Early Cretaceous deepwater rifts of the Camamu-Almada Basin of northeastern Brazil and their implications for the distribution of deepwater source and reservoir rocks

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Summary:
The Cretaceous Camamu-Almada rifted-passive margin occupies some 25,000 km^2—an area roughly the size of the New Jersey—along the Atlantic coastline of the state of Bahia in northeastern Brazil. Commercial hydrocarbon deposits have been discovered along the continental shelf; however, the deepwater zones of the Camamu-Almada basin remain largely untested by the drill bit.

A dataset acquired in 2012 and reprocessed in 2014 includes 17,840 kilometers of post-stack depth-migrated 2D seismic in a 118-line grid. These data allow for a high-resolution correlation of major rifts and tectonostratigraphy across the deepwater area of the Camamu-Almada basin. This study follow previous mapping studies of the same area by Brandão et al. (2021) and Vidigal-Souza et al. (2020). This study and those prior have identified a 150 kilometer-wide zone of complexly patterned normal faults bounding rifts of Valaginian to Aptian age.

This syn-rift section hosts established source-reservoir rock pairs, such as those previously described from the Morro Do Barro formation (Gonçalves et al., 2000). The results of this study support significant hydrocarbon resource potential in the deepwater area based on the distribution of these sediment-filled rifts.

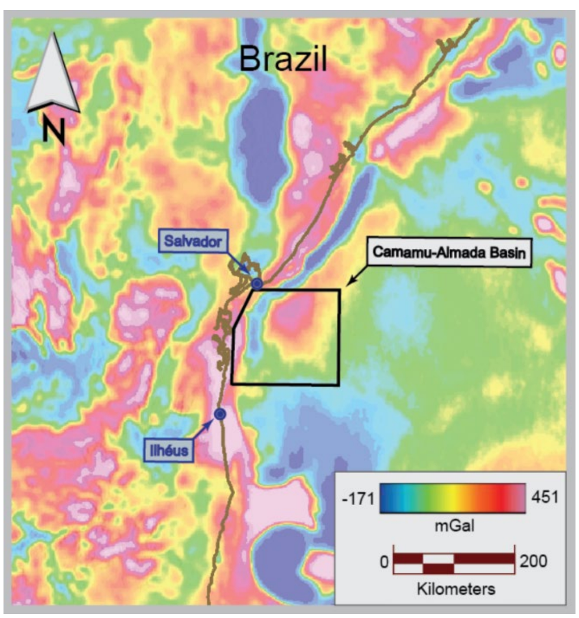

Figure 1. Free-air gravity plotted on regional location map of this study with the box showing the location of the study area in the Camamu-Almada basin.

Introduction:
The success of pre-salt hydrocarbon plays in southern Brazil has inspired both Brazilian and international exploration and production companies to renew exploration efforts in the rifted-passive margin of northeastern Brazil that extends well north of the productive, pre-salt plays of southern Brazil. For example, in the Sergipe-Alagoas, an Exxon-led consortium is currently drilling a deepwater exploration well. With this increased level of interest in the northeastern Brazilian margin, this study focused on the Camamu-Almada, located directly south of the Sergipe-Alagoas basin.

Geologic setting
The Camamu-Almada basin is a rifted-passive margin with a sedimentary record beginning with the latest Jurassic (Tithonian) Sergi Formation (Beglinger et al., 2012). The opening of the Southern Atlantic Ocean began with the breakup of the Paleozoic Gondwana super-continent in the early Cretaceous. Propagating northward from southernmost Argentina, active rifting progressively separated the continents of South America and Africa and formed the present-day South Atlantic Ocean (Aslanian et al., 2009).

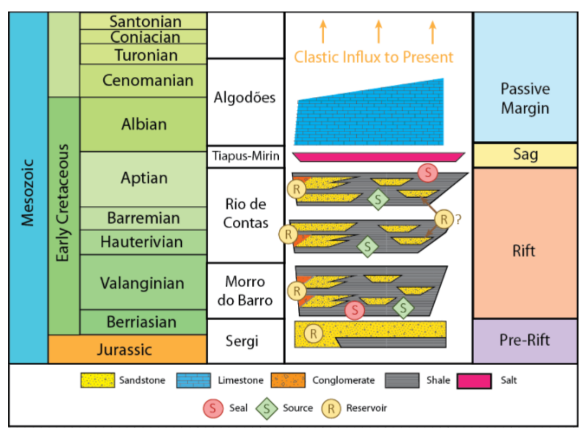

Fig. 2 – Stratigraphic chart showing the major formations of the Mesozoic petroleum system and their tectonic setting.

When the tip of rifting reached the Camamu-Almada area in the Neocomian (Caixeta et al., 2012), fluvial and dryland continental sedimentary rocks of the late Jurassic Sergi formation overlaid Precambrian crystalline basement (Gordon et al., 2013). Normal faults split and rotated Sergi Formation-capped basement blocks, and created half-graben which accumulated organic-rich fresh to brackish water lacustrine deposits of the Morro do Barro and Rio de

Contas Formations with the latter formation extending further basinward into the present-day deepwater area (Netto et., 1994) (Fig. 4).

Syn-rift lacustrine deposits of the Morro do Barro Formation are the primary source of oil and gas fields on the continental shelf and may also charge deepwater reservoirs deposited in similar rift settings as described from areas of shallow water oil production (Scotchman and Chiossi, 2009). The rifts that contain the Morro do Barro(!) petroleum system includes both the lacustrine source rocks and associated sandstone reservoirs of the same age (Barremian-Aptian). The overlying Rio de Contas Formation, the uppermost syn-rift interval, also contains rich source rocks with total organic carbon values of 1.7-7.6 percent by weight and hydrogen index values of 360-726. (Gonçalves et al., 2000). By the Aptian-Albian, rifting ended with the onset of oceanic crust emplacement in a distal setting east of the rifts with a shift towards carbonate deposition (Figures 2, 3).

Methods:

IHS Kingdom Suite ®, 2019, was used for seismic interpretation. For well data, Geopost Energy® provided access to a GIS database with well locations and header information. Structural and stratigraphic analysis of seismic data followed well-established workflows for identifying uniformities, reflector truncations, and reflector offsets. Reflector geometries were important for correlating syn-rift graben-filling packages. Regionally extensive normal faults (Figure 4) were traced in map view using fault pick grouping based on plane continuity verifiable with real-world geological models.

Results:

Fault traces

The study generated maps across the top of acoustic basement and traced the extensional faults which deformed this surface during the rift tectonic phase of the Camamu-Almada basin. The syn-rift megasequence—which reaches thicknesses of over 1,750 meters in deepwater regimes (3,300 meters nearshore – Romito et al., 2021) —was well-imaged and present in deepwater zones that remain untested by drilling (Figure 5). The distribution and thickness of syn-rift sediments were mapped on a regional scale (Figure 3). Syn-rift sediments are present as far as 145 kilometers basinward of the coastline in the central area of the basin (Figure 3).

Fault trace patterns show a significant increase in complexity moving south from the Camamu sub-basin, across the Itacaré high and into the Almada sub-basin (Figure 3). The offsets on regional normal faults decrease in the basinward direction (Figure 4). The southern Alamada sub-basin also has a greater number of large-offset antithetic faults, most of which connect to a master synthetic fault to form a full graben (Figure 3) Some rifts are isolated and form depocenters containing up to 800 meters of syn-rift deposits (Figure 3).

Charge fairway

The southern half of the Camamu sub-basin hosts three of the largest oil and gas fields on the continental shelf (Manti Field – 17 BMm^3 GIP, Pinauna Field – 10.8 MMm^3 OIP, and Sardinha Field - 12 MMm^3 OIP 5.4 BMm^3 GIP) (add ref). The fields are adjacent to the area of the basin with the widest margin of hyperextended continental crust (Figure 3). This fairway of wide hyperextended continental crust—adjacent and seaward of the shelf oil and gas fields also hosts the thickest deposits of syn-rift strata contained with full grabens and half-grabens bounded by large-offset normal faults. This apparent charge fairway (Figure 3) extends from the shoreline to water depths over 3,000 meters and abuts the LoCC (limit of continental crust – Romito et al., 2021) (Figure 3).

Application of this study to deepwater exploration

Sweet-spots favorable for charging commercially-viable hydrocarbon deposits are present in the deepwater area of the Camamu Basin (Figure 3). Generally, these sweetspots are located within full grabens and half-grabens that developed during the active rifting phase (Figures 3, 4, 5). Given the proven charge potential of syn-rift source rocks (Morro do Barro(!) petroleum system - Gonçalves et al., 2000) the results of this study support the presence of an active petroleum system outboard of the current deepest water wells. This proposed petroleum system is likely capable of charging hydrocarbon accumulations in pre-rift and syn-rift sandstone reservoirs as well as those present in the overlying sag and passive margin megasequences (Figs. 4, 5).

Conclusions:

The deepwater regime of the Camamu-Almada basin of northeast Brazil has dozens of basement-intersecting normal faults traceable at basin-scale which exert first-order control on the thickness and distribution of syn-rift megasequence strata. Mapping the faults that bound rift structures such as half grabens shows the likely location of a fairway of higher syn-rift (Figure 3) source rock thickness and thus higher charge potential for both syn-rift and passive margin reservoir units (Figures 4, 5).

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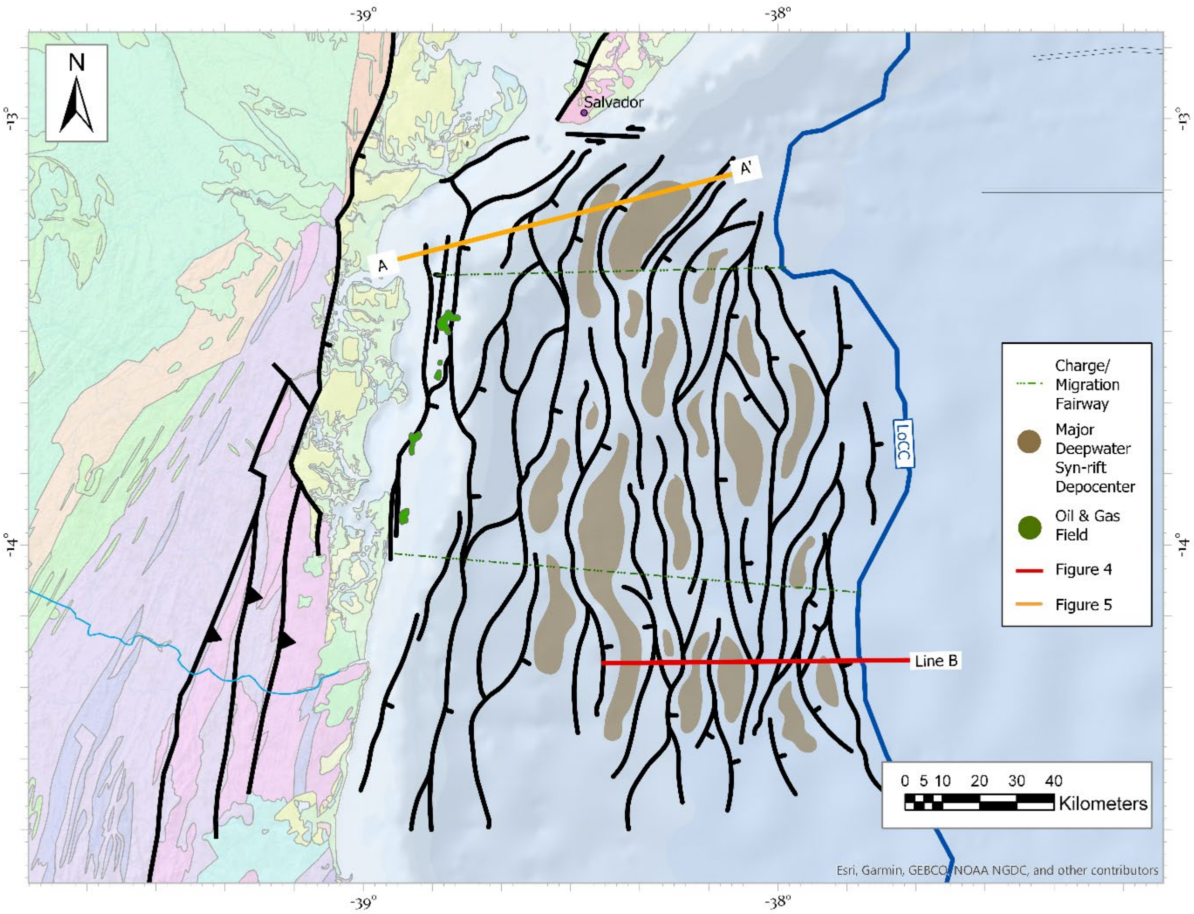

Figure 3. Pattern of normal faults bounding half-grabens and full grabens that host thick sections of syn-rift strata interpreted from a grid of TGS seismic data for the deep-water area and from compilation of previous studies by Gonçalves et al., (2000); Romito et al., (2021); and Vidigal-Souza et al. (2020) in the onland and coastal areas. Green polygons in the nearshore area are illustrated reservoirs of the shelf oil and gas trend featuring fields such as the Manati. This productive area occupies the horst block seen on the cross section from Gonçalves et al., (2000) shown in Figure 5. The interpretation is the source of these oils are lacustrine shale of the Berriasian-Valangian Morro do Barro Formation and Rio de Contas Formation that were deposited in the rift east of this elevated block.

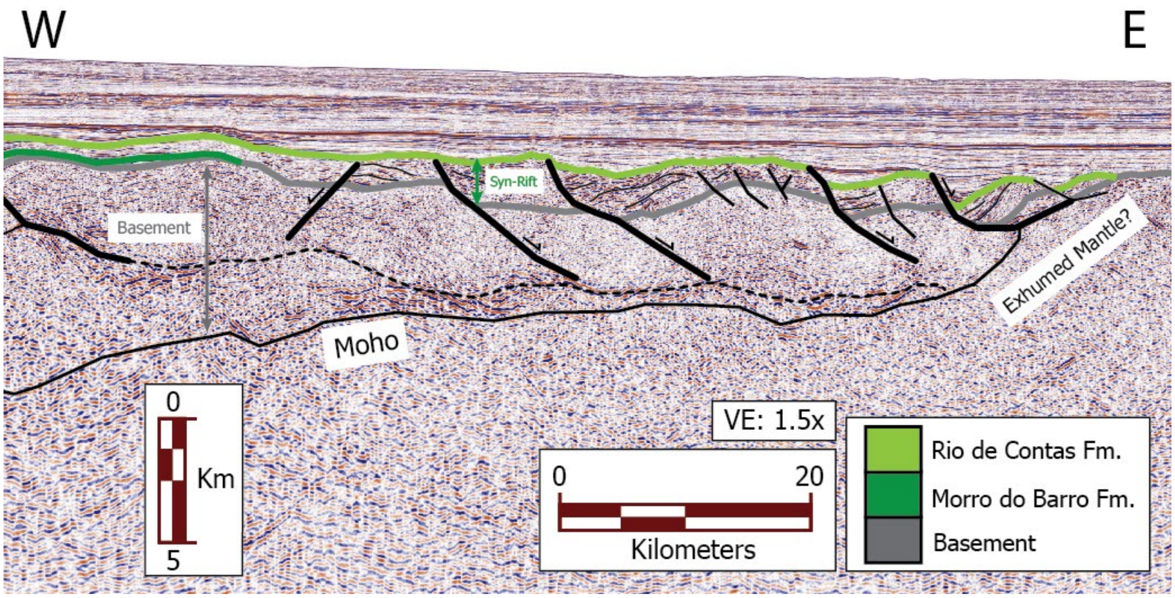

Figure 4. Deep-penetration seismic line B modified from Romito et al. (2021) and located on the map of the Almada sub-basin shown in Figure 3. The section shows the Moho, extended continental basement, the pre-rift section (Latest Jurassic (Tithonian) Sergi Formation), the syn-rift section (Berriasian-Aptian Morro do Barro and Rio de Contas Formations), and overlying sag and passive margin units of Cretaceous and Cenozoic ages. Romito et al. (2021) proposed a small area of exhumed mantle seen on the eastern side of the above line.

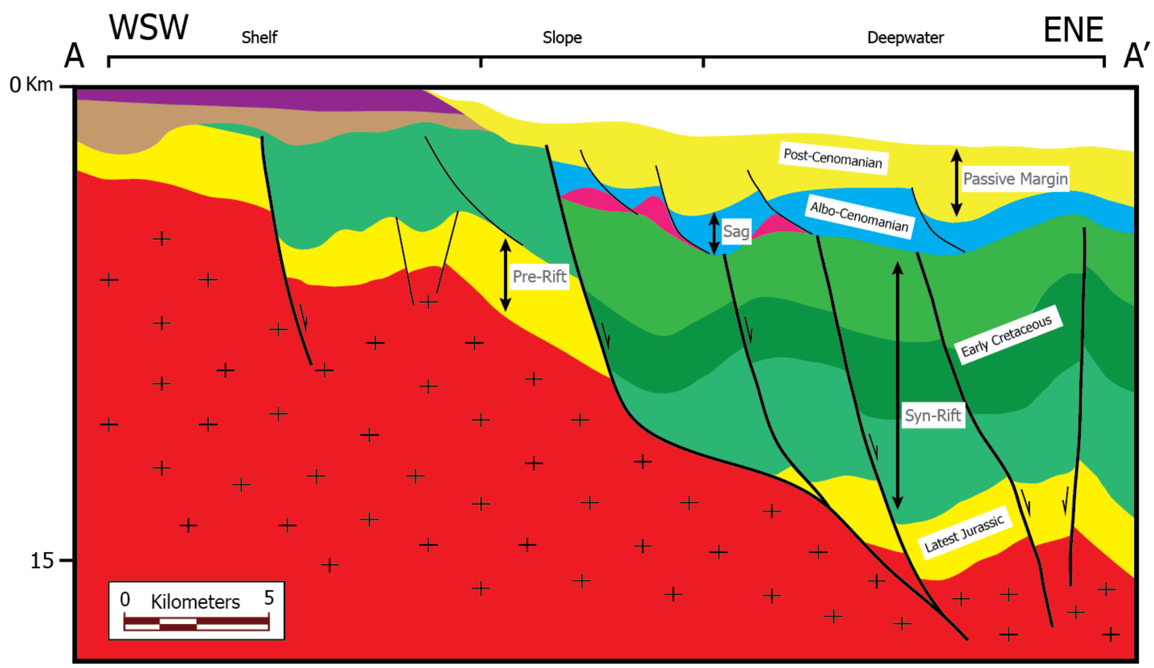

Figure 5. Cross-section based on a seismic line of the shelf-to-deepwater transition in the Camamu sub-basin modified from Scotchman and Chiossi (2009). Key formations include the following: 1) Precambrian basement shown in red; 2) pre-rift section (Latest Jurassic (Tithonian) Sergi Formation) shown in yellow; 3) the syn-rift section in light and dark green (Berriasian-Aptian Morro do Barro and Rio de Contas Formations); and 4) the overlying sag and passive margin units of Cretaceous and Cenozoic ages in red, blue, yellow, brown and purple. Coastal production of oil in the coastal zone of the Camamu basin is likely charged by upward migration from oil-prone lacustrine shale in the syn-rift section. We propose that this same petroleum system may be present in the broad fairway shown on the map in Figure 3.

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