Introduction

The deepwater region of the Pará Maranhão Basin is considered underexplored but early analyses of high-quality 2D seismic surveys (Fig. 1) indicated that it likely holds significant hydrocarbon potential. Shallow water exploration results confirmed two working petroleum systems in the basin (exhausted oil field PAS-9/11 and sub-commercial oil well MAS-5)(Opdyke, S. and Balabekov, Y., 2018). The presence of source rock intervals across the neighboring equatorial basins in Brazil has also been confirmed. Recent deepwater oil discoveries in Ceará (Pecém) and Potiguar (Pitú and Anhangá) Basins targeted passive margin sedimentary units and illustrated deeper functioning petroleum systems in the region (Agência Petrobras, 2024). The northern continuation of the Equatorial Margin into Guyana and Suriname revealed to the world fantastic discoveries that are nowadays producing close to 1 MMbopd. The conjugate margin of Equatorial West Africa (Ghana and Ivory Coast) hosts a number of deepwater, stratigraphic trap discoveries that are analogous to the emerging play targets in Equatorial Brazil. This assessment is focused on the crustal nuances, volcanic structures and drift phase sedimentary units of the Pará-Maranhão Basin.

The Pará-Maranhão Basin of the Equatorial Atlantic Ocean is located between the Foz do Amazonas and Barreirinhas Basins of Brazil. This offshore basin covers approximately 100,000 km^2 and has a range of water depths of 100 m to greater than 4,000 m, with the majority being greater than 1,500 m. The Harpia well (aka PAS-027) drilled in 2011 is the single well in the deepwater region of this basin. The well was drilled in 2,060 m of water and reached a total depth of 5,690 m (location in Fig. 1). The well's bottom target penetrated allochthonous Miocene carbonate debris with shows of oil. Since the results of this wildcat were announced, no other deep water Pará-Maranhão wells have been drilled, despite evidence of a functioning petroleum kitchen.

Data and Methods

In this study we use ~19,400 km^2 of recently acquired, preliminary processing from the PAMA 3D seismic volume (Fig 1) and calculated seismic attributes to assess key features within the basin. Imaging of key Cretaceous units requires a robust seismic velocity model achievable with modern DM-FWI (Dynamic Matching-Full Waveform Inversion) 3D processing algorithms.

Observations and Discussion

Early Equatorial Atlantic oceanic crust formed along margin segments at centers of pull-apart basins and underlies the area of interest (AOI) and the interpreted 3D volume. The Saint Paul Fracture Zone (SPFZ) also intersects the AOI (Fig 1). Oceanic crust north of the fracture zone is an average of 5.25 km-thick and dips to the northwest in a flexural response to the sedimentary loading of the Amazon Cone. Localized flexure is present in locations with significant igneous overburden (Fig 2). The fracture zone itself is highly structured and observed to be composed of both reverse and normal faults (Fig 2). The oceanic crust to the southeast of the fracture zone is heavily intruded with igneous features.

The early basin evolution of the region took place during the Cretaceous Magnetic Quiet Zone (CMQZ) (121-83 Ma) (Ogg, 2012). Newly acquired magnetic data are heavily overprinted with anomalies related to post-rift volcanism in the area (Fig 1). Seismic data reveals evidence of extensive intrusive volcanism (Fig 2). The timing for these is variable and range from Albian to Miocene. Magnetic data confirms contrasting magnetic pole orientations present during various intrusive/extrusive igneous events across the AOI (Figs 1& 2). These varied magnetic signatures support the interpretation of multiple phases of intrusive/extrusive magmatic events in the basin. Most importantly, in all cases these volcanic features-imposed controls on post-volcanism depositional fairways.

Structural features in the AOI range in scale from interbed polygonal faulting, mass-transport systems and complex gravitational fold and thrust belts (FTB) (Fig 2). The ages of two FTBs within the study area are from the Santonian and Miocene (Fig 1). The Santonian FTB is present in the southeastern region of the AOI (Fig 1) while the Miocene FTB overlies the earlier structures and is present along a proximal strike position in the study area (Fig 1). The FTBs cover areas of ~1,500 km^2 and ~4,900 km^2, respectively. In these features, we observe significant structuration owing to periods of shelf-positioned stratigraphic aggradation and epeirogenic-scale tectonic events. From a more regional perspective, a thrust fault related to the SPFZ remained active during the Paleogene and exerted control on depositional systems in the area.

Within the AOI, thick post-rift passive margin phase sedimentary units are interpreted to be composed of deepwater deposits from the Albian to present, reaching maximum thickness of approximately 8 km (Fig 2). Cretaceous-Oligocene units contain seismic facies indicative of channels, lobes, mass-transport complexes and turbidite deposits (Fig 3). Figure 3a shows a well-defined Late Cretaceous channel in calculated Trace Envelope Attribute and an unattached distal located lobe. Figure 3b highlights an updip Oligocene channel (Trace Envelope Attribute) controlled by volcanic bathymetry that expands to a large fan reworked by sediment waves. An amplitude map of a SW-NE-oriented deep water turbidite system (channel and downdip fan) is shown in Figure 3c, which also illustrates the reservoir potential beyond the 3D volume's coverage. The recently acquired PAMA 3D volume has also effectively imaged potential carbonate build-ups on the numerous volcanic highs (Fig 3D) in the basin. The scenario is analogous to Exxon's Ranger discovery in Guyana. As imaging progresses, we expect to better discern between carbonate build-ups and lava deltas on the tops of the volcanic highs.

Exploration efforts have revealed two petroleum systems in the region. The most important, that source the discoveries in Guyana/Suriname and Ghana/Ivory Coast has as source rocks, Cenomanian and Turonian organic-rich shales. Shelf-positioned wells and the Harpia discovery (oil shows) confirmed this functioning petroleum system in the Pará-Maranhão Basin as having been sourced from these source intervals. Well data and newly acquired 3D seismic data brings resolution to seismic facies that further support both source and reservoir deposition (Figs 2 & 3a-c), while seismic amplitude anomalies with AVO response support the presence of oil and gas.

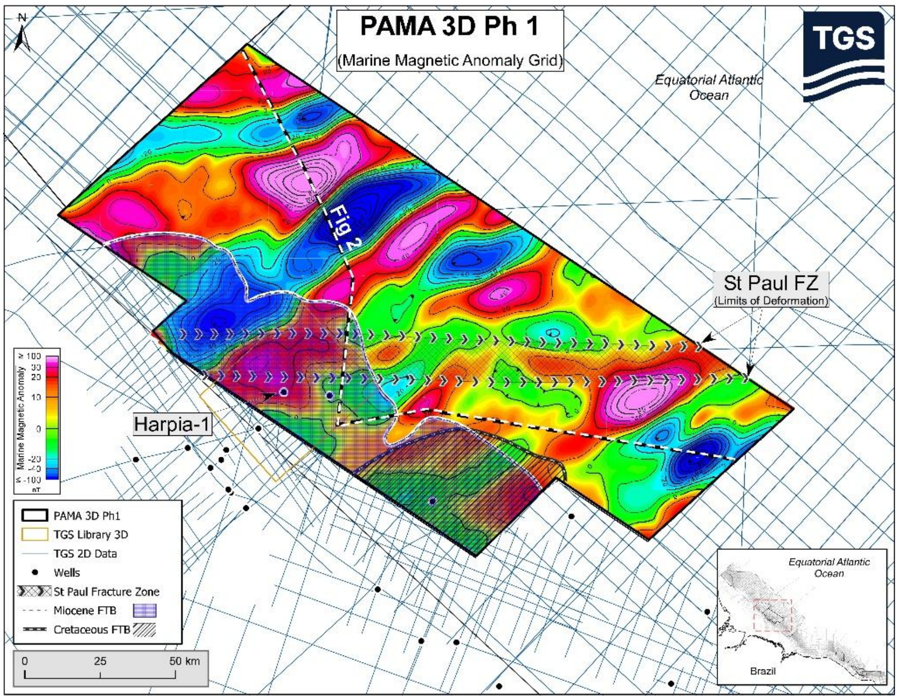

Figure 1: Location map of PAMA 3D survey with acquired magnetic anomaly grid with regional 2D data and wells. Two fold-and-thrust belts are (Miocene and Cretaceous) located in the southwest portion of the study area and the location of the St. Paul Fracture Zone is highlighted. Arbitrary line location for Figure 2 is located with the dashed black and white line.

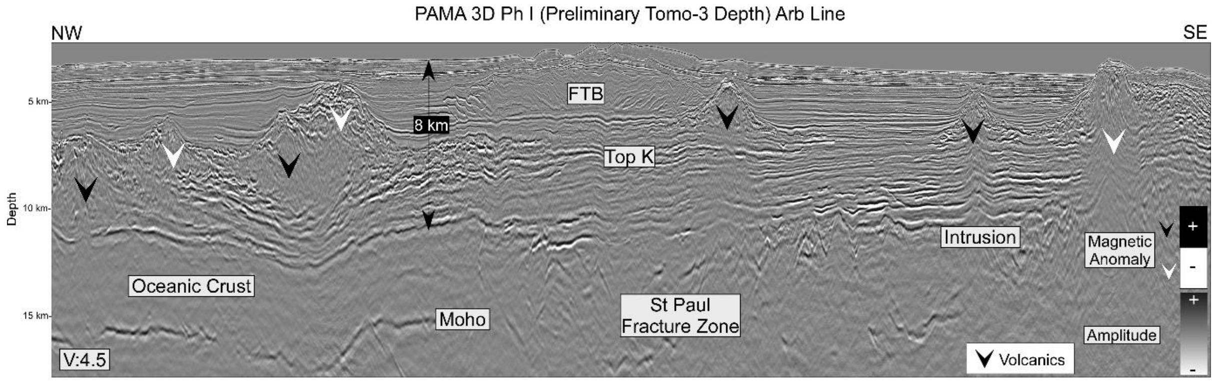

Figure 2: Preliminary depth-migrated seismic section is an arbitrary line across the PAMA 3D (Location on Fig 1). Key features are labeled showing the deformation of oceanic crust, the St Paul Fracture Zone, overlying volcanics and the Miocene fold and thrust belt. Contrasting magnetic anomalies of volcanic features are labeled with “V’s” where black is positive and white is negative.

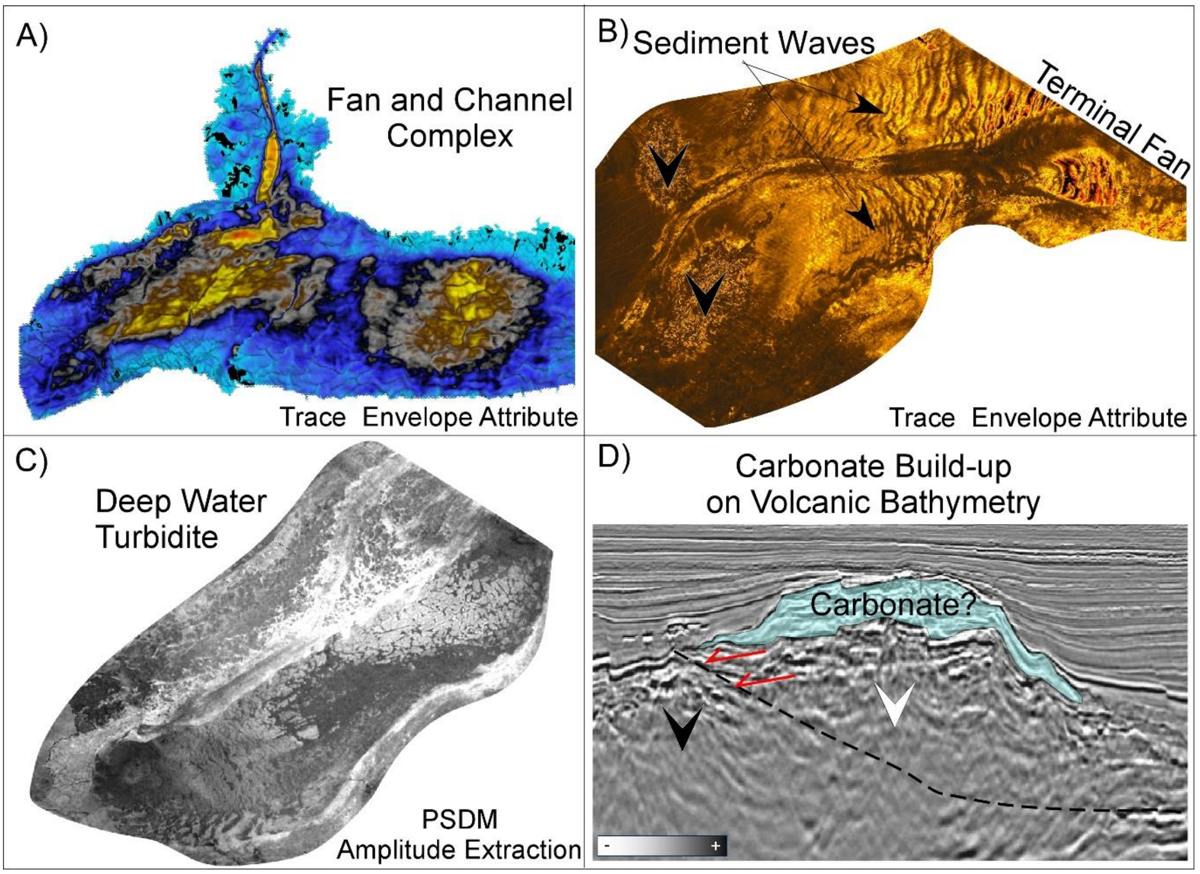

Figure 3: Examples A-C highlight prospective stratigraphic features within the PAMA 3D survey where A is a Late Cretaceous example and B/C are Early Tertiary depositional examples. D shows a potential carbonate build-up on the top of a volcanic structure.

Conclusions

In summary, details of the deepwater region of under-explored Pará-Maranhão are now better observed with modern 3D seismic data. Stratigraphic and structural details can more accurately be tied into the regional framework of Brazil's Equatorial Margin, and the understanding of the basin's prospectivity is greatly improved.

References

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