Tectonic Framework of the Rio do Peixe Basin (Northeast Brazil)

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Abstract

The “Interior Basins” of Northeast Brazil represent erosional remnants of a series of basins located south of the Potiguar Basin, overlying the pre-Cambrian crystalline basement of the Borborema Province. These basins were originated during the early Cretaceous rifting that shaped the present continental margin of northeastern Brazil. Besides their own hydrocarbon exploration potential, the Interior Basins provide terrain analogues for better understanding the continental margin basins, this being one of the objectives of the Interior Basins Project (agreement PETROBRAS / UFRN / PPGG), which supported the seismic survey in the Rio do Peixe Basin, subject of this paper. Combined with gravity and field data, the seismic sections allowed an improved view of the three-dimensional architecture of the Rio do Peixe Basin. In this basin, the combination of the current erosion level with the geometry of the main faults highlights the existence of different half-grabens (Pombal, Sousa, Brejo das Freiras), whose sedimentary filling (apart from Cenozoic deposits) defines the Rio do Peixe Group, comprising the Antenor Navarro (alluvial fans / braided channels), Sousa (shallow lacustrine / floodplain) and Rio Piranhas (alluvial fans / braided channels) formations. Structural data integration characterizes a NW-extension kinematics for the rifting event, responsible for fault nucleation controlled by basement structures, particularly the location and foliation dip of the late Neoproterozoic, Brasiliano strike-slip shear zones. Based on the structural style and petrographic-diagenetic features, one can infer larger original dimensions for this basin and similar counterparts in the region, which were reduced (with exposure of the crystalline highs) by the significant erosion that occurred in late to post-rift and subsequent evolutionary stages of this region.

Introduction

The "Interior Basins" of Northeast Brazil is a set of remnants of early Cretaceous basins overlying the pre-Cambrian basement of the Borborema Province or older, Paleozoic to Jurassic, sedimentary covers. These basins are related to the rifting event that shaped the current continental margin of Northeast Brazil, being located south of the Potiguar Basin and north of the Tucano-Jatobá rift basins. The basement is cut by shear zones originated during the Brasiliano orogenic cycle; segments of these shear zones were reactivated during the Phanerozoic evolution. The Rio do Peixe Basin (hereafter abbreviated by RPB), located immediately north of the Patos (Shear Zone) Lineament, consists of neocomian sedimentary rocks. It is a current object of interest due to the local occurrence of oil near to the surface, NW of Sousa town (Mendonça et al. 2006). The RPB is located at the limit between the Paraíba, Ceará and Rio Grande do Norte states (Figure 1). Pre- or post-rift deposits occur in other basins to the south of the Patos Lineament, specially in the Araripe Basin. The evolution and tectonic models of this region during Cretaceous times were addressed by several authors (Françolin and Szatmari 1987; Szatmari et al. 1987; Sénant and Popoff 1991; Matos 1992, 1999; Ponte et al. 1991; Françolin 1992; Françolin et al. 1994; Ponte and Ponte Filho 1996; Valença et al. 2003; Arai 2006).

The interior basins are part of the so-called Cariri Potiguar Trend (Matos 1992, 1999), having been the object of mapping and exploratory activity (seismic campaign in Araripe and some surveys) by the DNPM, SUDENE and companies associated with PETROBRAS, between the end of the 60s to the 80s (synthesized by Braun 1969; Ghignone et al. 1986; Ponte et al. 1991; Ponte and Ponte Filho 1996). Besides the exploratory interest, these basins constitute terrain analogues for better understanding the basins located at the continental margin, which is one of the goals of the Bacias Interiores Project (PETROBRAS/UFRN/PPGG), which supported the seismic survey at the Rio do Peixe Basin, object of this study (see preliminary note by Antunes *et al*. 2007).

A significant portion of the work about these basins encompasses their litho- and biostratigraphy, particularly at Araripe and Rio do Peixe (Ghignone et al. 1986; Brito 1987; Arai et al. 1989; Mabesoone 1994; Valença et al. 2003; Arai 2006; Silva et al. 2008). The sampled layers contain paleontological associations (ostrachods and palynomorphs) of the Rio da Serra and Aratu stages, with a major erosive event inferred by the lack of (the?) Buracica and Jiquiá (stages) at the top of the section (Ponte et al. 1991). The bio/chronostratigraphic correlation between these basins and those of the continental margin (specially the Potiguar Basin) is one of the main arguments for the interpretation that these deposits belong to a sinrift context.

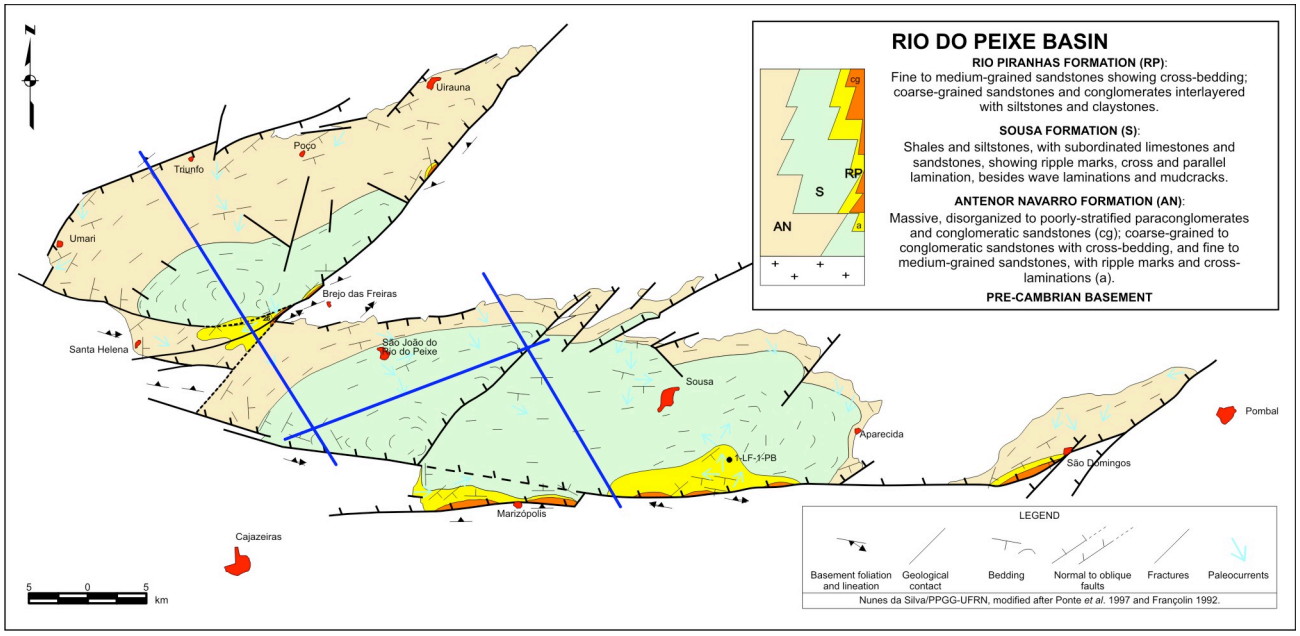

Figure 1: Simplified geological map and location of the Rio do Peixe Basin. From west to east, the half-grabens of Brejo das Freiras, Sousa and Pombal are illustrated, along with their flexural margins, fault borders and steps, and relay/directional ramps. Note the location of seismic lines related to the 0295_RIO_DO_PEIXE_2D survey (in blue) acquired by the Bacias Interiores Project. Geology modified after Ponte et al. (1991), Sénant and Popoff (1991) and Françolin (1992).

Although knowledge is still poor in relation to architecture and tectonic evolution of the Interior Basins, modern structural data (Sénant and Popoff 1991; Françolin 1992; Françolin *et al*. 1994) and gravity, magnetic and radiometric surveys (summarized and reinterpreted by Castro et al. 2007) are available for the RPB, in addition to the preliminary results of the UFRN Bacias Interiores Project. Two alternative hypotheses attempt to explain the rift evolution of these basins in the regional geodynamic context, either with a model involving NW-trending extension during Neocomian and Barremian times (Matos 1992, 1999; Sénant and Popoff 1991), or a more complex model involving the reactivation of E-W-trending (with sinistral kinematics) and NE (with a dextral movement component; Françolin et al. 1994) strike-slip lineaments, also involving NW extension.

The Seismic Survey at the Rio do Peixe Basin

As one of the main products of the Bacias Interiores Project, the acquisition of a seismic survey at the Rio do Peixe Basin represents a partnership between the Universidade Federal do Rio Grande do Norte through the Programa de Pós-Graduação em Geodinâmica e Geofísica (UFRN/PPGG) and PETROBRAS and Brain Technologies companies.

Three high-quality 2D lines were acquired (two lines with NW-SE orientation, parallel to the direction of maximum extension of the RPB, and one NE-trending line, transversal and linking the other two - see the location of the seismic lines in Figure 1), totaling about 80 km of surveying. This survey (0295_RIO_DO_PEIXE_2D, ownership of UFRN) was completed in early 2007, marked the pioneering work of UFRN as the first Brazilian University to be an EAD (Enterprise for Data Acquisition) at the Brazilian Agency for Petroleum, Natural Gas and Biofuels (ANP). The processing of seismic data was performed at the PETROBRAS UN RN-CE office at Natal/RN, and the interpretation has been done using the application package Geographix from LandMark Graphics Corporation.

The seismic survey was planned according to the structural model built for the RPB based on previous (specially Françolin 1992 and Françolin *et al*. 1994) and ongoing (Bacias Interiores Project) work, including the acquisition and interpretation of detailed gravity data by the UFRN Project. This data set allowed the compilation of a sedimentary thickness map (or basement depth map, Figure 2) applying the inversion technique. This map displays a nice fit with the well LF-1-PB (Lagoa do Forno), providing an additional reference frame for the interpretation of the seismic data.

Seismo-Structural Interpretation

The 2D seismic sections, obtained by the Bacias Interiores Project with the support of Brain Technologies and PETROBRAS, in addition to field geological and gravity data, enabled an enhanced three-dimensional view of the architecture of Rio do Peixe Basin (Figure 3). In the Brejo das Freiras and Sousa half-grabens (as well as at Pombal), the basement and the overlying early cretaceous sedimentary layers dip towards SE or south,

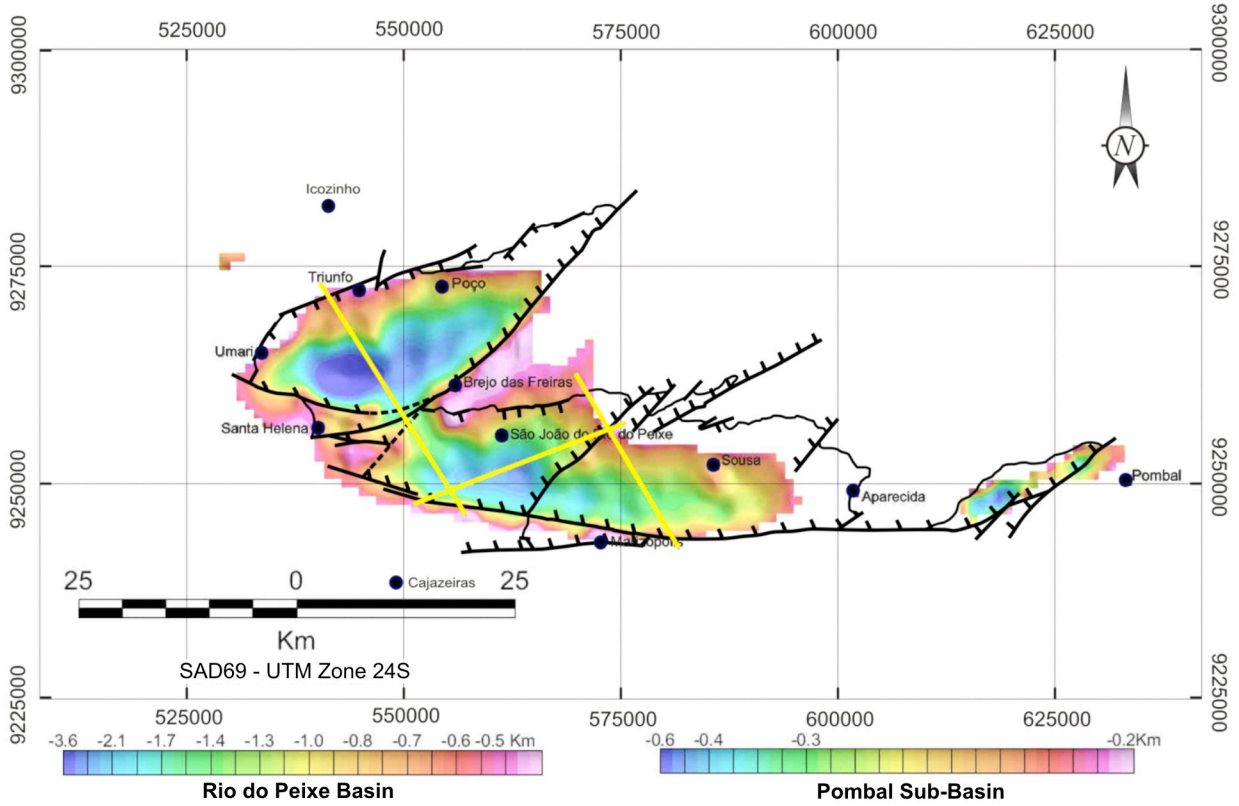

Figure 2: Inversion of gravity data from the Rio do Peixe Basin (survey of the Bacias Interiores Project; PETROBRAS/UFRN/PPGG), with estimation of the depth to the top of the basement. Observe the location of seismic lines (in yellow) in relation to the structure of the depocenters.

as a result of normal or oblique-normal faulting (Figure 1). In the directional ramp tips, the sedimentary layers and the basement dip towards the central portion of the depocenters (Figure 1).

The Brejo das Freiras half-graben, elongated along the NE-SW direction, is controlled by a main NE-trending normal fault, or fault zone (the Brejo das Freiras fault), sometimes with a minor dextral component. This fault displays a listric profile dipping to NW (Figures 1 and 4a). Towards SW, this fault and progressively curves to an E-W direction. Along the NW border of the half-graben, corresponding to its flexural margin, the sedimentary units unconformably overly the crystalline basement, cut by synthetic and antithetic normal faults with small displacements. Strata thickening towards the Brejo das Freiras fault (Figure 3a) typifies the syntectonic deposits that fill the half-graben. This fault displays a stepwise structure which, combined with normal dragging, generates folds affecting the sedimentary sequence.

The Sousa half-graben has its major axis oriented in the E-W direction. Its southern limit is defined by the E-W-trending and N-dipping São Gonçalo fault (Figures 1 and 4b), which presents an oblique normal-sinistral displacement (including variations from such behavior along the different fault segments). The rift section strata show subtle thickening towards S/SE (Figure 3b). The northern boundary of this half-graben is also marked by an unconformity exposed along its flexural margin. The Sousa half-graben has two depocenters, separated by a NE-trending normal fault dipping to NW, which defines an internal high (Figure 3b). The oil occurrence of Sítio Sagui coincides with that high. Normal dragging and folds in the sedimentary layers are also recognized next to the border and inner faults (Figure 3b).

Along strike, the steps of the border faults (Figure 3) correspond to relay-ramps, as in the case of Marizópolis and the curved, St. Helena steps. The correlation of seismic reflectors (the younger ones overly the higher steps) indicates that the segmentation of the border faults follows a piggyback style, attesting to the syntectonic deposition of the sedimentary pile.

Subordinate late meso-scale faults, with movement direction opposite to that described above for each set (NE and E-W), probably represent an episode of moderate inversion in the basin; some features in the seismic lines are consistent with this interpretation.

Conclusions

The integration of structural data allowed the characterization of a kinematic framework with NW-trending extension for the rifting event at the Rio do Peixe Basin. Fault nucleation was clearly controlled by the basement structure, in particular the location of the Brasiliano shear zones and the dip of their mylonitic

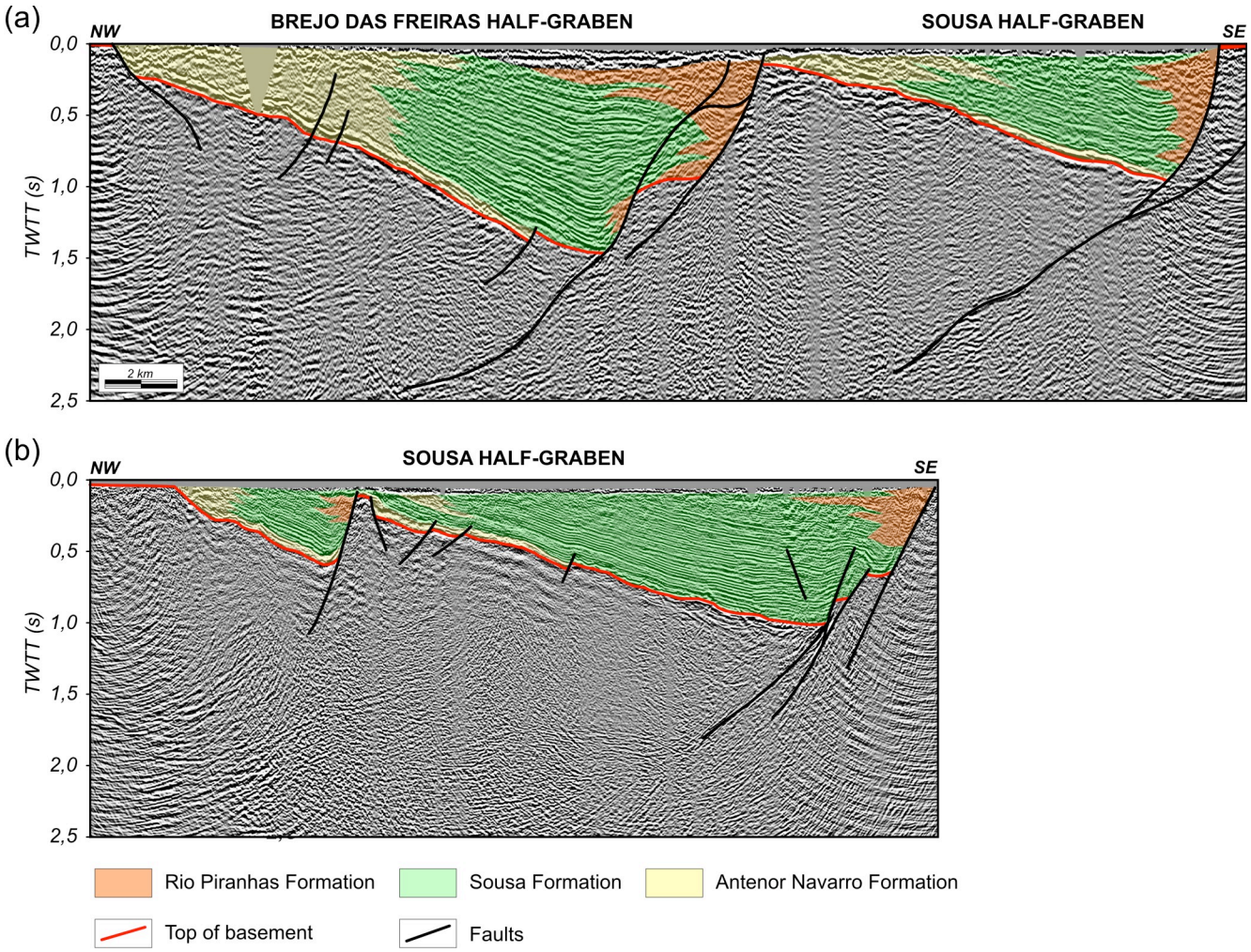

Figure 3: Seismic sections of the 0295_RIO_DO_PEIXE_2D survey: (a) seismic section 0295-2090 that crosses, from NW to SE, the Brejo das Freiras and Sousa half-grabens. The development of drag folds, related to the border faults of both half-grabens, is noteworthy. Notice the step-faulting and the thickening of the sedimentary layers towards the border faults, specially to the Brejo das Freiras one, at the SE edge of the compartment; (b) seismic section 0295-2088 located in the Sousa half-graben. This half-graben consists, in fact, of two minor compartments tilted to S/SE and separated by an internal high. Once again, notice the presence of drag folds at the faulted borders of both second order compartments.

foliations. The ductile (pre-Cambrian) kinematics is strike-slip and dextral in both NE and E-W sets. During the early Cretaceous reactivation, NE-trending structures acted as normal faults, or oblique faults with a subordinate dextral component, well shown by N-S to NNW-trending mesofaults. On the other hand, the E-W faults (varying from ENE to SSW-trending) display oblique (sinistral) to normal displacements, depending on their orientation and spatial distribution. The kinematics and en-énchelon pattern of the NE-trending faults, associated to the E-W structures along the Sousa half-graben, are compatible with synchronous or penecontemporaneous activity along these two trends, and the transtensional kinematics inferred for this half-graben.

Based on the geometry and style of structures (supplemented by petrographic and diagenetic observations of the sedimentary units), it can be inferred larger original dimensions for the Rio do Peixe Basin (and other examples in the region), which were reduced exposing the crystalline basement along structural highs. The expressive, km-scale denudation thus inferred took place during late to post-rift (post-middle Barremian to late Aptian) and subsequent evolutionary stages of the Borborema Province. The size of the Rio do Peixe half-grabens are of the same order of magnitude as those observed in the Potiguar Basin, a positive aspect in assessing the exploratory potential of the Interior Basins.

The relationships described, particularly the strata growth and the presence of conglomerate wedges following the major faults, are typical and diagnostic of syntectonic deposits filling half-graben structures. In this context, the lateral transition between the different sectors of the depocenters (flexural margin, depocenter axis and faulted margin), leads to contemporaneous relations of lithostratigraphic units, at variance with the classical

models of purely vertical stacking of strata. Although these relationships may be demonstrated through field data in well exposed areas, high quality seismic lines, like those acquired in the RPB, prove once more to be the ideal tool for understanding a complex tectono-stratigraphic framework.

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