STRATIGRAPHIC CHARACTERIZATION OF RIFT BASINS FROM STACKING PATTERNS AND ITS GENETIC SIGNIFICANCE

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ABSTRACT

The Brazilian Cretaceous rift section is the most prolific province of the petroleum systems of the Brazil. The main source rock, also reservoir-prone is the *Pre-Salt Province*, where giant fields (with recoveries over 6.000 millions of bbl) has been discovered since. As resultant of the recent discoveries, the Brazilian rift section has been drilled deeper and new seismic surveys and old data reprocessing has been made. The petroleum exploration geology must guide these new frontiers, developing modern models and theories that allow the exploration to obtain an advanced geological knowledge of the petroleum systems and its prospects. In this way, the stratigraphic analysis, as component of the multidisciplinary group of basin analysis, offers methods and models to explain and predict the stratigraphic framework and the most accurate compartimentation of syn-rift packages for hydrocarbon exploration.

The geological evolution of rift basins is related to tectonics events, these events control the accommodation generation and destruction (sedimentation and erosion). As observed on the proposed model, the generation and destruction of accommodation occurs simultaneously, and consequently, depositional packages are correlated laterally with unconformities. Often, the accommodation created is instantaneous on the geological time, but the fill (by sediment supply) is delayed. It is controlled by erosion, transport and drainage arrangement. Therefore, the accommodation created by a tectonic pulse, is filled after a delay, showing a distinctive stacking pattern, observed after the tectonic event. The delayed sedimentary supply is observed only at the flexural margin of the half-graben, while in the faulted border, the sedimentary input is instantaneous, developing a package genetically related to the tectonic event, compound by several distinct stacking patterns, depending from their positioning at the rift basin.

INTRODUCTION

The establishment of the sequence stratigraphy concepts for sedimentary basin analysis, such as the stacking patterns characterization, key-surface recognition and the depositional sequences and unconformities mapping have become mainstream for the stratigraphic analysis applied to hydrocarbon exploration. However, these theories and methods were developed exclusively to passive margins, where the eustatic control exists and rules the deposition (Posamentier et al., 1988 and Van Wagoner et al., 1990). On other hand, the Brazilian explorations perspectives have been dramatically changed since the largest syn-rift eastern margin deepwater province (informally named Pre-Salt Province) was drilled (in 2007). This province encompasses giant oilfields that are ranked among the largest #50 fields of the world (with average recovery of 6.000 millions of bbl, being able to reach volumes of 30.000 millions of bbl, as pointed by Berman, 2008). The Brazilian Pre-Salt Province comprises the Early Cretaceous syn-rift continental basins related to the Gondwana Supercontinent breakup, which generated the post-rift South Atlantic Ocean passive margin basins. The source rock are deep continental lacustrine shales, and the reservoirs comprises shallow level lake carbonates, continental and lake-margin sandstones.

Sequence stratigraphy can be applied to rift basins analysis to obtain more accurate and predictive results. However, its application requires an adaptation to contemplate the main control parameters of the deposition and preservation on rift basins. So, these concepts adaptation is discussed on this study, where the main controls of a rift basin are pointed, and its relationship are observed and a correlation and a mapping model is proposed, slicing the sedimentary succession in genetic packages. These models are supported by several studies on syn-rift sections of Brazilian sedimentary basins, but this paper is focused on the Cumuruxatiba Basin.

SEDIMENTATION CONTROL PARAMETERS IN RIFT BASINS

In rift basins, tectonic is the main parameter, controlling the deposition (accommodation creation) and erosion (accommodation destruction). Secondary controls are the sedimentary supply and climate that overprint the depositional patterns, eustacy being the less important control because in continental rifts (such as this case study) have no marine influence.

Erosion and Deposition Contemporaneity

The depositional packages in a rift basin are controlled by tectonics, as an instantaneous event in geological time, named a tectonic pulse. The tectonic pulse can create accommodation (that permits deposition), and at the same time, destroy accommodation (generating erosion). When the general basin geometry is a half-graben, the tectonic pulse generates block rotation, developing a descending movement at the footwall (subsidence creates accommodation), and simultaneously an ascending movement at the hangingwall (uplift creates erosion). So, the depositional packages of a rift basin are contemporaneous to laterally adjacent erosive events, thus erosion and deposition, being contemporaneous in time, can be related to the same event – the tectonic pulse (Figure 01A).

The Delay of the Sedimentary Supply

As seen before, one single tectonic pulse generates at the same time erosion and deposition. However, the depositional event observed on the sedimentary record seems delayed relative to its tectonic pulse. It's occurs because the pulse is instantaneous in geological time (generating accommodation on the footwall, and uplifting the hangingwall), but the area available for erosion at the hangingwall takes a time to be eroded, transported and deposited on the footwall. In this way, a tectonic pulse is pictured as an event with fast accommodation creation, without an affective supply characterized by a depositional succession of deep lacustrine shales, succeeded by a progradation from the flexural margin or from the axial input of sandstones and coarse deltaic and costal lake deposits, due to the delayed supply related to the tectonic pulse. In this way, depositional events from the flexural margin and axial input syn-pulse are pictured as deep lacustrine fine-grained sediments, and depositional events post-pulse are pictured by fluvio-deltaic and coastal lake coarse-grained sediments associated to the delayed progradation of the tectonic pulse (Figure 01B).

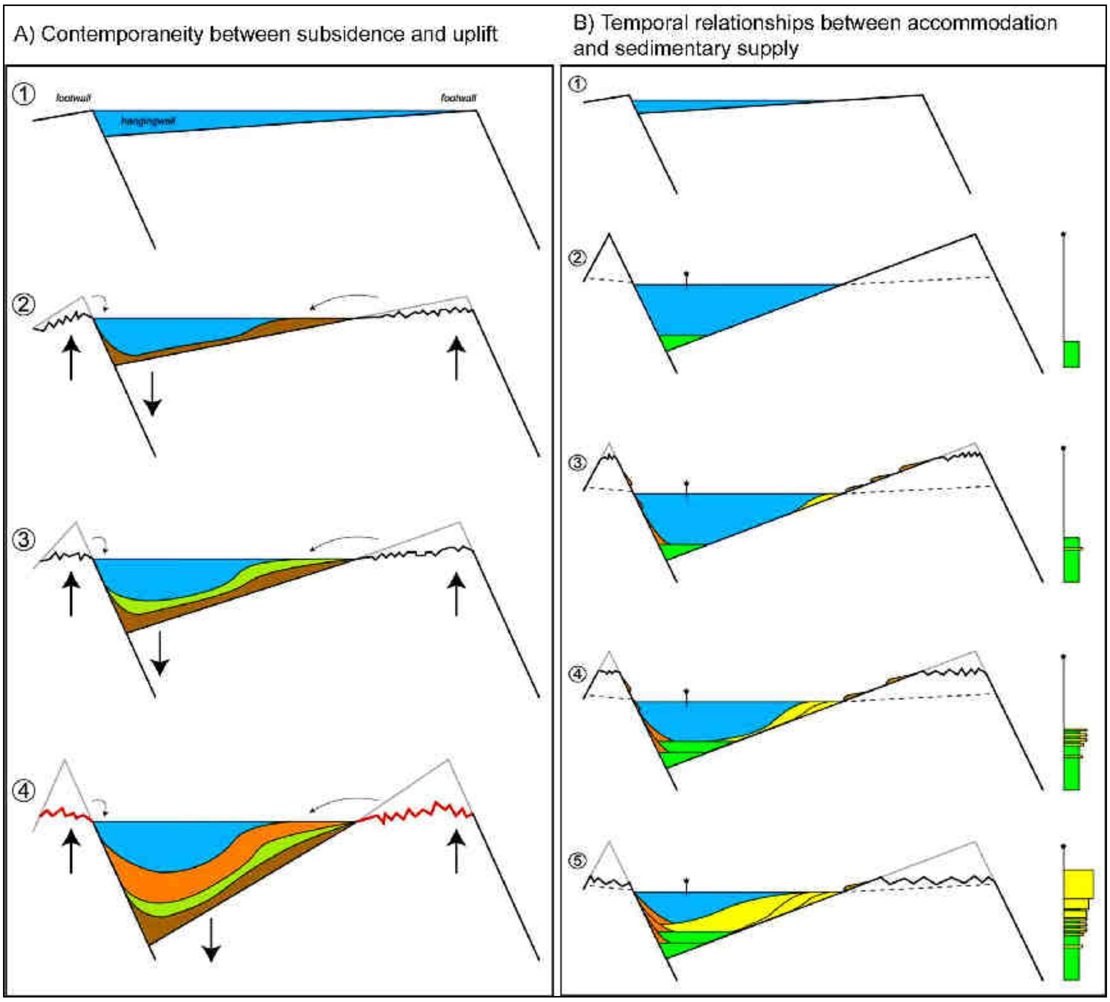

Figure 01(a): Evolutional model showing the relationship between uplift at the footwall and subsidence at the hangingwall, and consequently deposition of a sedimentary package time-correlate to an unconformity; (b) evolutional model showing the relationship between the accommodation creation due to a tectonic pulse, and the delayed input of the sedimentary supply related to this pulse.

THE GENETIC MEANING OF THE STACKING PATTERNS

The relationship between the control parameters is clear and systematic when mapping independently the depositional packages by its inputs: flexural margin and axial as one type, and faulted border as another. The mapping of tectonic system tracts, as proposed by Prosser (1993), where a stacking pattern pictures a specific situation of the basin related to a “tectonic pulse” curve (in contrast to the eustatic curve of the classic stratigraphy model of Posamentier et al., 1988). However, at this study it has been observed the existence of a significant contribution from the faulted border, dominantly composed by clastic wedges, commonly of conglomerates, associated to fandeltas, and submarine turbidites.

These faulted border supply response is instantaneous at the tectonic pulse, due to the small distance from the uplifted footwall to the adjacent depocenter at the hangingwall. Therefore, the faulted border deposits are commonly thick but have very short lateral extension. Consequently, the syn-pulse period is pictured at the faulted border region by a substantial input of sediments, and the post-pulse period by a retreat of the clastic wedge related to the fault.

Is proposed in this study the use of the tectonic system tracts, adapted from Prosser (1993), to describe the distinctive features of the different sediment inputs of the half-graben, and to refine the delayed supply model, as presented in Figure 02.

The **Rift Initiation Tectonic System Tract** is marked by several thin cycles, where the accommodation created is successively filled, at a shallow, but tectonically controlled broad basin, with a small and scattered fault system, picturing an initial phase, tectonically controlled, but in equilibrium between accommodation creation and sedimentary supply.

The **Rift Climax Tectonic System Tract** represents the syn-pulse event, where the accommodation creation rate overpass the marginal supply, generating retrogradations at the flexural margin, while at the border fault, the conglomeratic wedge advances towards the depocenter, depositing expressive syn-pulse packages.

At the end, the **Rift Filling Tectonic System Tract** represents the post-pulse event, where the delayed sedimentation advances over the flexural margin and axial input, as a prograding continental and coastal wedge, while at the faulted border, the clastic wedge retreats, reflecting the low tectonic activity.

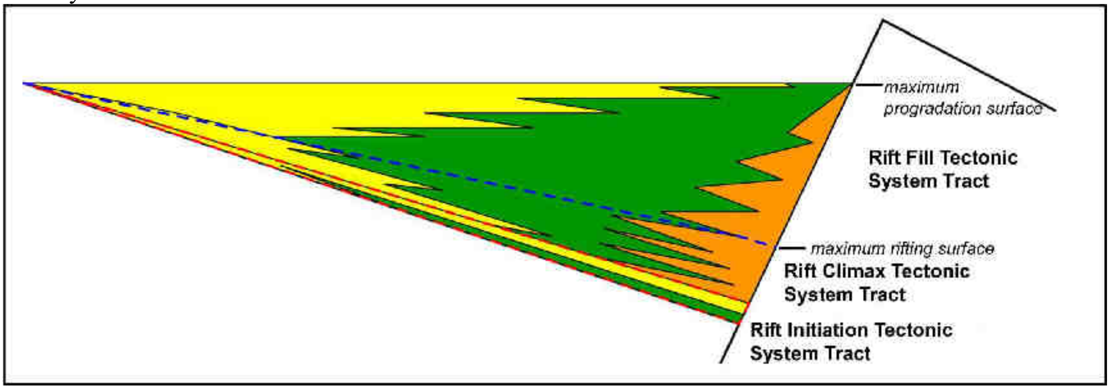

Figure 02: Tectonic System Tracts model proposed, with its respective stacking patterns.

Therefore, the mapping of genetic units at a rift basin must be developed from the analysis of stacking patterns, keeping in mind that each tectonic system tract allows different stacking patterns, depending on their location inside the half-graben, requiring a clear understanding of the basin geometry prior to the stratigraphic analysis of spatial arrangement. On a detail scale, the mapping of rift units may show high frequency stacking patterns, related to lake level fluctuations, due to climatic changes (Scholz, 1995), compatible with the classic eustatic system tracts.

RESULTS

As an example of the proposed model, we selected a key-area, were a stratigraphic section was elaborated, with S-N orientation (Figure 03), located at Cumuruxatiba Basin, at the eastern Brazilian margin, where the flexural margin is positioned to the southeast, and the faulted border to the northwest, on a diagonal setting. The basal section is a succession of lacustrine floods, interlayered with marginal fillings, picturing a Rift Initiation Tectonic System Tract (RITST). Over the RITST, occurs retrogradational packages, very thick at the wells W3 and W4, which together with the progradation of the W5 (faulted border) belong to the Rift Climax Tectonic System Tract (RCTST). Ovelied by the retrogradation of the clastic wedge of the W5, together with the progradation on the wells W2, W3 and W4, that compose the Rift Fill Tectonic System Tract.

The vertical datum of the wells is the final rift surface (beginning of the Alagoas/Aptian level), which represents the final rift geometry. The correlation of the tectonic system tracts matches with the available biostratigraphic ages, and can be observed and mapped at seismic sections.

CONCLUSIONS

As presented above, the stratigraphic evolution of rift basins is complex, but the understanding of the sedimentation from control parameters is a precise way to establish sedimentary packages for the systematic mapping in rift sections. However, is not quite enough to recognize the stacking patterns and to explain them with relationships from lake level and tectonics, because at one single tectonic system tract may occur different stacking patterns, depending on the location of the analysis at the basin. Therefore, it's necessarily to recognize the spatial geometry of the basin and its genetic controls to carry out a correct and useful stratigraphic analysis at rift basins.

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REFERENCES

Berman, A. 2008. Three super-giant fields discovered offshore Brazil. WorldOil Magazine, February 2008, v.229, n.2.

Blair, T.C. & Bilodeau, W.L. 1988. Development of tectonic cyclothems in rift, pull-apart, and foreland basins, sedimentary response to episodic tectonism. Geology, v.16, n.6, p. 517-520.

Heller, P.L., Angevine, C.L., Winslow, N.S. & Paola, C. 1988. Two-phase stratigraphic model of foreland-basin sequences. Geology, v.16, n.6, p. 501-504.

Posamentier, H.W., Jervey, M.T. & Vail, P.R. 1988. Eustatic controls on clastic deposition I – conceptual framework. In: Wilgus, C.K., Hastings, B.S., Kendall, C.G., ST. C., Posamentier, H.W., Ross, C.A. & Van Wagoner, J.C. (Eds.) Sea-level changes: an integrated approach. Society of Economic Paleontologists and Mineralogists Special Publication, 42, 407 p. 1988.

Prosser, S. 1993. Rift-related linked depositional systems and their seismic expression. In Tectonics and Seismic Sequence Stratigraphy (Ed. Williams, G.D. & Dobb, A.) Geological Society Special Publication No. 71, pp 35-66.

Scholz, C.A. 1995. Seismic stratigraphy of an accommodation-zone margin rift-lake delta, Lake Malawi, Africa. Geological Society, London, Special Publication, n.80, p. 165-181.

Van Wagoner, J.C., Mitchum, R.M., Campion, K.M. & Rahmanian, V.D. 1990. Siliciclastic sequence stratigraphy in well logs, cores, and outcrops: concepts for high-resolution correlation of time and facies. AAPG Methods in Exploration Series, n. 7.

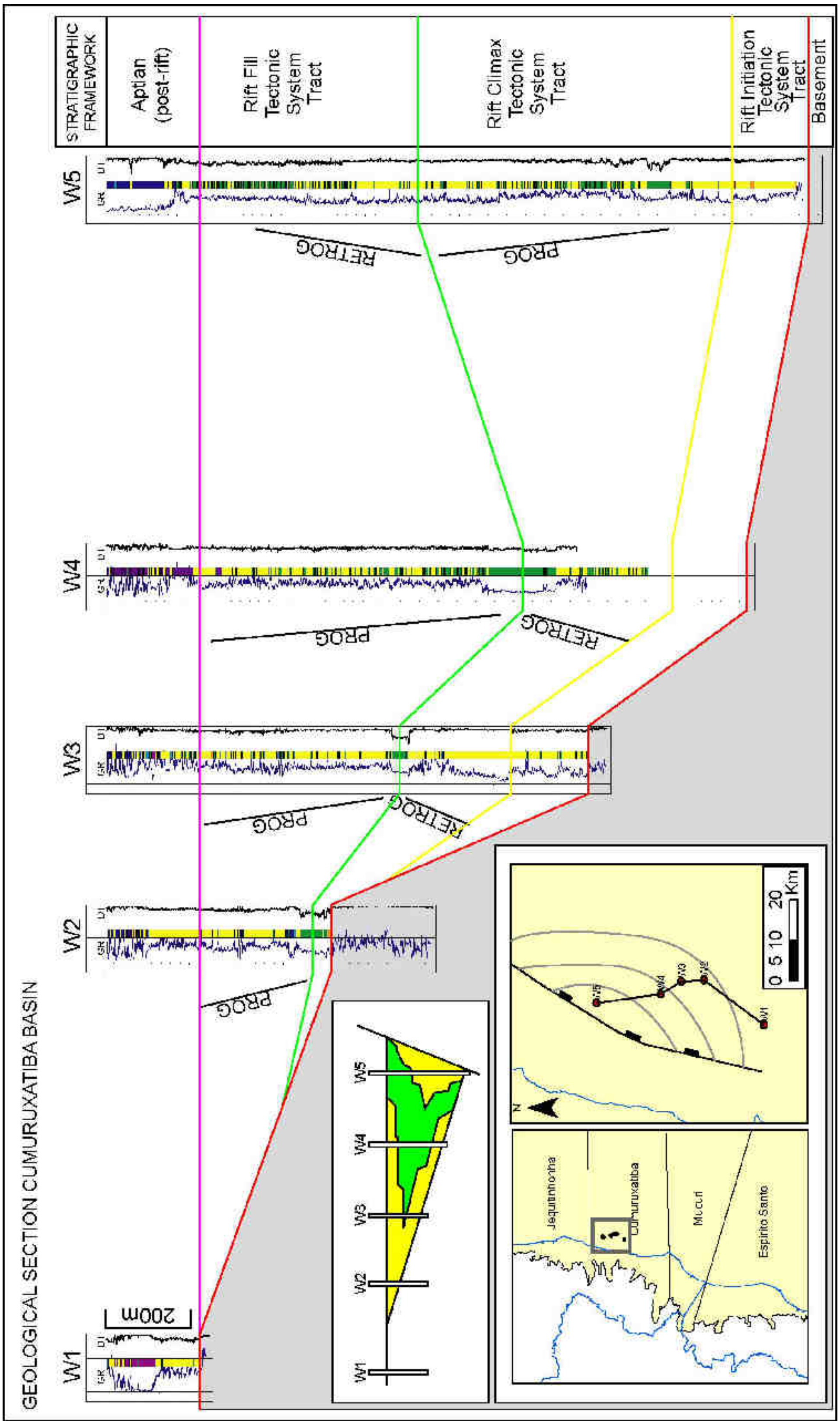

Figure 03: Stratigraphic correlation section at the Cumuruxatiba Basin, showing the Tectonic System Tracts.