Enhanced 3D seismic data utilized for attribute-assisted interpretation and seismic facies classification of deepwater channel complexes in the Icaraí sub-basin, Equatorial Margin

Miguel R. Cavalcante de Morais[1], Ian C. de Oliveira Souza [1], Narelle Maia de Almeida[1,2,3], Ana Clara B. de Souza[1,2,] Francisco Vitor M. Lopes[1,2]; Karen M. Leopoldino Oliveira [1,2,3]

[1]Grupo de Inovação e Pesquisa em Energias e Recursos Minerais (GIPEM)/Universidade Federal do Ceará (UFC);
[2]Laboratório de Geologia e Geofísica Marinha e Aplicada à Energia (LGMA)/Universidade Federal do Ceará (UFC);
[3]Instituto Nacional de Ciência e Tecnologia de Geofísica do Petróleo (INCT-GP/CNPq);

Abstract

The Ceará Basin, part of the Brazilian Equatorial Margin (BEM), originated from the breakup of Gondwana and is divided into the Mundaú, Icaraí, Acaraú, and Piauí-Camocim sub-basins. The BEM basins are considered promising targets. Recognizing the importance of seismic interpretation advancements, this research aims to map a channel system from the Albian to the Maastrichtian. Using seismic data from PGS and well data from the National Agency of Petroleum, Natural Gas, and Biofuels (ANP), the top and base of two channel systems were mapped with model grid. Seismic attributes were then generated and analyzed, and unsupervised machine learning classification was employed to enhance the interpretation. The study observed the evolution of the two channels from proximal to distal margin and their correspondence with energy variations, suggesting the presence of promising reservoirs due to inferred coarse sedimentation.

Introduction

The Brazilian Equatorial Margin (BEM) has attracted special attention in recent years from both the scientific community and the industry following the discovery of significant oil and gas reservoirs in its African counterpart, as well as in the offshore basins of Guyana, Suriname, and French Guiana (Huaicun 2014).

Due to this increased attention, it has been realized that the true potential of the basins comprising the BEM is still far from being fully quantified. Recognizing the rapid advancement of seismic interpretation and modern technologies improving data resolution and characterization, it is essential to utilize these data in the basins of this margin.

This study focuses on the evolution of a channel system originating from the Albian to the Maastrichtian (121 Ma to 72 Ma) during the drift phase of the Icaraí sub-basin, which has been relatively less studied compared to the Mundaú sub-basin. The aim is to develop a reservoir model focusing on channel geometry and connectivity, both stratigraphically controlled. Changes in internal patterns indicate variations in channel deposition or erosion (Payenberg et al., 2024). To describe this evolution more accurately, a hierarchical channel classification model by Bridge and Tye (2000) was used, distinguishing between proximal, intermediate, and distal areas.

Methodology

This study used a seismic volume covering 2700 km², acquired, processed, and provided by PGS. The processing flow included Full Wave Inversion (FWI) and depth migration, resulting in a volume with 4240 inlines and 2922 xlines.

Chronostratigraphic and facies information were obtained from the publicly available wells 1-BRSA-1150-CES and 1-BRSA-1114-CES, provided by the National Agency of Petroleum, Natural Gas, and Biofuels (ANP).

Surface mapping employed the model-grid technology of Paleoscan software, which merged seismic horizons based on wavelet similarity and relative distance. Seismic attributes such as RMS Amplitude, Sweetness, Sobel Similarity, GLCM Homogeneity, and spectral decomposition were applied for geomorphological interpretation. Following attribute analysis, unsupervised machine classification using Generative Topographic Mapping (GTM) via the AASPI software from the University of Oklahoma was conducted.

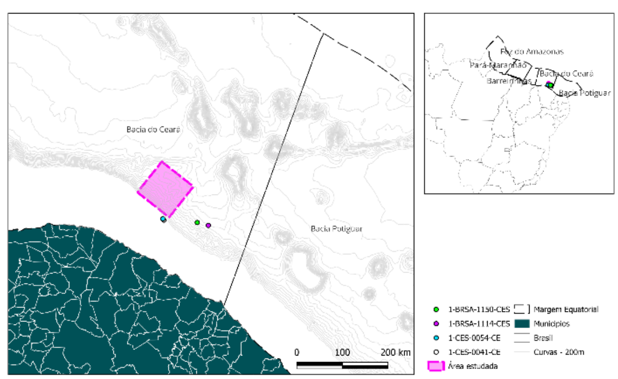

Figure 1 - Map depicting the location of the study area.

Results

From seismic interpretations, two surfaces representing the top and base of the channel system were generated. At the base (Figure 2), two channels were well-defined, initially separated by internal highs, gradually converging towards deeper regions, with a total width of approximately 10 km. Thus, the interpretation was divided into proximal, intermediate, and distal areas.

Following surface mapping, a Real Geological Time (RGT) model was generated. This method aided a better data interpretation, reducing uncertainties in mapping by correlating seismic data more effectively (Cubizzolle et al., 2021). In addition to mapping, this model allowed the identification of discontinuities.

Proximal area

Channel 01, oriented east-west in the southernmost part of the area, is deposited above Aptian folds. It has low sinuosity and a U-shaped morphology, indicating high energy and moderate excavation power near the base, resulting in onlap features. Levee-shaped seismic facies and laterally continuous reflectors, intersected by concave-shaped reflectors, are observed towards the top of the channel (Figure 2b).

Channel 02, also east-west, has a V-shaped morphology, indicating greater excavation power and energy than Channel 01. Near the base, south-to-north trending channels suggest a directional change. Levee features are present but less pronounced than in Channel 01. The channel transitions to a convex shape at the top, forming a topographic high, with continuous and concave reflectors indicating channel presence (Figure 2b).

Intermediate area

In the intermediate zone of the seismic data, Channel 01 features are more closed and present a pronounced U-shaped morphology. Excavation begins further north with evident concave reflectors. Levee features are absent. Reflectors briefly become more horizontal before returning to a concave shape, indicating energy changes, and end with horizontal reflectors and downlap terminations at the top (Figure 2c).

Channel 02 shows a different pattern here, starting with a U-shape instead of a V-shape, indicating energy loss. Reflectors quickly become horizontal, then form convex-shaped seismic facies, showing greater sediment deposition in the southern part of the channel, shifting southeast to join Channel 01. Levees appear concentrated to the southwest, likely due to a rapid change in the channel direction, with the channel extending about 4 km (Figure 2).

Distal Area

In the more distal area, the two channels converge losing their U or V shapes. This area is partially above the folds from the compressive event but is moving out of its influence. Three zones can be identified here: 1) The deeper zone, near the base, has nearly horizontalized concave reflectors; 2) A middle zone features with convex structures forming a dome, with downlap terminations to the north and unconformities to the south; 3) Near the top, a new channel erodes these features, likely formed after the Maastrichtian, extending beyond the studied area (Figure 2d).

Discussions and conclusions

The results show that the channels evolved differently as they moved away from the continental margin. Initially confined and erosive with high energy, both channels eventually open up, possibly forming fans and dispersing sediments eastward, which may lead to strong turbidite elements.

Based on the turbidite system classification by Reading and Richards (1994) and Dalrymple & James (2010), the area resembles a gravel-rich system with multiple sources. This is characterized by a dominant feeder system, stable channel length and width, and increased source area lifespan with reduced erosion. The seismic data shows horizontal reflectors indicating deposition, suggesting grain sizes from coarse sand to gravel. This configuration implies the potential for a promising hydrocarbon reservoir.

However, it is noted that the channel receives a new influx of energy when the channels above begin to appear, but they are smaller in size and lifespan, with a rapid transition to a depositional system, in all described areas. The evolutionary configuration resembles that described by Payenberg et al. (2024), classifying channel evolution systems, and evolving into a valley system, where there is deposition and channel construction that appears to be in a V-shape.

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References

BRIDGE, J. S., & TYE, R. S. (2000). **Interpreting the dimensions of ancient fluvial channel bars, channels, and channel belts from wireline logs and cores**. AAPG Bulletin, 84(8), 1205-1228

CUBIZOLLE, F.; DAYNAC, N.; LACAZE, S. **From Seismic Interpretation to Property Filled Gridding Using the Relative Geological Model**. In: 82nd EAGE Annual Conference & Exhibition. Amsterdam, The Netherlands, European Association of Geoscientists & Engineers, 2021, p. 1–5

DALRYMPLE, Robert Walker; JAMES, Noel P. **Facies models 4**. St. John's: Geological Association of Canada, 2010. (GEOtext, 6).

HUAICUN, J. 2014. **Progress and revelation of exploration of large oil and gas fields around the globe**. Science and Technology Review, 32,76–83.

PAYENBERG, T.H.D.; WILLIS, B.J.; SIXSMITH, P.; et al. **Quantification and classification of a giant fluvial-distributive system - the Triassic Mungaroo Formation, NWS, Australia.** Earth-Science Reviews, v. 249, p. 104676, 2024.

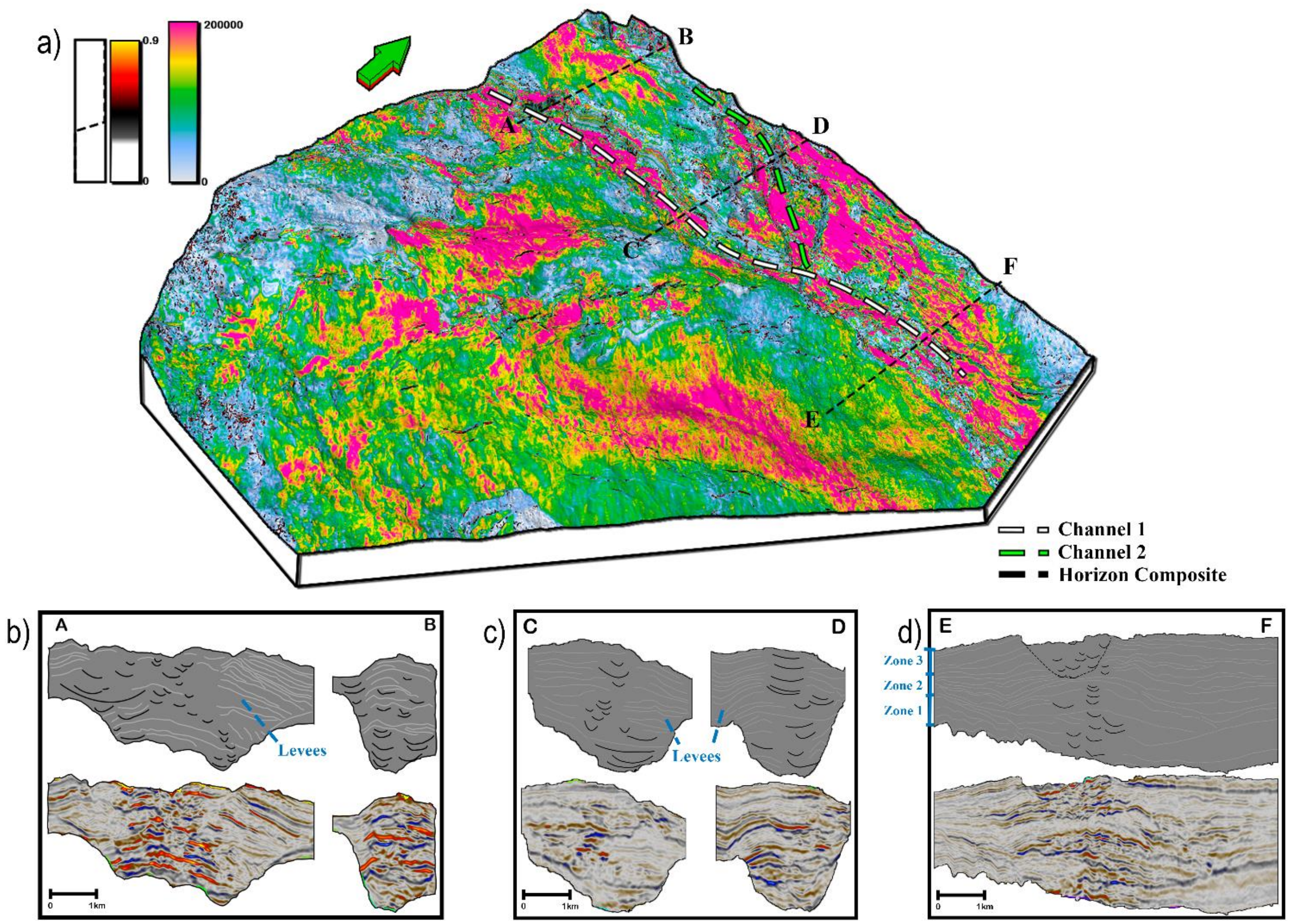

Figure 2 - a) 3D model of the base of the channel system, with three seismic lines perpendicular to the channel direction. Channel 1 is on the left (white), and Channel 2 is on the right (green). The RMS amplitude + Variance attributes were applied for a better visualization; b) A-B cross-section of proximal area, presenting levees. Channels are represented in black; c) C-D cross-section of intermediate area; d) E-F cross-section of distal area.