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Seismic geomorphology and evolution of Miocene Turbidite Systems in the Albacora East Field (Campos Basin)

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Abstract

The Campos Basin, situated along the southeastern Brazilian continental margin, is characterized by extensive deep-water turbidite systems influenced by salt tectonics and gravitational processes. Within this context, the Albacora Leste Field hosts Oligocene–Miocene turbidite reservoirs primarily composed of sandstones from the Carapebus Formation. This study aims to investigate the geomorphological evolution and depositional architecture of the Miocene turbidite deposits found in the Albacora Leste Field through the interpretation of a high-resolution 3D seismic volume and spectral decomposition analysis. Spectral decomposition was performed using three frequency components (16, 36, and 57 Hz), enhancing channel and lobe geometries at different stratigraphic levels. Four stratal slices were analyzed between the Marco Azul and Intra-Middle Miocene horizons, revealing the temporal evolution of depositional features such as channel migration, abandonment, and lobe progradation. The results indicate a progressive infill of the northern and southern channels by sand, followed by a shift of the main depocenter toward the northwest during the youngest interval, coinciding with a decrease in system energy. The integration of frequency responses and geomorphological patterns allowed for the identification of key depositional elements and a better understanding of the temporal evolution of this turbidite system.

Introduction

The Albacora Leste Field is part of the Campos Basin, located in southeastern Brazil between the states of Espírito Santo and Rio de Janeiro (Fig. 1 A). It lies within the drift megasequence of the Campos Basin (Winter et al., 2007). The main reservoirs are associated with post-salt Oligocene–Miocene turbidite deposits of the Carapebus Formation. The accumulations occur in a depocenter situated in an intraslope basin, which is controlled by salt structures and alternating tectonic regimes of extension and compression (Lemos et al., 2006; Casagrande, 2022). The main Miocene reservoirs, named AB-140 (Fig. 1 D) and AB-210 (Fig. 1 C), are characterized by extensive turbidite lobes and channels influenced by halokinesis (Casagrande, 2022).

The architectural development of these turbidite systems is closely linked to the dynamic evolution of channels and lobes deposited over time. Thus, the geomorphological and stratigraphic analysis of key Miocene intervals is essential for understanding the mechanisms of sediment transport and accumulation in this sector of the basin. In this study, based on high-resolution 3D seismic data and the application of the spectral decomposition attribute, we identified and interpreted depositional features at different stratigraphic levels. The main objective was to outline the temporal evolution of the Miocene turbidite complex in Albacora Leste, through the analysis of stratal slices extracted between the Marco Azul and Middle Intra-Miocene horizons, highlighting the identification of channel and lobe geometries and their migration patterns.

Dataset and methods

The methodology applied in this study is based on the interpretation of a 3D seismic volume, supplemented by data from 20 wells used to support stratigraphic correlation and calibrate the seismic response. PRIO acquired the seismic data in 2023 and processed them using Kirchhoff Pre-Stack Depth Migration (KPSDM). It is a high-quality volume, with a vertical seismic resolution of approximately 19.7 meters in the area of interest of the Albacora Leste reservoirs.

Initially, we mapped the following stratigraphic surfaces: base of salt, Marco Azul, base of the AB-140 reservoir, and the Intra-Middle Miocene. Based on this, we used the stratal slicing method for the analysis focused on the Miocene turbidite complexes, which consists of a proportional and linear slicing between two horizons. This procedure was applied to adjust variations in strata thickness, improve visualization, and extract horizons representing genetic depositional units on a relative geologic-time scale (Zeng, 2010). The methodology was implemented in Python, resulting in the extraction of 18 stratal horizons between the Marco Azul horizon (base) and the Intra-Middle Miocene horizon (top). Of these, only four were selected for detailed analysis in this study: Stratal A representing the AB-210 reservoir, Stratal B representing the base of the AB-140 reservoir, Stratal C corresponding to the top of AB-140, and Stratal D representing the base of the AB-120 reservoir (Fig. 1B).

To characterize the geomorphology of the depositional system, we generated attributes from spectral decomposition to delineate turbidite channels and identify the primary sandy depositional system. Spectral decomposition is an effective tool for interpreting channelized features, faults, lateral lithological variations, and depositional environments (Chopra & Marfurt, 2007; Oliveira, 2024). According to Partyka et al. (1999), lateral frequency variations reflect changes in stratal thickness and lithological properties. Based on this, the seismic cube was decomposed into three components (16, 36, and 57 Hz) using the continuous wavelet transform (CWT) method, which decomposes the seismic volume into phase and magnitude components across different frequency samples, enhancing temporal and vertical resolution, and allowing geological interpretation at multiple scales.

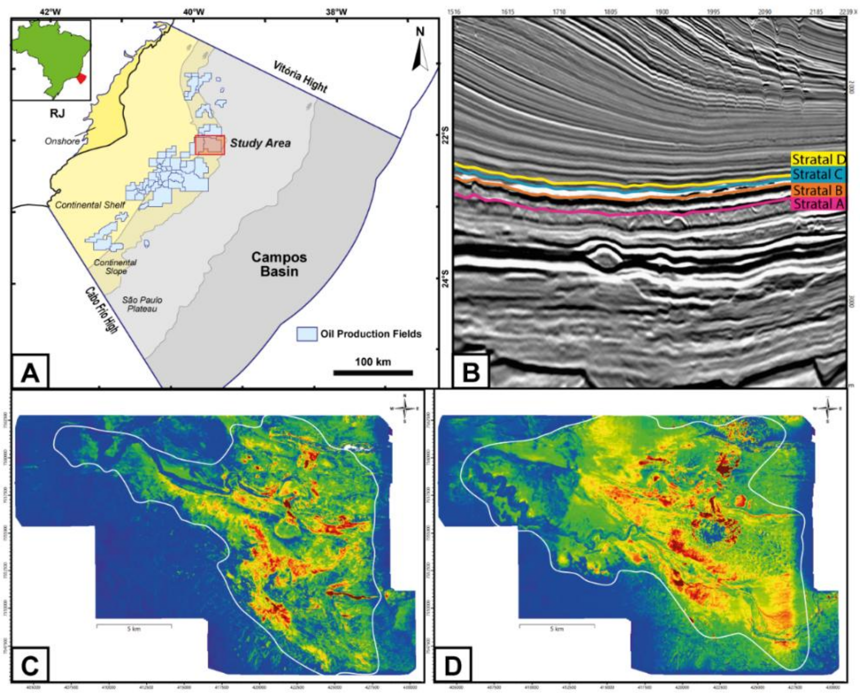

Figure 1: A - Location map of the Campos Basin and the Albacora Leste Field. B - Stratal horizons used for spectral decomposition analysis. C - RMS amplitude showing the area of occurrence of the AB-210 reservoir. D - RMS amplitude showing the area of occurrence of the AB-140 reservoir.

Results

Four stratal slices were selected for spectral decomposition analysis using three different spectral magnitude components (16, 36, and 57 Hz). RGB blending offers improved visualization of channel geometries compared to other attributes. We chose these frequencies based on qualitative observations of high and low frequency compositions. This method enabled a clearer visualization of channel and lobe geometries, as different frequencies highlight distinct sedimentary features.

In Stratal Slice A, the RGB spectral decomposition highlights a sinuous channel in the northern part of the area, characterized by red tones (~16 Hz), which suggests tuning at lower frequencies. A narrow red trace beneath this channel may correspond to a paleochannel. Although the southern channel is morphologically distinct, it lacks significant color contrast with the surrounding areas, indicating an erosional surface without notable sandy fill. Cyan and blue (~57 Hz) areas are interpreted as turbidite lobes and sand fills, while the purple and darker surrounding areas are interpreted as finer-grained background sediments. In Stratal Slice B, spectral responses become more variable, with cyan, yellow, and green hues providing broader coverage of turbidite lobes. The northern channel preserves red edges and shows increased cyan infill, suggesting thicker and more continuous sandy deposition. The southern channel also becomes more distinguishable from adjacent areas, though its infill remains limited, possibly indicating an erosional bypass phase.

In Slice C, overall color intensity diminishes, with subtler cyan, yellow, and green tones reflecting a lower-energy system and increasing dominance of fine-grained material within the lobes. The northern channel appears less defined, with red frequencies occurring only along isolated segments, likely indicating advanced stages of infill or abandonment. In contrast, the southern channel becomes more prominent, exhibiting stronger blue hues that signify recent sandy deposition tuned to higher frequencies. It displays a broader morphology toward the east, suggesting a loss of confinement and a possible transition into lobe-like deposition. Additionally, a new channel emerges in the far northwest, marked by linear contrasts in spectral response. Lastly, in Stratal Slice D, the northern and southern channels are poorly defined and likely represent fully filled or inactive conduits. The northwest channel becomes the dominant feature, marked by blue and cyan tones along the well-defined levees of sandy deposits. Red, purple, and green patches in the broader area reflect a mixture of lithologies, with purple hues likely representing mud-rich zones. The observed distribution indicates the waning phase of the turbidite system. This uppermost horizon captures the transition from active channel-lobe deposition to a more quiescent setting.

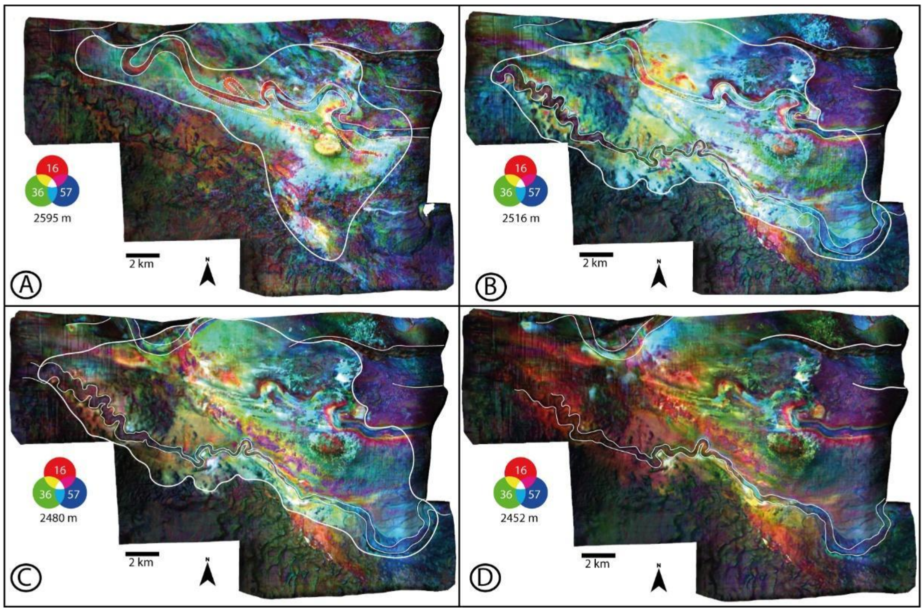

Figure 2: A, B, C, and D showing the respective stratal horizons with their geometries identified through RGB spectral decomposition (16, 36, and 57 Hz).

Conclusions

The analyzed stratal slices correspond to Miocene reservoir intervals in the Albacora Leste Field and provide key insights into the geometry of turbidite deposits and associated channel dynamics. Stratal Slice A, interpreted as the base of the AB-210 reservoir, reveals a well-developed turbidite lobe partially eroded by a later main channel. The former channel course is delineated by low-frequency responses (red), suggesting its original path lay deeper than the current one. Stratal Slice B, corresponding to the AB-140 reservoir, shows significant thickening and lateral continuity of turbidite sandstones within the northern channel, indicating active sediment infill and migration into adjacent areas.The southern channel becomes more defined at this level, yet shows limited sandy infill, which may correspond to a bypass channel incision eroding previously deposited turbiditic lobes. In Stratal Slice C, the reduced intensity of high-frequency responses reflects a decrease in depositional energy and sand supply near the top of the AB-140 reservoir. However, the southern channel appears more sand-filled compared to the previous stratal slice, suggesting this interval corresponds to its depositional phase and indicating a transition from a confined to a more laterally unconfined setting toward the west. Lastly, Stratal Slice D marks the waning phase of turbidite activity in this interval. A new channel system emerges in the northwest portion of the area, exhibiting strong spectral responses and well-defined levees, and is interpreted as the base of the AB-120 reservoir. These results support a progressive evolution of the turbidite system from confined channels and lobes toward more dispersed and mud-prone terminal deposits.

Acknowledgments

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