Submission code: 8N0RA5K9N4

See this and other abstracts on our website: https://home.sbgf.org.br/Pages/resumos.php

Tectonic Segmentation during rifting of the Brazil Equatorial Margin

Julia Fonseca (UFRN/OGS), Helenice Vital (Federal University of Rio Grande do Norte), Cesar Ranero (Institute of Marine Sciences (ICM) (CSIC))

Tectonic Segmentation during rifting of the Brazil Equatorial Margin

Abstract Summary

We have studied the Brazilian Equatorial Margin (BEM) along over ~600 km from the East-Ceará to the Potiguar Basins using ~10000 km 2D seismic data showing of crustal-scale images. We investigated rift structure and the evolution of the tectonic structure and stratigraphy from inception to breakup. The tectonic structure and associated sedimentary processes indicate a complex margin segmentation that exhibits a temporal evolution. Seismic interpretation revealed that margin is segmented into three major domains: Southern, Central and Northern. Each segment is characterized by a distinct tectonic structure and evolution and is limited by abrupt tectonic boundaries. The segment boundaries define linear trends in the basement that extend from under the continental shelf to the deep-water domain. Furthermore, the segment boundaries indicate the onset and evolution of segmentation during rifting. The trend of each segment boundary appears to delineate flowlines of the opening direction. Thus, the segment boundaries are a proxy to analyze the time evolution of the orientation of the extensional stresses. We have additional connected the available fault and dike patterns with the geometry of the boundaries to infer the orientation of paleo-stresses. We have integrated the distribution, geometry and age of structures along the margin to produce an evolutionary model for the entire BEM from initiation to break up.

Introduction

The oceanic segmentation has been well documented since the early maps of the global mid ocean ridge (MOR) produced from single-beam echo sounders. These maps revealed that the MOR linear structure is segmented by fracture zones striking perpendicular to the trend of the speeding centers, and originally defined as Transform Faults. (Wilson, 1965;). Conversely, the segmentation of continental margins has not been studied in comparable detail, because most of their tectonic and magmatic structure is covered by thick sediment accumulations, and it has mostly been inferred from comparatively widely spaced sampling. As a result of this limitation, the significance in margin segmentation and its relation to tectonic/magmatic processes is poorly understood and most interpretations remain speculative. To study continental rift segmentation, we have investigated the BEM structure focusing on the changes of the along-margin structure from the East Ceará to the Potiguar Basins (Figure 1a). The crustal structure, syntectonic sediment distribution over these basins have been investigated to define temporal basin evolution (Fonseca et al., 2024; submitted to JGR 2025). The margin structure along strike supports a first order segmentation into three major segments denoted Southern, Central, and Northern Segments. We currently examine the spatial-temporal evolution of their tectonic structure and have defined the location, nature, geometry and spatial evolution of their boundaries. The Equatorial sector was the last segment connecting Africa and South America during the rifting of West Gondwana, in early Cretaceous but the age of break up and rift kinematics are debated (Matos, 1999; Moulin, 2010; Heine et al. 2014; Fonseca et al., 2024). The rifting led to the formation of several sediment basins on the conjugate margins. Along the Brazilian Margin, these basins include Potiguar, Ceará, Barreirinhas, Pará-Maranhão, Foz do Amazonas. The BEM rift evolution and breakup age have not yet been fully understood, because many works are based on either poor-penetration low resolution or a sparse coverage of seismic lines, and because the area lacks seafloor magnetic lineation due to Cretaceous Magnitude Quiet Zone (Moulin et al., 2010). Thus, uncertainties in rift evolution and continental breakup cause different plate kinematic reconstruction producing subsequent seafloor spreading ranging from Aptian to Albian. However, recently available seismic data calibrated with industry drillholes support earliest Albian age of first oceanic crust along Potiguar Basin (Fonseca et al., 2024).

Method

We interpreted ~10.000 km of post-stack 2D seismic data provided by provided by the Brazilian

National Agency of Petroleum, Natural Gas, and Biofuels (ANP) (Figure 1a). The grid covers 600 km along the BEM. Seismic data acquisition was conducted by WesternGeco for TGS in 2000 and 2001 using a 4050 meter long, 324-channel Syntrac streamer. We interpreted 4 key horizons across the entire grid: Moho, basement top, synrift top and seabed (Figure 1b) using Kingdom Suite. In sequence, we interpolated each key horizon using the data-adaptive Gradient Projection gridding algorithm from. The result of the interpolation is a set of grids which represent Moho, basement top, synrift top and seabed (in two-way travel time TWT). Then, we used Petrel E&P calculator tool to apply subtraction operations between two surfaces (in time) to obtain thickness. Figure 2 shows the basement thickness map in time. Finally, to convert thicknesses to depth, average velocities are applied: 6000 m/s for the basement based on nearby wide-angle seismic data (Aslanian et al., 2021), 3500 m/s for the synrift, and 2500 m/ for postrift (see Fonseca et al., 2024). The results of the seismic interpretation are shown through surface and thickness maps which are color-coded to display variations in thickness. The basement thickness, for example, is a good proxy to understand how the margin was extended during rifting. The synrift thickness, provides information of distribution of syntectonic deposits during rifting. We used the seismic lines, especially those along strike, and the maps to define the different segments.

Results

Our results indicate that the study are is segmented into three major domains: Southern, Central and Northern Segments. The Southern Segment is characterized by an EW slope (Figure 2) structure, abrupt lateral basement thinning, and steep faults indicating strike-slip kinematics. On the contrary, main extension in the Central and Northern Segments is related to normal faulting kinematics and their slope orientation is NW-SE (Figure 2). However, these two segments represent different tectonic domains since the focalization of the deformation is decoupled and occurred further outboard along the Central Segment. The Northern Segment presents a comparatively thinner basement (Figure 2) and thicker syntectonic (Figure 1b) deposits across much of the margin, compared to the Central Segment. These differences suggest that extension occurred at different rates in the three major segments. The three segments are bounded by tectonic structures defined in seismic images by abrupt lateral changes in basement structure offset associated to locally enhanced faulting (e.g. Figure 1b). The Segment Boundary 2 structure in Figure 1b delimit the Central and Northern segments. This boundary is a sharp lateral change in basement and synrift thicknesses where the Fortaleza High is cut by steep faults thinning basement from >20 to <15 km thick. The Northern Segment thinner basement is covered by ~3-5 km thick synrift sediment with rotated strata, while the Central Segment presents <1.8 km synrift deposits. When plotted on the top of the basement thickness map, the imaged segment boundaries form a consistent linear structure visible from under the continental shelf to the deep-water basin. The boundaries geometry indicates the evolution across time of continental segmentation during rifting. Likewise, the orientation of these boundaries is similar for all segments supporting that they approximately correspond to flow lines indicating the opening direction. Available information of onshore faulting and swarms of dikes (Figure 1a) with nearly the same age as the beginning of extension in Potiguar (Valanginian ~141-134 My) allow to infer the paleo-stresses. Thus, we connected the geometry inferred from the onshore geology with the flow lines given by the segment boundaries to produce an evolutionary model. The initial Phase 1 deformation occurred in a triple-point configuration, each with different opening direction. This configuration was possibly modified during a kinematic reorientation of South American (e.g; Moulin et al., 2010; Szatmari and Milani., 2016) and caused two arms to stop opening during Phase 2. Phase 2 extension focused along two arms, creating a margin-type structure, which readjusted internal deformation given rise to the three major segments. Rift extension responded to a gradual change in kinematics into a Phase 3, when the Southern Segment developed a transcurrent fault system, establishing a strike-slip setting at Southern Segment. Margin extension finished during Phase 4 with the initiation of spreading cells with a distribution mimicking the main rift segmentation, which remained as segmentation giving rise to oceanic fracture zones. We propose that the tectonic segmentation of the margin initiated during Barremian-Aptian (Phase 2) time as response to a lithospheric-scale of the mode of deformation caused by the change in plate kinematics imposing a change in opening direction.

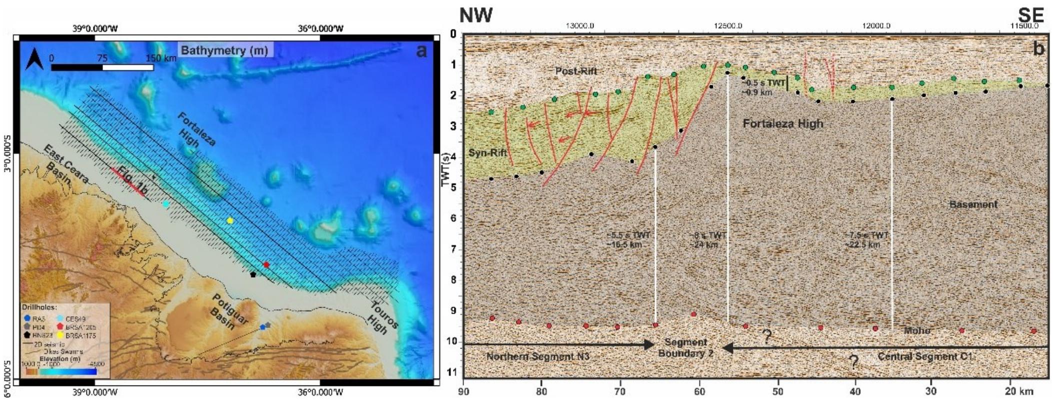

Figure 1 a) Elevation map with GEBCO bathymetry of the BEM. The East Ceará and Potiguar basins are delimited by thin black continuous line. The track chart of seismic grid is black lines. Red line is a segment of a strike seismic line showed in figure 1b. Sediment calibration with industry drillholes was discussed by Fonseca et al. (2024). Swarms of dikes (After Macêdo Filho et al., 2023) intruded the continental crust during the early rift phases (Hollanda et al, 2019; Macêdo Filho et al., 2023). **b)** Section of seismic line 6100 below the continental shelf (modified from submitted paper Fonseca et al., 2025). Red, black and green dots indicate the Moho, top basement and top synrift respectively. Basement is shaded gray and synrift deposits shaded green. The Segment Boundary 2 represents an abrupt lateral change in basement and synrift thicknesses where the Fortaleza High is cut by steep faults thinning basement from >20 to <15 km thick. The Northern Segment presents thinner basement covered by ~3-5 km thick synrift sediment with rotated strata.

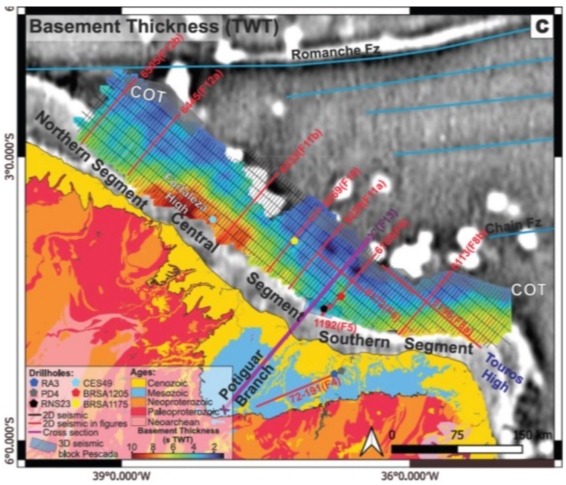

Figure 2- Map color coded from the basement thickness map in TWT (from Fonseca et al., 2024). Basement structure allows to define the margin has a Southern, a Central and a Northern Segment. The maps have overlaid the seismic tracks as black lines. Red lines are discussed in Fonseca et al., 2024. Blue lines are ocean fracture zones interpreted from the vertical gravity gradient data (VGG) Sandwell et al., 2014.

Conclusions

Maps of basement thickness, synrift deposits distribution and Moho depth support that BEM along Potiguar- East Ceará was segmented during rifting. The three segments evolved with different tectonic styles. Each segment is limited by abrupt structural changes which indicates the changes are controlled by tectonics. These boundaries, when plotted in map view, form linear continuous structures indicating the beginning and propagation of the segmentation and flow lines for the opening. The distribution of faults, dike swarms and the geometry of segment boundaries produce information on the evolution of the orientation of local and regional stresses and in therefore in the opening direction documenting a scenario of changing kinematics. We propose that it was the gradual rotation of the main stress orientation that caused the readjustment of the deformation of the continental lithosphere into segmented domains of distinct deformation.

Acknowledgments

We acknowledge the Brazilian National Agency of Petroleum, Natural Gas and Biofuels (ANP) for providing the dataset. We also express our gratitude to the Instituto Nacional de Ciência e Tecnologia do Atlântico (INCT-Atlântico), supported by CNPq, FAPERGS, and CAPES, for funding the research grant of J.F. and for providing the infrastructure necessary for the development of this project. We are grateful to the Graduate Program in Geodynamics and Geophysics (PPGG) at the Federal University of Rio Grande do Norte , as well as the GGEMMA laboratory, for their support in preparing the project and for their collaboration with technical support during the seismic interpretation. We also acknowledge Schlumberger for the Petrel E&P Software academic institutional license. We thank HIS for providing the Kingdom Suite software through an academic institutional license. We also extend our appreciation to the Barcelona Center for Subsurface Imaging (CSI) at the Marine Sciences Institute (ICM), where part of this research was conducted.

References

Aslanian, D., Gallais, F., Afilhado, A., Schnurle, P., Moulin, M., Evain, M., et al. (2021). Deep structure of the Para-Maranhao/Barreirinhas passive margin in the equatorial Atlantic (NE Brazil). *Journal of South American Earth Sciences*, *110*, 103322. https://doi.org/10.1016/j.jsames.2021.103322

Fonseca, J. C., Ranero, C. R., Vannucchi, P., Iacopini, D., & Vital, H. (2025). Tectonic segmentation of the Brazilian Equatorial Margin rift. Submitted to Journal of Geophysical Research: Solid Earth.

Fonseca, J. C., Ranero, C. R., Vannucchi, P., Iacopini, D., & Vital, H. (2024). The tectonic structure and evolution of the Potiguar-Ceará rifted margin of Brazil. Tectonics, 43, https://doi.org/10.1029/2023TC008184

Heine, C., Zoethout, J., & Müller, R. D.: (2014) Kinematics of the South Atlantic rift, Solid Earth, 4, 215–253, https://doi.org/10.5194/se-4-215-2013, 2013.

Hollanda, M. H. B. M., Archanjo, C. J., Macêdo Filho, A. A., Fossen, H., Ernst, R. E., de Castro, D. L., et al. (2019a). The Mesozoic Equatorial Atlantic Magmatic Province (EQUAMP). In R. K. Srivastava, R. E. Ernst, & P. Peng (Eds.), *Dyke Swarms of the World: A Modern Perspective* (pp. 87–110). Springer. https://doi.org/10.1007/978-981-13-1666-1

Macêdo Filho, A. A., Hollanda, M. H. B. M., Fraser, S., Oliveira, A. L., Melo, A. C. C., & Dantas, A. R. (2023). Correlations among large igneous provinces related to the West Gondwana breakup: A geochemical database reappraisal of Early Cretaceous plumbing systems. *Geoscience Frontiers*, *14*, 1–26. https://doi.org/10.1016/j.gsf.2022.101479

Matos, R. D. (1999). History of the northeast Brazilian rift system: Kinematic implications for the break-up between Brazil and West Africa. Geological Society, London, Special Publications, 153(1), 55–73. https://doi.org/10.1144/GSL.SP.1999.153.01.04

Moulin, M., Aslanian, D., & Unternehr, P. (2010). A new starting point for the South and Equatorial Atlantic Ocean. Earth-Science Reviews, 98(1–2), 1–37. https://doi.org/10.1016/j.earscirev.2009.08.001

Wilson, J. (1965). A New Class of Faults and their Bearing on Continental Drift. Nature, 207, 343-347. https://doi.org/10.1038/207343a0

Sandwell, D. T., Müller, R. D., Smith, W. H. F., Garcia, E., & Francis, R. (2014). New global marine gravity model from Cryo-Sat-2 and jason-1 reveals buried tectonic structure. Science, 346(6205), 65–67. https://doi.org/10.1126/science.1258213

Szatmari., P. & Milani., E. J. (2016) Tectonic control of the oil-rich large igneous-carbonate-salt province of the South Atlantic rift. Marine and Petroleum Geology, 77, 567-596. https://doi.org/10.1016/j.marpetgeo.2016.06.004.