Seismic stratigraphy and structural framework of the central region of Tucano basin (Cretaceous, Brazil)

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Abstract

The central portion of Tucano Basin, a Cretaceous continental rift basin in northeastern Brazil, was investigated for its structural and stratigraphic characteristics, using post-stack 2-D seismic data, well data and gravity data. Methodology was steered by the principles of rift basin sequence stratigraphy, aided by seismic facies and seismic attribute analysis, targeting at an adequate identification of stratal terminations and on the mapping of structural features, such as top of the basement and faults, and unconformities. The literature on Central Tucano basin traditionally recognizes only two depositional sequences forming the rift sedimentary infill, but the present stratigraphic analysis resulted in a framework of seven intra-rift unconformities, forming eight third-order rift sequences. Seismic thickness maps were created with the purpose to illustrate the location of the depocenters during the sequences' deposition and the direction of the sedimentation flow. This paper discusses the role of tectonics on that particular stratigraphic framework and introduces a new view on the rift sedimentary infill for the deep central portion of Tucano basin.

Introduction

The Tucano basin is located at the Brazilian northeastern margin (Fig.1) and is part of the Recôncavo-Tucano-Jatobá (RTJ) rift system, an intracontinental rift that evolved as an aborted arm associated with the rupture of the supercontinent Gondwana, which led to the opening of the Southern Atlantic Ocean (Santos et al., 2010). Fault and accommodation zones divide the Tucano basin into three portions: South Tucano, Central Tucano and North Tucano, with Central Tucano being the main study object of the present paper. The RTJ rift evolved in three tectonic phases: pre-rift, syn-rift and post-rift. Since one of the main goals of this paper is to perform an interpretation of the rift sequence's sedimentary succession, the principle of rift basin sequence stratigraphy was applied, which allowed to study the basin through the point of view of depositional sequences, identifying stacking patterns, stratal terminations and unconformities.

As the entire RTJ rift, the Tucano basin has a half-graben geometry, whose asymmetry is given due to the main border fault, called the Adustina fault. The basin is characterized by a N-W dipping extensional fault system, resulting in a domino-style, where an expressive west dipping antithetic fault defines the Cícero Dantas low, the deepest structural low of the entire RTJ rift, whose sedimentary succession, according to Costa et al. (2007), reaches depths of over 16 km.

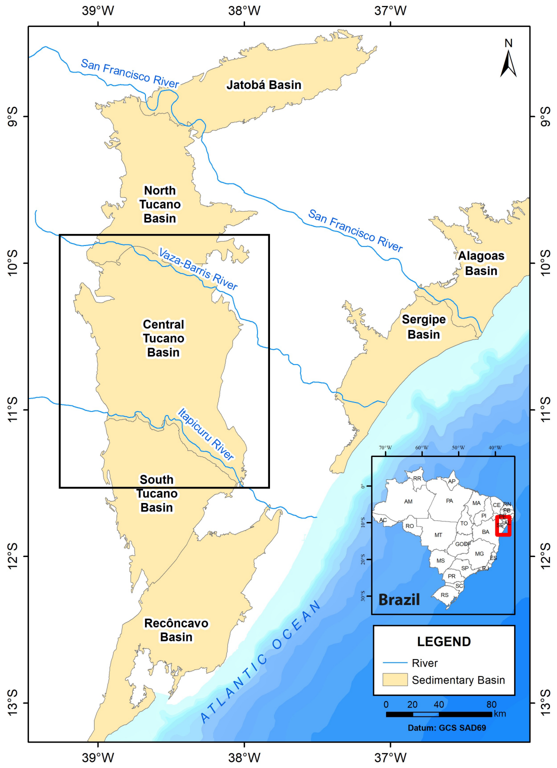

Figure 1: *Location of Tucano basin at the Brazilian northeastern margin. The black rectangle represents this paper's study area.*

Method

The dataset was granted by the Brazilian National Petroleum Agency (ANP) and consists of post-stack 2-D seismic lines and exploratory wells, where only a few of those were able to be tied to the seismic, due to the fact that most of them were lacking essential data; and a total Bouguer anomaly map with grid cell size of 1000 meters.

To analyze the study area, the first step performed was the generation of a residual Bouguer anomaly map (Fig. 2a), with the purpose to analyze the data disposition in relation to the Central Tucano depocenter (CTD) and

South Tucano depocenter (STD). With this step performed, seismic and well data were superimposed on the Bouguer anomaly map.

The methodology used in the present paper was steered by the principles of rift basin sequence stratigraphy, which focuses on analyzing changes in facies and geometric character of strata and identification of key surfaces to determine the chronological order of basin filling and erosional events (Catuneanu et al., 2009).

The procedures that were performed include: seismic well-tie, which was useful to the seismic stratigraphy interpretation, allowing the identification of unconformities through gamma-ray logs; seismic attribute analysis, such as TecVA (or *Pseudorelief*), generating amplitude maps that provides a relief effect on seismic data, allowing the identification of structural features, such as faults and basement top surface; mapping of reflector terminations (such as truncations); delimitation of stratigraphic surfaces and seismic facies analysis.

Mapping of erosive truncations was an important step in this work, since its occurrence indicates the presence of unconformities that delimitates stratigraphic sequences. Since well data and gamma-ray logs were scarce, the identification of truncations on seismic data was a necessary step on the interpretation of rift sequences.

Through the delimitation of stratigraphic surfaces, seismic thickness maps of the interpreted sedimentary sequences were also generated. These maps allow to infer the location of the basin's depocenters during the deposition of sequences and the direction of the main sedimentation flows.

Results

To analyze Central Tucano basin's structural framework, seismic attribute analysis, especially TecVA, was crucial on the enhancement of important features, such as faults and the basement surface (BS). The BS usually presents itself as a high amplitude reflector due to the high acoustic impedance contrast between igneous rocks from the crystalline basement and the pre-rift sedimentary rocks. However, in Central Tucano basin, the BS didn't show these characteristics, thus, being mapped through seismic facies analysis that was enhanced through TecVA, delimitated in the region where facies with a chaotic configuration pattern ended.

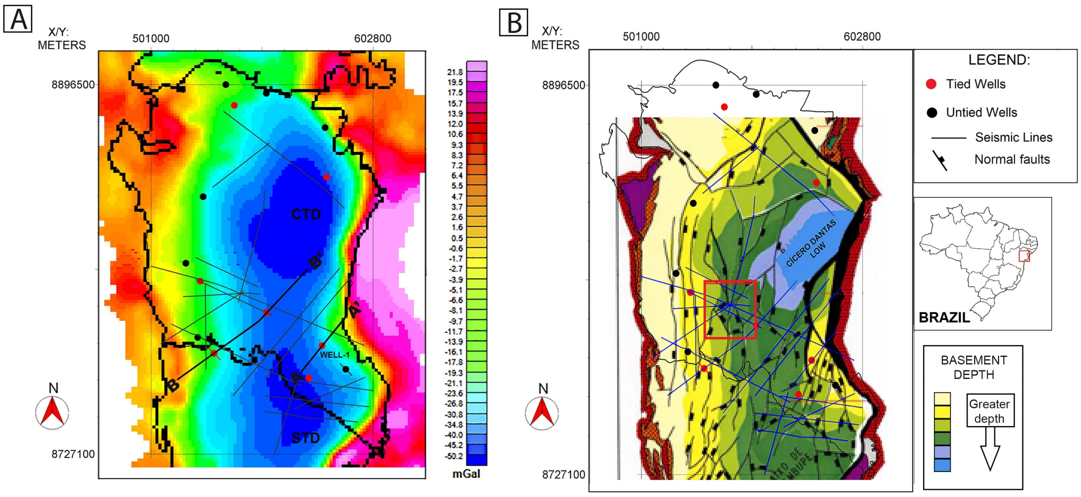

Figure 2: *a) Residual Bouguer anomaly map with seismic and well data in Central Tucano basin, with locations of seismic lines A-A' and B-B', and well-1. CTD = Central Tucano depocenter, STD = South Tucano depocenter; b) Simplified structural map modified from Aragão et al. (1994). The red square enhances the region with negative flower structure as displayed by seismic sections shown in Figure 3.*

The simplified structural map in Figure 2b shows a region, highlighted by the red square, where several seismic lines pass through a negative flower structure. The use of TecVA was useful on the mapping and enhancement of this feature on seismic sections (Fig. 3), also aiding on the identification of several faults along the data. The presence of negative flower structures in Central Tucano basin indicates the occurrence of transcurrent/strike-slip fault zones, generating transtractional structures, originated through the combination of directional and normal movements.

Besides from the basement, the pre, syn and post-rift sequences were also analyzed. Costa et al. (2007) traditionally recognizes only two depositional sequences in Tucano basin that forms the rift section's sedimentary infill, however, the present stratigraphic analysis recognized a framework of seven intra-rift unconformities, forming eight third-order rift sequences, which will be discussed next.

Pre-rift sequence

The syn-rift unconformity (SRU), which separates the pre-rift strata from the rift ones, was a highlighted surface in several seismic lines, presenting itself as a high amplitude reflector with good continuity, and accentuated truncations in all seismic sections in the proximal region. In well data, the SRU was marked where the composite log (Fig. 4) indicated the top of Sergi Formation, a sand-prone unit, which according to Tucano basin's stratigraphic chart, is the formation that delimits the pre-rift sequence.

The pre-rift sequence maintains constant thickness along the entire data (Fig. 5 and 6), around 480 ms, as it is shown in the seismic thickness map in Figure 7. The seismic thickness maps from all sequences were generated only in the central to south portions of Central Tucano basin, due to the lack of seismic data in the northern region of the basin. The anomaly peaks that appeared in the central portion of the map are caused by interpolation errors also due to the lack of data in the area.

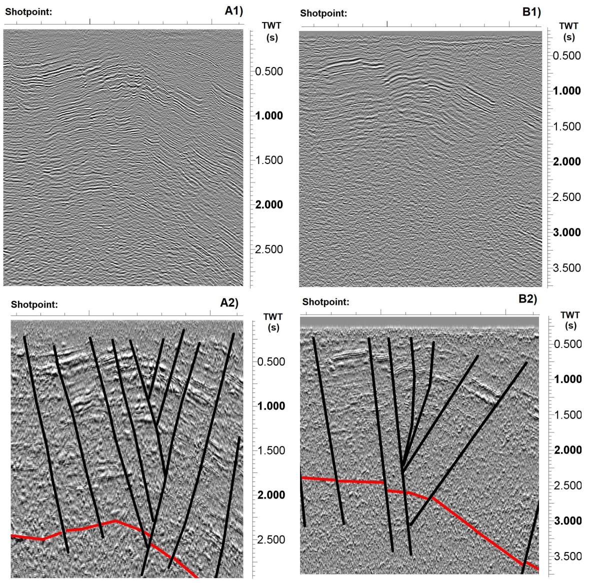

Figure 3: *Negative flower structure (black lines) observed in seismic sections located in the red square area in Fig. 2b. A1, B1) Uninterpreted seismic sections; A2, B2) Interpreted seismic sections with TecVA seismic attribute. Red line = basement surface (BS).*

Rift sequences 1 and 2

Rift sequence 1 is limited at the base by the SRU and at the top by the intra-rift unconformity 2 (RU-2), while rift sequence 2 is limited at the base by RU-2 and at the top by intra-rift unconformity 3 (RU-3). The unconformities had been marked mainly by the presence of stratal termination, such as truncations, in several basin areas, as seen in Figure 5.

One of the main characteristics of rift sequences 1 and 2 is the increase of its thickness towards the depocenters of both Central and South Tucano basins, as seen in Fig. 6.

In terms of seismic facies, in the proximal region, a chaotic configuration pattern was observed, with reflectors of low amplitude, bad continuity and medium frequency, which accounts for seismic facies patterns of lacustrine mudstones. Towards the depocenter, reflectors start to show a higher amplitude, good continuity and high frequency with parallel configuration, typical of shale and lacustrine siltstones intercalated with distal sandstones.

In the seismic thickness maps for rifts 1 and 2 of Figure 7, it is also possible to notice the direction of sedimentation flow, with increasing thickness towards the basin's depocenter, where in the flexural border, the sequences show thickness of 46 ms to rift 1 and 36 ms to rift 2, while in the depocenter, the thicknesses reach 729 ms and 464 ms, respectively. In that way, it is possible to notice a resemblance between the seismic thickness maps and the Bouguer anomaly map shown in Figure 2a.

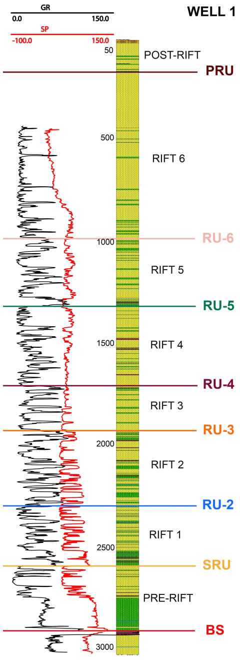

Figure 4*: Well-log data 1 with unconformities delimitating rift sequences. Black curve = Gamma-ray log; Red curve = Spontaneous Potential log. See Fig. 2a for well location.*

Rift sequences 3 and 4

Rift sequence 3 is limited at the base by RU-3 and at the top by intra-rift unconformity 4 (RU-4), while the rift sequence 4 is limited at the base by RU-4 and at the top by intra-rift unconformity 5 (RU-5). RU-4 is an unconformity of regional character recognized along all Recôncavo-Tucano-Jatobá rift system and even in a few continental margin basins, such as Sergipe-Alagoas and Espírito Santo basins. According to Costa et al. (2007), the coverage of RU-4 identifies a tectonic event that Bueno (2001, 2004) related to the diachronism that characterizes the propagation to the north of the east margin rift system. Even though RU-4 has a regional character, the unconformity does not present itself with a high amplitude reflector due to the fact that its contact is between sandstones, thus not creating a significant acoustic impedance contrast or changes in the Gamma-Ray log patterns.

There is also an increase in thickness for rift sequences 3 and 4 towards the depocenters of Central and South Tucano basin, noticeable both in seismic sections (Fig. 6) and in the seismic thickness maps (Fig. 7), also resembling the Bouguer anomaly map.

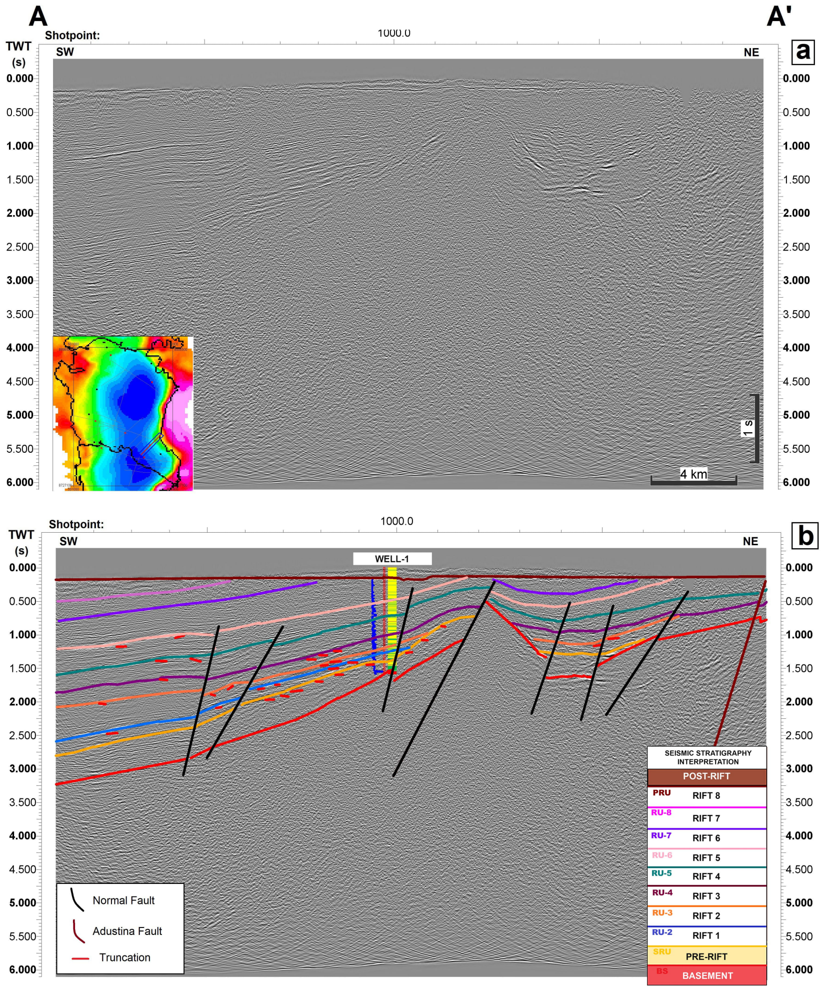

Figure 5: *a) Uninterpreted strike seismic section A-A' and insert with line location; b) Interpreted seismic section A-A' with well-1 and insert with seismic stratigraphy interpretation. Note the presence of truncations in the rift sequences.*

Rift sequences 5 and 6

Rift sequence 5 is limited at the base by RU-5 and the top by intra-rift unconformity 6 (RU-6). RU-6 presents itself as the highest amplitude and frequency reflector of the entire data, standing out from the rest of the reflectors in all seismic sections. Rift sequence 6 is limited at the base by RU-6 and at the top by intra-rift unconformity 7 (RU-7), with this last one presenting itself as a high amplitude and good continuity reflector only in the distal portion of the basin, next to the main border fault. RU-7 truncates the post-rift unconformity (PRU) in the central region of the basin, thus not appearing in the flexural margin, only being identifiable from the central region towards the distal portion of Central Tucano basin. Rift sequences 5 and 6 also show an increase in thickness towards the depocenter (Fig. 8), where rift 5 shows thickness of 89 ms next to the flexural margin and 801 ms next to the depocenter. Since RU-7 truncates the PRU in the central region of the basin, rift sequence 6 does not appear in the flexural margin, having thickness of 144 ms in the central region and 743 ms next to the depocenter.

Rift sequences 7 and 8

Rift sequence 7 is limited at the base by RU-7 and at the top by intra-rift unconformity 8 (RU-8), while rift sequence 8 is limited at the base by RU-8 and at the top by the post-rift unconformity (PRU). Rift sequences 7 and 8 are only found from the central to the distal areas of the basin, thus not appearing in the flexural margin.

RU-8 does not display high amplitude reflector in any seismic section, but has been interpreted as an unconformity due to seismic facies changes and the presence of subtle truncations.

The seismic thickness maps for rift sequences 7 and 8 (Fig. 8) also show an increase in thickness towards the depocenters, with thickness of 23 ms in the central region and 489 ms next to the depocenters.

Post-rift sequence

The post-rift unconformity (PRU) presents itself as an extensive angular unconformity observed along the entire basin, which separates syn-rift deposits from post-rift sediments. The PRU is truncated by the unconformities RU-4, RU-5, RU-6, RU-7 and RU-8 and its respective sequences along the seismic sections shown in this paper, with the PRU having high amplitude and good continuity in most sections, also being easily recognized.

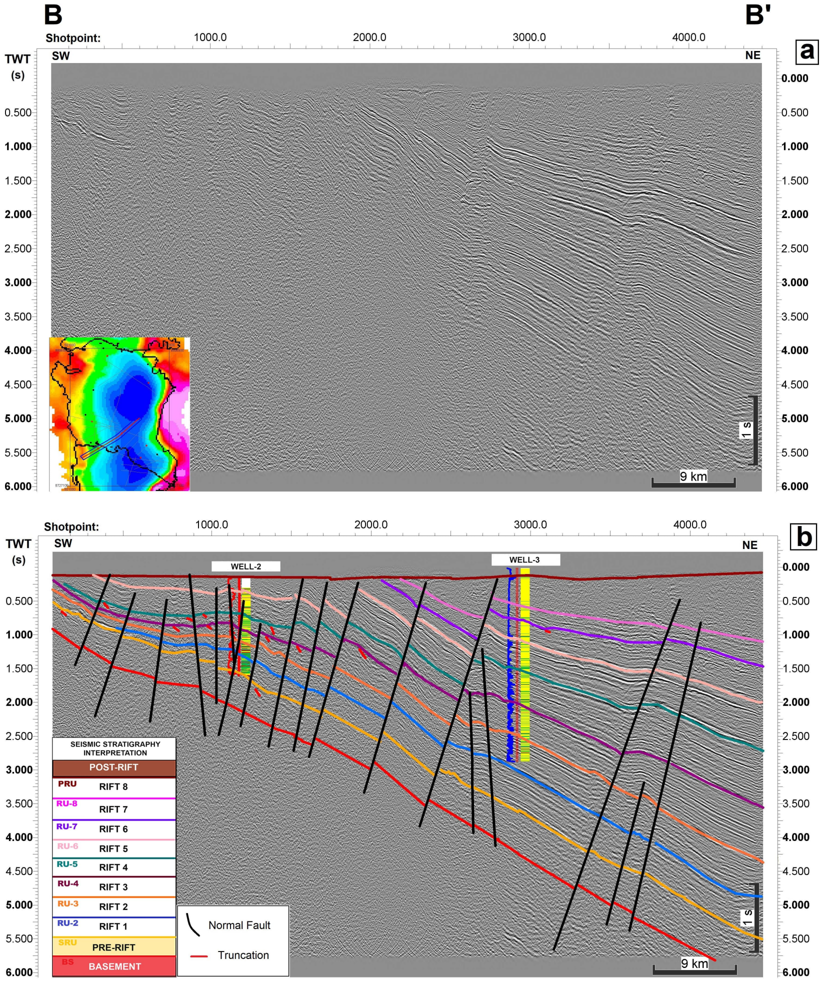

Figure 6: *a) Uninterpreted strike seismic section B-B' and insert with line location; b) Interpreted seismic section B-B' with wells 2 and 3, and insert with seismic stratigraphy interpretation. Note the increasing thickness towards the depocenter.*

Discussion

Costa et al. (2007) proposes the existence of only one syn-rift unconformity, dividing the rift phase into two sedimentary sequences. However, unconformities are characterized as erosive events that separates two sequences, indicating that the deposition of sediment was not continuous and the basin experienced a greater number of periods of tectonism, with constant reactivations of the main border fault during the rifting period. As Central Tucano basin's depocenter reaches depths of approximately 16.000 meters, it is more likely that more than one erosional event occurred, due to the great amount of basin's sedimentary infill. Since unconformities are identified by the presence of erosive truncations resulted from the sediment's progradation towards the base level, the large amount of truncations identified in the seismic sections indicates the presence of more than one unconformity, resulting in a framework of eight syn-rift sequences, different from that presented by the literature.

Conclusions

The Bouguer anomaly map was useful for understanding and visualizing the basement layout in relation to the basin, locating Central and South Tucano basin's depocenters.

TecVA seismic attribute analysis allowed a better mapping of the basement surface and the main faults in seismic sections, identifying the presence of a negative flower structure, which indicates the occurrence of shear zones in the region.

The seismic stratigraphic analysis allowed the identification of seven intra-rift unconformities, resulting in eight third-order sedimentary sequences, where stratigraphic charts previously indicated only one unconformity and two rift sequences, besides from the SRU and PRU. These results demonstrate that the basin experienced greater periods of tectonism, with constant border fault reactivation during the rifting period. Mapping of stratal terminations, such as truncations, was the most important tool on the identification and interpretation of these surfaces, which allowed the delimitation of the sedimentary sequences presented. The seismic thickness maps made it possible to identify the direction of sedimentation flow and the thickening of the sedimentary sequences towards the depocenters of Central and South Tucano basins, with the exception of the pre-rift sequence, which remained with constant thickness throughout the entire basin.

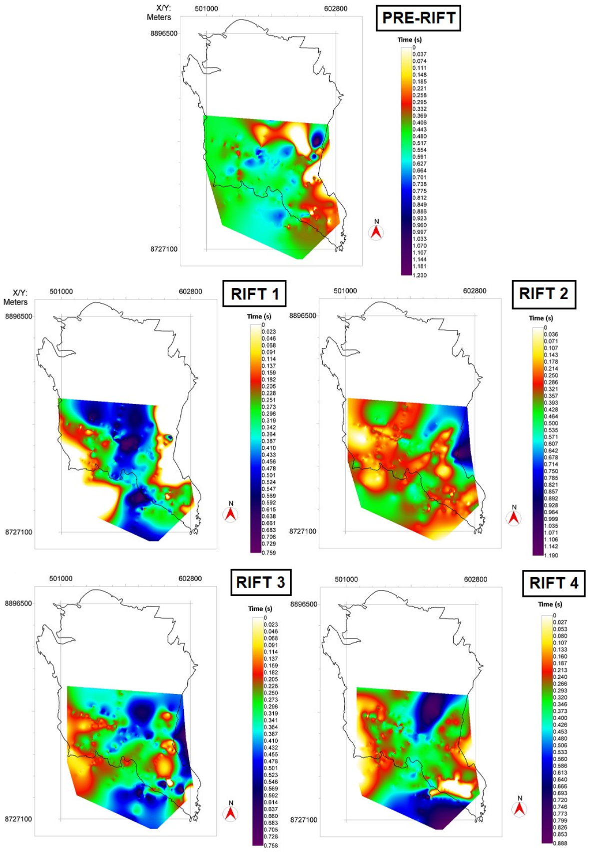

Figure 7: Seismic thickness maps of pre-rift and intra-rift sequences from 1 to 4. Note the direction of sedimentation flow towards the basin's depocenters.

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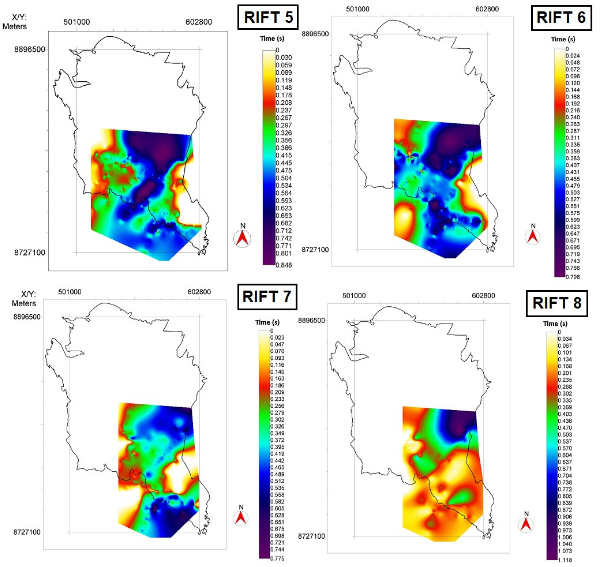

Figure 8: Seismic thickness maps of pre-rift and intra-rift sequences from 5 to 8. Note the direction of sedimentation flow towards the basin's depocenters.

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