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TÍTULO DO TRABALHO:

CONTINENTAL-OCEANIC CRUSTAL TRANSITION IN THE PARAÍBA BASIN PLATFORM, NORTHEAST BRAZIL: IMPLICATIONS FOR PETROLEUM POTENTIAL

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Abstract

In the last few years investigations were produced addressing questions involving the evolution of conjugate Atlantic margins of Brazil and West Africa. However, academic investigations have been hindered by poor data availability between the areas of the Pernambuco Shear zone and the Touros High, Northeast Brazil. This has led to a poor view of the regional paleo-tectonosedimentary evolution of the area as well as complicated attempts to undertake correlations with regional counterparts in Africa. The region, placed between two plateaus (Pernambuco and Touros plateaus), is characterized by a high basement profile, narrow platform, little crustal stretch and an abrupt shelf break. This feature makes the region a unique case on the Brazilian margin. Here we present a new investigation into the characteristics of this zone, based on seismic, and geophysical satellite-acquired (Grav and Mag) data. The integrated modeling allows an interpretation of the continental-oceanic transition and the structural configuration of the zone, which represents a basement high and narrow platform due minor stretching of the continental and transitional crust with a thin cover of sedimentary rock. A short transition zone separates the continental and oceanic crust domains. The continental-oceanic boundary (COB) is positioned approximately 95 km from the coastline. The characterization of this zone is very important to our understanding of the Atlantic's evolution, specifically in the transition region between the distensive and transforming branchs of the South Atlantic, and also to better understand the oil potential of the region.

Introduction

There is an enormous amount of research that has focused on the conjugate evolution between the Brazilian and African margins. The majority of work has focused on the Angola, Congo and Gabon basins (Africa), and their counterparts Santos, Campos, Recôncavo, Sergipe-Alagoas and Pernambuco basins (Brazil) (Meyers *et al.*, 1996; Karner & Driscoll, 1999; Blaich *et al.*, 2008; Aslanian *et al.*, 2009). These studies did not address questions concerning the different characteristics of the margin between the Pernambuco Shear Zone (PESZ) and the Touros High, represented by the Paraíba and Natal Platform basins (Barbosa & Lima Filho, 2006; Barbosa et al., 2008), named by Lima Filho & Barbosa (2010) as the "exception zone" of NE Brazil (Fig. 1). This region represents the eastern portion of the Borborema Province (BP) of Northeast Brazil formed by Pre-Cambrian terrains and two continental-size Shear Zones: PESZ and the Patos Shear Zone (PASZ), which forms the Transversal Zone of Northeast Brazil (ZTN) (Figs 2 and 3). One important reason for the lack of knowledge regarding this area is likely due to the complete absence of data available from academic research, including onshore and offshore wells and detailed geophysic surveys, such as seismics. Due the low perspective of its oil potential since the 1970s, there has been no drilling of stratigraphic wells along the coastal zone, and none in more than 400km of extension of offshore area. The only available seismic data represents a set of a dozen 2D lines produced in the 70´s (Barbosa et al., 2008). Few researches have addressed the questions concerning the characteristics of this region, its evolution and relation to the Atlantic's opening (Fainstein & Milliman, 1979; Rand & Mabesoone, 1982; Brito Neves *et al.*, 2002; Barbosa & Lima Filho, 2006; Barbosa *et al.*, 2008). Fainstein & Miliman (1979) were the first to suggested that the region between the two plateaus, the Recife-Natal zone, represents a region with a narrow platform and an abrupt platform break, contrary to neighbouring basins, such as the Potiguar Basin, to the North, and the Pernambuco and Sergipe-Alagoas basins, to the south.

Recent work has attempted to determine the main characteristics of the region, though the absence of data has not permitted detailed conclusions. Using analysis of 2D seismic lines, Lima Filho & Barbosa (2010), proposed that the evolution of the Recife-Natal zone evolved as a cold and thick piece of the eastern BP border, contrary to its counter-part in Africa, the Douala-Niger Delta Basins, which exhibits a more stretched continental crust and a thick sedimentary column (Fig. 1). The authors argued that the Pernambuco Plateau, and the Exception zone (Fig. 1), was formed during the last phase of the rift propagation, from south to north, until the inflexion region, before the transforming branch. When the rift reached the PESZ there was an inflection of the rift axis to the east, on the African side. The central region of the BP formed by the ZTN acted as a giant accommodation zone (Matos, 1992; Barbosa *et al*., 2006) and probably caused this rift axis offset (Lima Filho & Barbosa, 2010). Barbosa et al. (2008) suggested that rift forces began to break the BP nucleus (as indicated by the Araripe-Potiguar depression, and the aborted Recôncavo-Tucano-Jatoba rift), after which the rifting was offset to the east and attacked the BP border, separating it from African plate. The BP termination, formed by the Paraíba and Natal Platform Basins, remained as a structural high presenting minor stretching and thinning (Barbosa *et al.*, 2006, 2008) due its rheological nature. This hypothesis could help explain the asymmetry between the conjugate margins (Fig. 1).

Regional 2D seismic data in the Paraíba Basin shows a platform with a high basement profile, a low gradient platform and an abrupt shelf break, which formed an escarped-slope and a large by-pass zone, generated by an abrupt shelf break, to the oceanic basin (Lima Filho & Barbosa, 2010). The platform exhibits normal faults, which formed small, shallow grabens. The interpretation of the seismic basement position, had led some authors to estimate that the sedimentary cover over the platform ranges from 800 m (near shore) to 1,5 km (in the shelf break) in thickness (Fainstein & Milliman, 1979, Barbosa et al., 2006; Lima Filho & Barbosa, 2010). The platform is mainly dominated by carbonates, probably from the Upper Cretaceous and the occurrence of rift deposits has until now only been tentatively suggested (Barbosa et al., 2006, 2008, Lima Filho & Barbosa, 2010).

The transition from the continental domain to the oceanic basin, passing by the abrupt escarped shelf break and slope, is still uncertain (Fainstein & Milliman, 1979; Lima Filho & Barbosa, 2010). The abated blocks in front of the slope formed a strong break in the topographic gradient with respect to the platform (Fig. 4), which could indicate that these blocks just fell and slipped into the mantle during the rifting process with minor stretching (?). The position of the Continental-Oceanic Boundary (COB) in this region and proximities was suggest by some authors, mainly based in the analysis of geophysical regional data (Meyers *et al*., 1996; Karner & Driscoll, 1999; Blaich *et al*., 2008; Aslanian *et al*., 2009), although there is considerable debate about this. Fainstein & Miliman (1979) analysed seismic data along the studied zone and proposed that the position of oceanic crust was relatively close to the platforms abrupt-slope. Lima Filho & Barbosa (2010) also proposed a position for the COB based in the interpretation of a 2D seismic line that spans approximately 130 km from platform to the oceanic basin. The extension of the oceanic crust, and the occurrence of rift related deposits over it, is an important achievement in identifying the the petroliferous potential of the region.

The objective of this work is to determine the Continental-Oceanic transition in front of the Paraíba Basin platform, using one seismic line (Lima Filho & Barbosa, 2010), and geophysical data available from satellite projects. We successfully produced a satisfactory integration of results, which allowed us to suggest a position for the COB, and to give new evidence on the structural style of the margin in the studied region.

Materials and Methods

Data from the TOPEX/POSEIDON satellite project were used to construct a gridded 1'x1' free-air gravity anomaly field and a topographic-bathymetric relief model (Figs. 1 and 2). A gridded 0,1x0,1 gridded magnetic anomaly field was produced using data from the WDMAN Project, which constitutes integration from the CHAMP Satellite and maritime surveys. Regional maps were created: Free-air gravimetric anomaly map (FAA); digital elevation terrain (DET); total Magnetic intensity map (TMI). The magnetic anomaly field was processed to obtain the Analytic Signal Amplitude Map (ASA). A deep isostatic compensation map (DIC) was generated, based on the gridded elevation model and the gridded gravity field. A 2D profile was extracted from the FAA data over the 2D seismic line (depth in time) (Fig. 1 and 4). This profile was modeled with the objective of differentiating the continental and oceanic crustal domains with the aid of the seismic interpretation (Fig. 2, 3 and 4). The density values, and the subdivision for the lower and upper crusts, utilized by the modeling of the 2D profile, was based on recent works that demonstrates that the differences between the crust regions are based in the observed heterogeneities of these transitions (Wilson et al., 2003; Dupré et al., 2011).

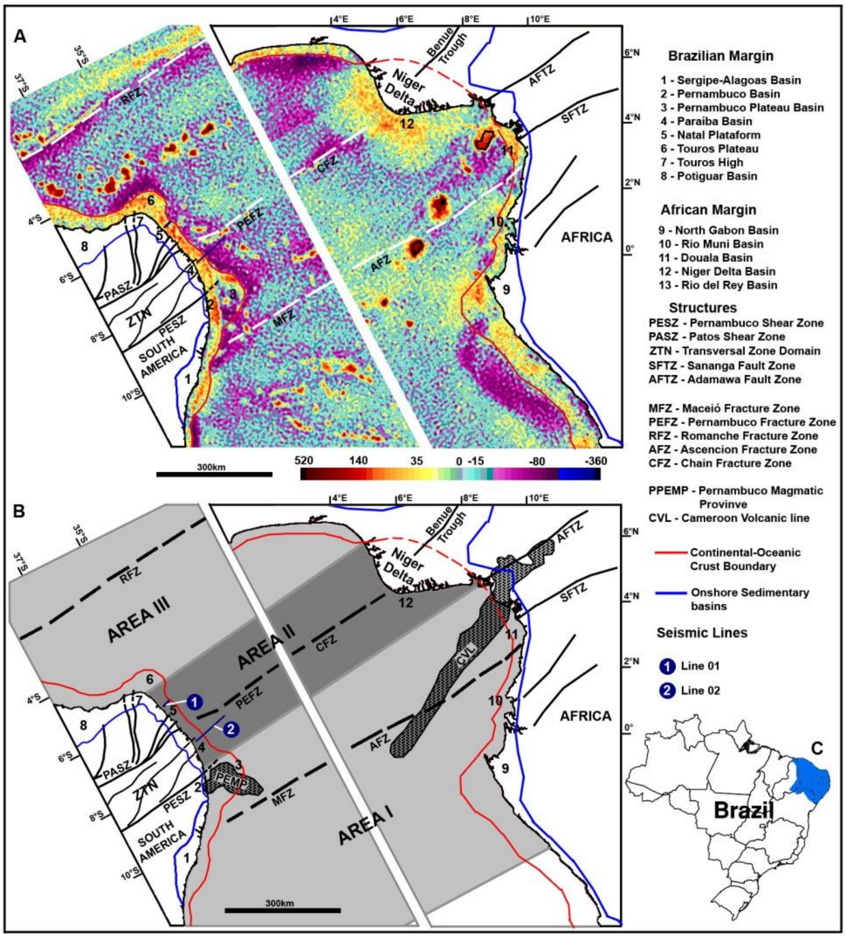

Fig.1 – Comparison of structures and geometry of Northeast Brazil and its African counterpart. A) Satellite gravity anomaly field (from Sandwell & Smith, 1997); B) Schematic margin correlations, showing three main zones. Area II presents major conjugate margins asymmetries, concerning the structural style and the sedimentary fill; C) Location of Borborema Province (BP) (blue area). The two maps are positioned for comparison purposes and are not a reconstruction of the plate drift. Position of the COB in both margins was constructed from Karner and Driscoll (1999) and Gomes (2005).

Results

The data was integrated with the modeled 2D profile (Fig. 4), focusing on the region of the interpreted seismic line (details in Figs. 2 and 3). The analyzed data is mainly qualitative, and guided by recent studies produced on Atlantic Margin evolution (Gomes et al., 2000; Watts, 2001; Wilson et al., 2003; Blaich et al., 2008; Aslanian et al., 2009; Winterbourne et al., 2009. Dupré et al., 2011). We interpreted three different zones (continental, transitional and oceanic) to systematically represent the main variations observed in the data, which are linked to the crustal domains. The maps chosen to illustrate these identified domains were the FAA, DET, DIC and ASA (Figs. 2, 3, and 4).

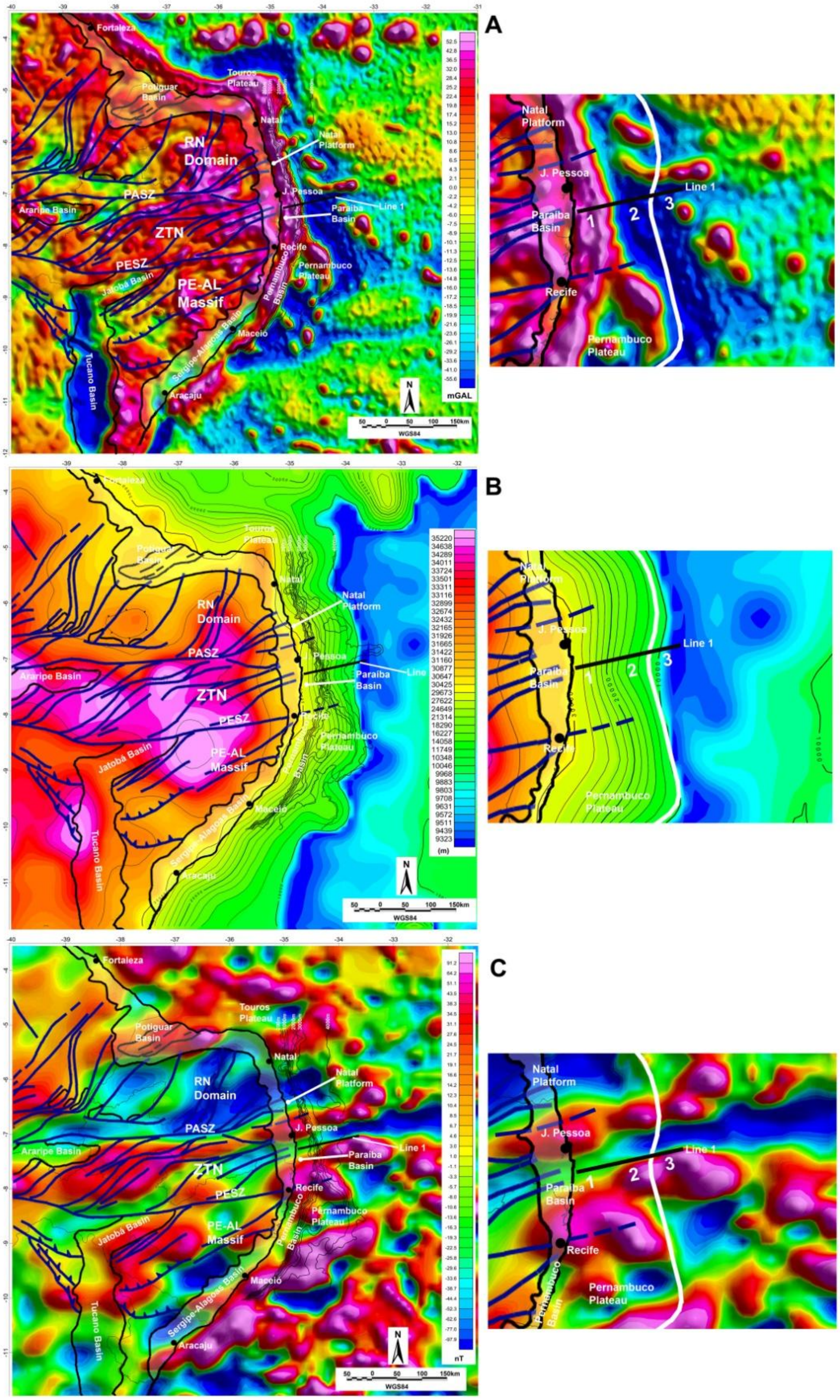

Figure 2 – A) Free-air gravity anomaly map (FAA); B) Deep isostatic compensation map (DIC); C) Total magnetic intensity anomaly map (TMI). A detail in the region of the seismic line/2D profile is showed for each map. Dark blue lines represent the main structures in the BP; Isobaths from 200 m to 4000 m are placed in the studied area. Regions 1, 2 and 3 represent the interpreted crust domains (continental, transitional and oceanic). White line represents the interpreted position of the COB.

Zone 1 (Preserved continental crust): Characterized by a low inclination of the basement from W to E, in the platform region. The FAA data show a decrease, from 47.0 to 0 mGal. The DET data suggests a decreasing of the bathymetric values from -20 to -1300 m, passing by the platform break and the beginning of its escarp. The DIC map show the ascension of the mantle-crust contact, passing from 30 to ~20 km, which was interpreted as a thinning of the continental crust. The ASA data show little variation in its values, from 266 to 330 nT/km (Figs. 2 and 3), possibly indicating a minor interference from magnetic bodies. The interpretation of the seismic basement shows a variation in the platform from ~0,7 to ~1,5s, close to its border. The tentative conversion from time to depth allows us to infer depths of between 0,7 to 1,5 km of sedimentary thickness. This sector represents approximately 60 km, from the coastline (Figs. 2, 3 and 4). This region was interpreted as the preserved continental crust with minor stretching and thinning.

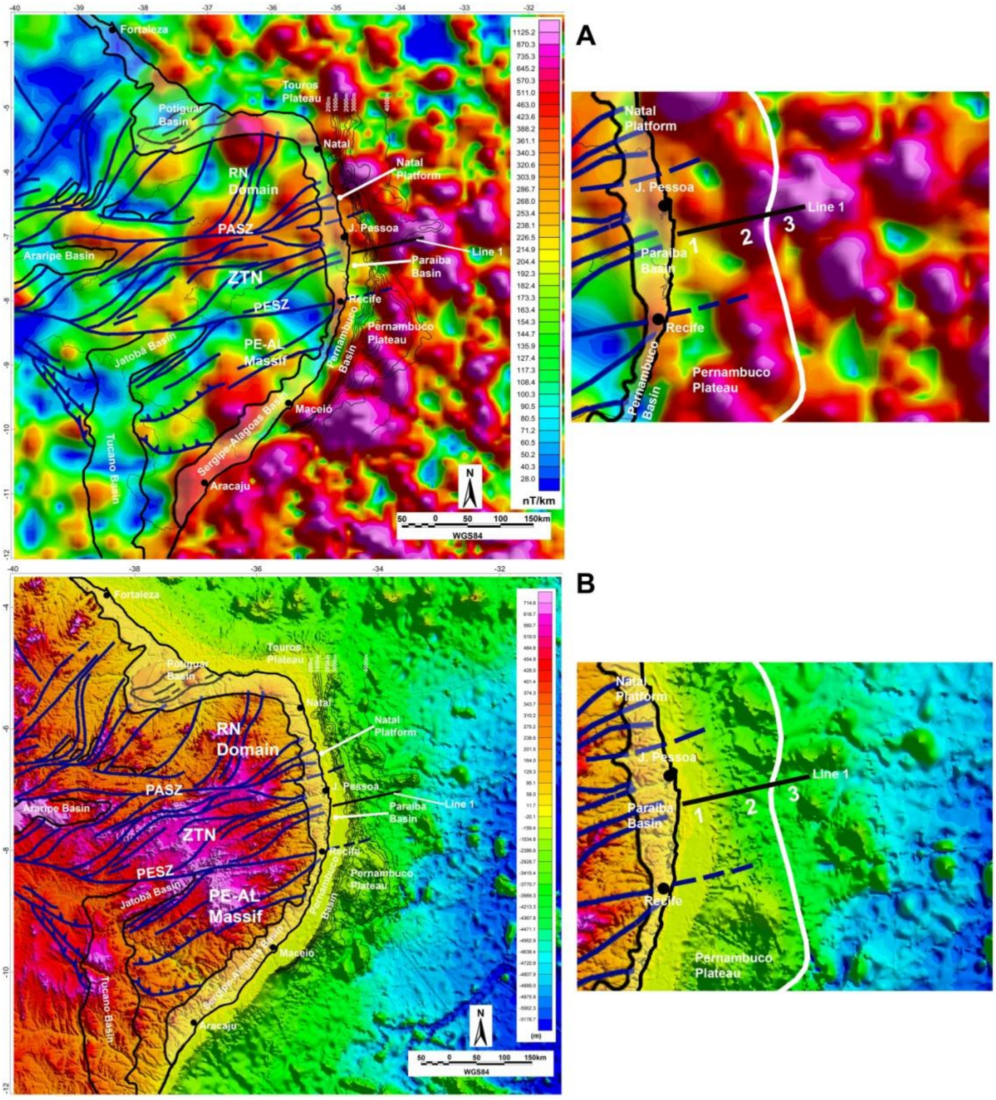

Figure 3 – A) Analytic signal amplitude map (ASA); B) Digital elevation terrain model (DET). A detail in the region of the seismic line/2D profile is showed for each map. Dark blue lines represent the main structures in the BP; Isobaths from 200 m to 4000 m are placed in the studied area. Regions 1, 2 and 3 represent the interpreted crust domains (continental, transitional and oceanic). White line represents the interpreted position of the COB.

Zone 2 (Continental stretched crust + transitional crust): In this region the FAA data shows a strong decrease in values from 0 to -48.0 mGal (Fig. 2), which is not related to a gravimetric depression, as would be expected in a deep basin. This strong decrease is probably related to the abrupt break in the border of the platform, in the direction of the slope escarpment (Fig. 4). The bathymetry values vary from -1300 to ca. -4000 m, indicating a short and abrupt break, down-slope towards to the oceanic basin. The DIC map show a variation linked to the fast ascension of the mantle, from 20 to ~11,25 km (Fig. 2). The ASA map shows a more intense positive variation in values, from 330 to 944 nT/km (Fig. 3), possibly due the presence of volcanic intrusions. The interpreted position of the seismic basement show a variation from ~1,5 s on the platform break region, to ~6,0 s on the oceanic basin region (Fig. 4). The border subvertical fault marks the shelf break, and the abated blocks form a depression at the end of the slope, but the limitation of the line depth, around 7.0 s, make it impossible to interpret the basement position with certainty in front of the slope (Fig. 4). The seismic-facies, from the slope region to the end of the line, suggest that the basement (transitional? And oceanic) is probably shallow, and the sedimentary cover is not expressive. Lima Filho & Barbosa (2010) tentatively suggest the presence of rift sediments in the down-slope region. However it's precise characteristics and the age of deposition remain unclear. Gomes et al. (2000), interpreted a 2D seismic line just few kilometers to south of that which is presented here, and suggested similar features – an abrupt platform-break and a short transition to the oceanic crust.

The integrated data suggest that sector 2 is mostly influenced by crustal thinning and weakening. The variation in this thinning-thickening along this transitional sector is possibly due the variation in the nature of the upper and lower crusts (heterogeneities) and its response to rifting processes (Wilson et al., 2003; Dupré et al., 2011). In the absence of deep seismic data to control the thickness of each stage, the model was only a tentative attempt to fit the FAA curve (Fig. 4).

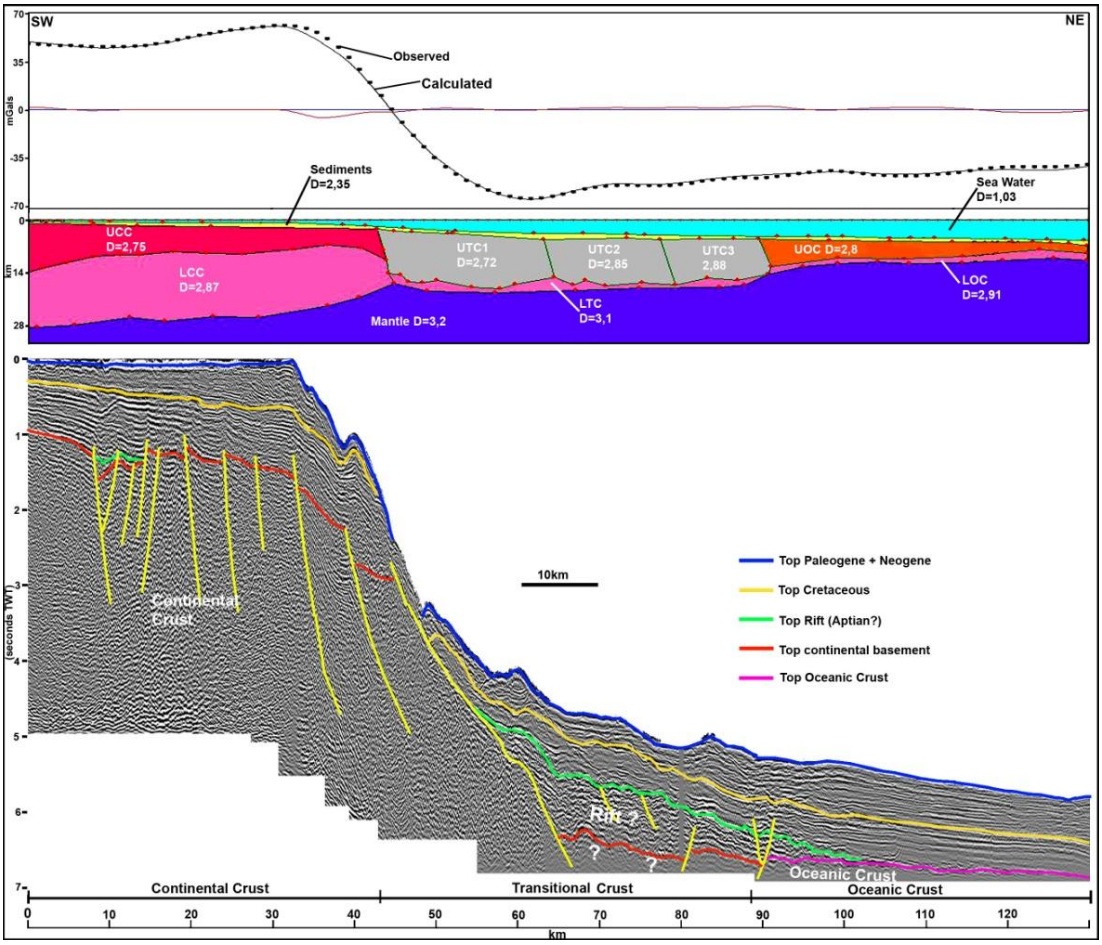

Figure 4 – Gravity profile modeled from the FAA data over the interpreted Seismic line location, which crosses the Paraíba Basin platform (Line 1) (UCC= upper continental crust, LCC= lower continental crust, UTC= upper transitional crust, LTC= lower transitional crust, UOC= upper oceanic crust, LOC= lower oceanic crust).

Zone 3 (Oceanic Crust): In this region the values of the FAA data show a small increase, from -47 to -41 mGals. The values of the bathymetry show a continuous decrease from ~4060 to 4500 m. The DIC map indicates a new stage of the mantle ascension, from 11,25 to ~9,5km. The ASA data shows a separate variation with a relatively sharp decrease from 944 to 1357 nT/km (Figs. 2 and 3). The interpreted seismic basement reaches a regional stability, between 6,5 and 7,0s of depth (Fig. 4). In this region it can be observed that the seismic-facies are dominated by a parallel configuration, which possibly represents post-rift deposits over the oceanic crust (Fig. 4). In this region the sedimentary cover thickness is estimated to be between 1,1 and 1,5 km. The integrated interpretation suggests that this sector represents the oceanic crust domain (Fig. 4).

Discussion

Despite the lack of available deep seismic data in the study area, the geophysical and seismic data analyzed here make it possible to generate a qualitative evaluation of the continental-oceanic crust transition on Paraíba Platform. The modeled gravity profile, adjusted with the interpretation of the seismic line, corresponded with important features in the region. The isostatic compensation map (DIC) was important in estimating crust thickness (Fig. 2), and the inferring the likely position of the COB. Tentative using of the crust´s subdivision into upper and low sector layers, for which different densities values could be adjusted (Wilson et al., 2003; Dupré et al., 2011), generated interesting results in our 2D model. The Paraíba Basin exhibits strong asymmetries in relation to its African counterpart, and probably, the different natures of each margin (thickness and rheological response) played important holes in its fact.

Conclusion

The margin of the Paraíba Basin is characterized by a narrow platform, with an abrupt break, an escarped slope and a short stretched zone of transitional crust (Fig. 4). It is possible that this marginal region suffered less thinning than neighboring areas, such as the Pernambuco and Alagoas basins, which show a more stretched block crust in the transitional zone, and a thicker sedimentary cover. The continent-ocean transition in the region of the Paraíba Basin is positioned approximately 95 km away from the coastline. The modeled profile shows three crustal domains: the continental sector, marked by positive gravity values an abrupt platform break; the transitional sector (weakened continental crust + transitional crust) which showed lower gravity values; and the third sector, where a new increasing tendency in the gravity values mark the beginning of the oceanic crust. The three sectors are linked to variations in the estimated crustal thickness (isostatic map): sector 1 varies from ~30 to 20 kms, and represents the preserved continental crust; sector 2 varies from 20 to 10 km and represents the transitional crust; and sector 3 represents the oceanic crust with values around 10km. The amount and distribution of rift deposits in the deepest part of the basin is still unclear. The sedimentary cover over the platform and the transitional crust zones seems to be less expressive than that which is observed in neighboring basins, which diminishes the basin´s petroliferous potential.

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