to a progressive control of mantle over crustal processes, a process associated with the onset of breakup.

In addition, the geophysical results show the regional importance of magmatism for the southeastern margin evolution.

Acknowledgments

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