Outer shelf 3D Coastal Geomorphological features in the Plio-Pleistocene of the Brazilian Equatorial Margin.

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Resumo

The development of interpretative software that allows automatic horizon picking introduces a new way of visualizing past morphologies. This study used a specialized 3D seismic interpretation software, to explore a seismic block north of the Brazilian Equatorial Margin, revealing the geomorphological evolution over the last 3.7 Myr. The horizons show coastline morphologies evolving with sea-level changes, including lagoonal environments during high sea levels and strandplain deposits as levels drop. Significant erosion during transgressions after 2.4 Myr formed abrasion coastlines, which were later buried by sediments when current circulation patterns returned to normal.

Introdução

Understanding how sea level variation affects coastal morphologies is crucial, and historical climate events provide valuable insights. The continental shelf serves as an excellent laboratory for studying the influence of climate variations. Its shallow bathymetry makes it highly susceptible to eustatic variations, leading to changes in coastline position and morphology. The passive margin of Equatorial Brazil is particularly suitable for such studies due to its high subsidence rate and continuous influx of sediments from the Amazon River, the world's largest watershed (Dai and Trenberth, 2002; Milliman, 2001; Nittrouer et al., 1986). These massive sediment inputs have resulted in significant sediment deposition on the continental shelf and within the deep Amazon Cone (Damuth and Kumar, 1975), enabling exceptional preservation of ancient morphologies.

While many studies focus on geomorphologies along the Amazon deep-sea fan, including channels, landslide scars, and mud volcanoes (Damuth et al., 1988, 1983; Jegou et al., 2008; Lopez, 2001; Maslin et al., 1998), few have identified and described geomorphologies along the shelf.

This study examines a 3D seismic block located north of the Amazon canyon, covering primarily the outer shelf. Using a software specialized in 3D seismic interpretation, numerous seismic horizons were generated, allowing for a comprehensive interpretation of the geomorphological evolution of the siliciclastic sediments brought by the Amazon River over the last 3.7 Myr (Cruz et al., 2019; Gorini et al., 2014; Tortarolo et al., 2024).

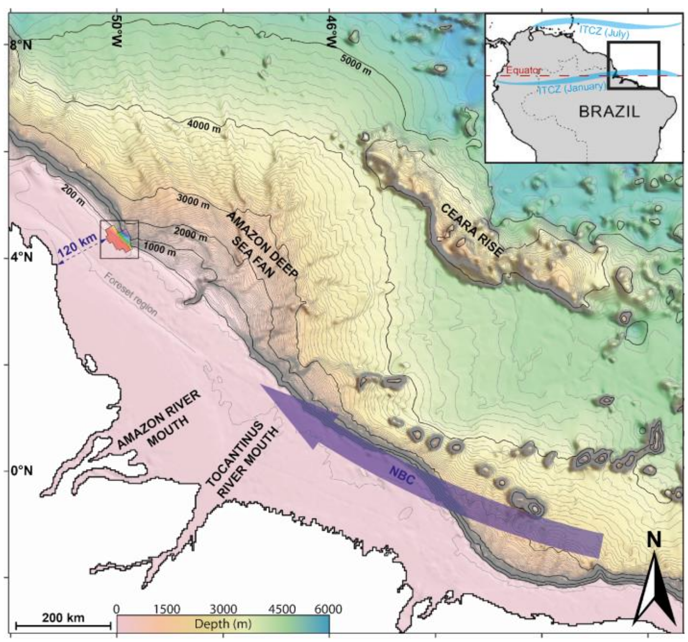


Figure 1: Bathymetric map of the NW Equatorial Brazilian Margin presenting the data used in this study. The 3D seismic block is shown with the seafloor horizon. The North Brazilian Current (NBC) is represented with a thick blue arrow.

Metodologia/Problema Investigado

To comprehensively understand the study area's evolution, a geo-model was constructed to obtain horizons rather than time slices. Before creating the geo-model, fault sets were generated using an automatic method. The model grid was established across the full seismic block using peak and trough picking at intervals of every 7 traces. The fault set was incorporated to prevent incorrect continuities during horizon propagation. The resulting model grid comprised over 60 million patches. The automatic interpretation was checked and refined to correct mis-propagations, focusing on the siliciclastic Plio-Pleistocene series.

Automatic interpretation encountered difficulties in areas of landslides and slopes, where deformation hindered lateral continuity of reflectors, and in the upper siliciclastic series, where significant erosion and poor data quality due to deep reservoir targeting affected propagation. Despite these challenges, manual checking and refinement used automatic picking tools due to the dataset's size. Horizons enabled a resolution of ~25 meters. Select horizons were meticulously refined to exemplify geomorphological features, and boundaries of the siliciclastic series were also refined to better constrain the model.

Ultimately, a geo-model was created and constrained by faults. From this geo-model, 300 horizons were generated between the Top of Amapá and the seafloor, facilitating data navigation and revealing numerous structures. Attributes like Root Mean Square Amplitude (RMSA) and Contour Curvature improved understanding of geomorphological evolution. RMSA highlighted lateral lithological variations, aiding in delineating sandy structures, while Contour Curvature highlighted horizon inclination variations. Signal deconvolution into various frequencies enhanced structural shape definition, presented in Red-Green-Blue visuals for simultaneous frequency observation. A flattening tool was used to reveal original structures' shapes before subsidence effects.

Resultados

The following Figures reveal different horizons with the main coastal geometries observed in the seismic block. These geometries evolve cyclically over time and are associated with significant sea-level falls occurring in 400 kyr cycles (Tortarolo et al., 2024).

Within the Figure 2, channels oriented at N60° perpendicular to the slope break and the present-day shoreline are the most notable structures. Two types of channels are identified: type 1 channels, which are straight and measure 800-1000 m wide. These channels show minimal erosion, approximately 18 m between their base and top. Their lengths range from 10 to 30 km. The upstream terminations of these channels are associated with sedimentary structures forming an arc and exhibiting trough and crest topography, with undulations of approximately 10 m and distances between crests varying between 200 and 300 m. These geometries extend over a restricted area parallel to the coastline, with a width of 8 km. The crest lines form semicircular structures around the upstream channels and become tangential to the zone boundaries.

A third type of structure in Figure 2 consists of reflectors located upstream of the channels inclined towards the mainland, forming clinoforms with lengths of approximately 100 m and heights of around 40 m. These clinoforms develop into lobes at the channel outlets, with reflectors exhibiting greater amplitudes than the surrounding area.

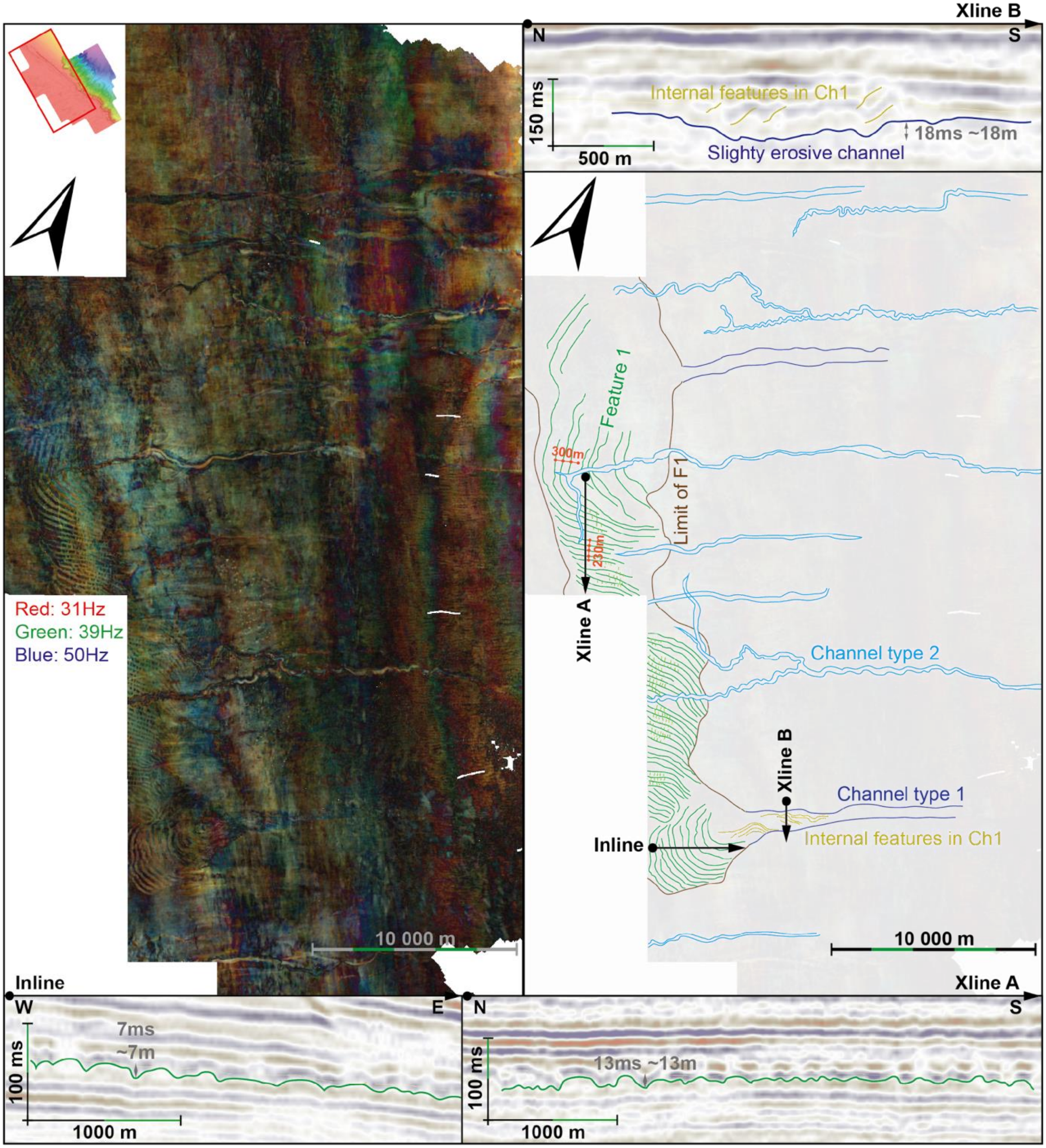


Figure 2: Seismic horizon part of a Highstand System tract visualised from above with in the left panel the seismic data treated with a Red-Green-Blue frequency filter and on the right side, the interpretation of the main morphologies observed. Some seismic lines (Xline or Inline) are presented along the Figures.

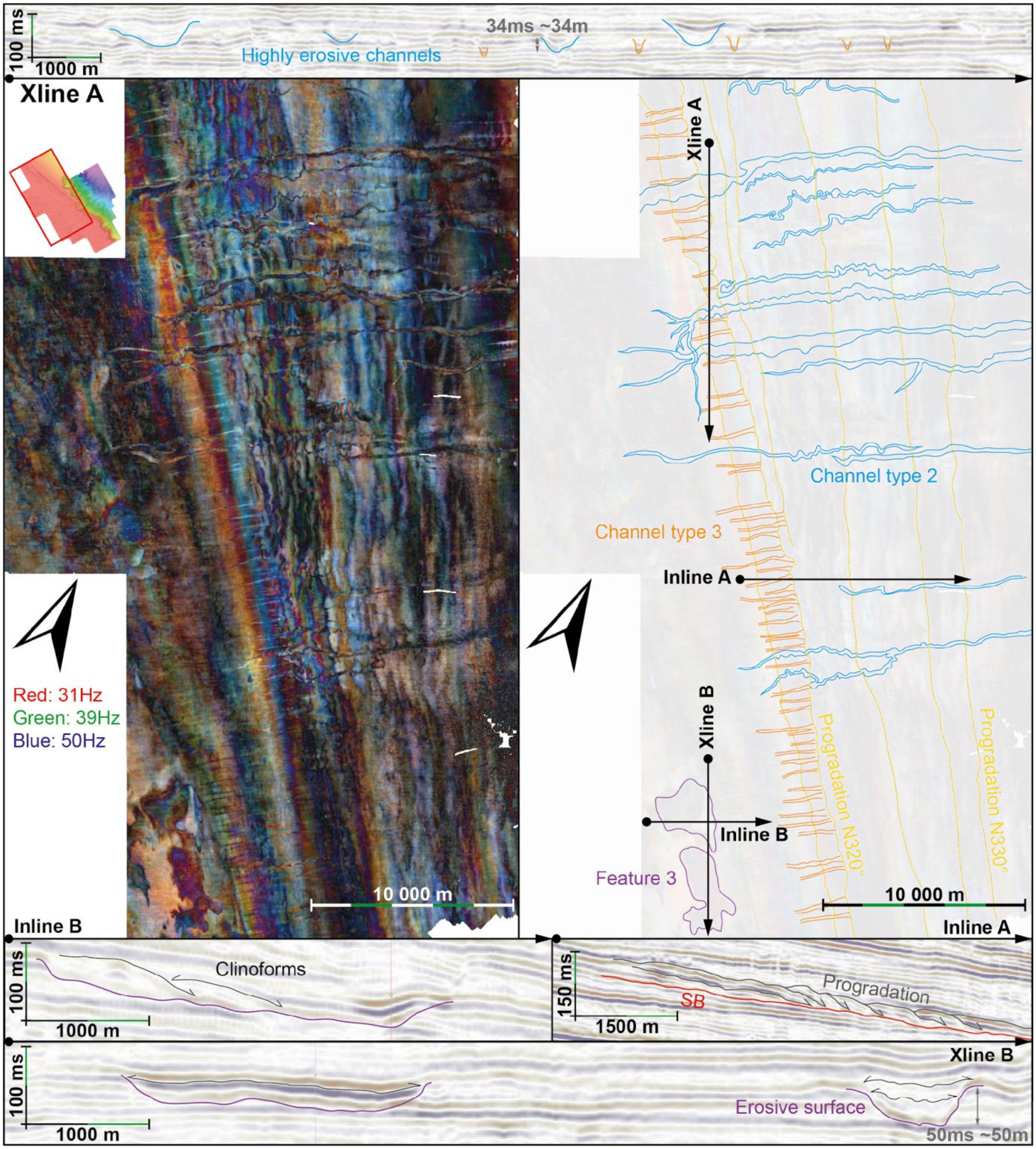


Figure 3: Seismic horizon part of a Falling Stage System tract visualised from above with in the left panel the seismic data treated with a Red-Green-Blue frequency filter and on the right side, the interpretation of the main morphologies observed. Some seismic lines (Xline or Inline) are presented along the Figures.

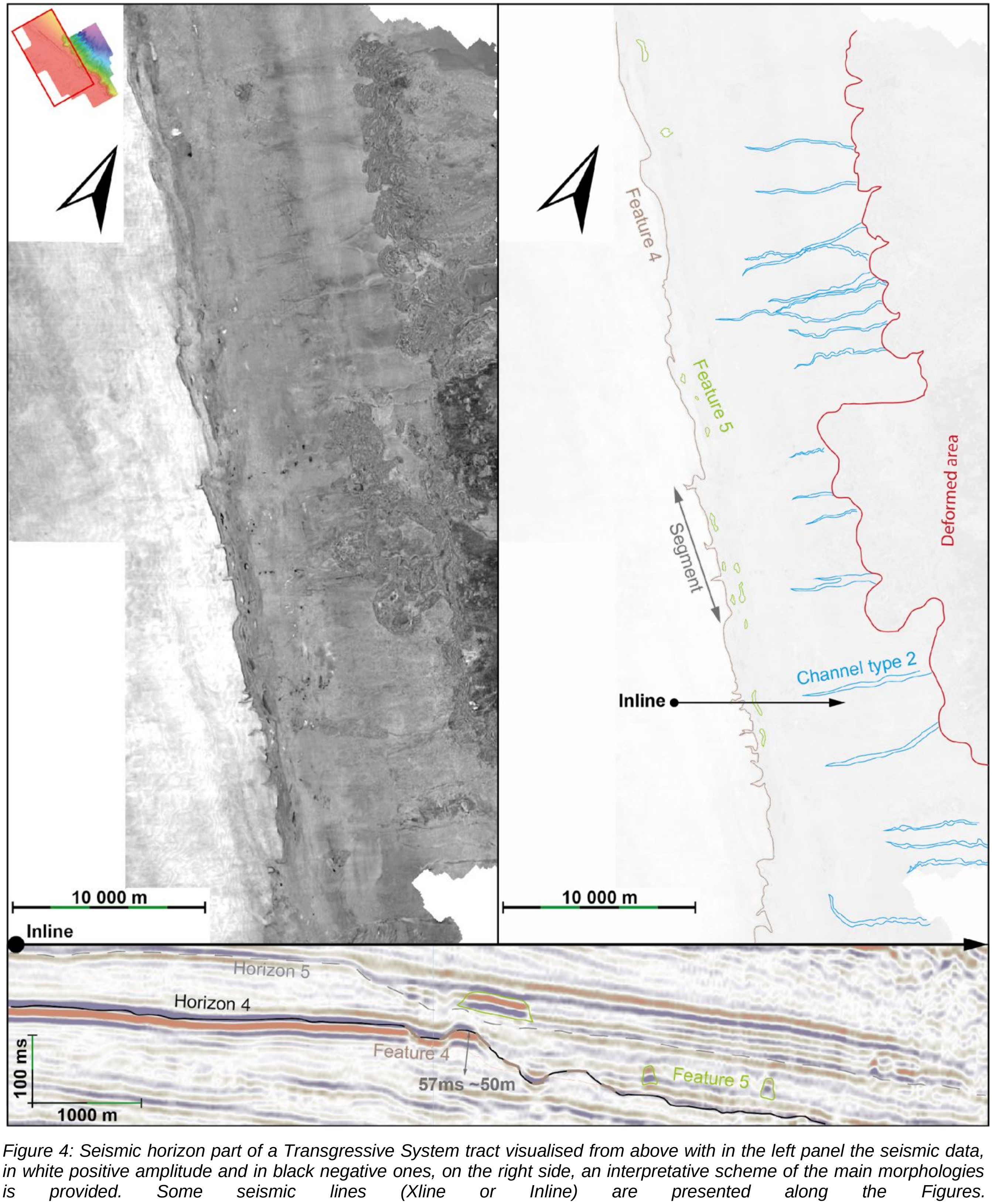


Figure 4: Seismic horizon part of a Transgressive System tract visualised from above with in the left panel the seismic data, in white positive amplitude and in black negative ones, on the right side, an interpretative scheme of the main morphologies is provided. Some seismic lines (Xline or Inline) are presented along the Figures.

Figure 3 reveals lineations oriented at N320°, parallel to the coastline, shifting to N330° towards the basin. These lineations are prograding clinoform boundaries, with clinoforms ranging from 800 to 500 m wide. The height difference between the base and top of a clinoform is approximately 25 ms TWTT. Two types of channels are identified in Horizon 2: type 2 channels, which are highly meandering and erosive, and type 3 channels, which are rectilinear. Type 2 channels, oriented N60°, can change direction near their upstream terminations, measuring around 20 km long and 200-300 m wide, with vertical differences of 25-50 ms TWTT. The frequency of channels increases from 0-10 in Figure 2 to 10-30 in Figure 3. Type 3 channels are rectilinear, 2-4 km long, 100 m wide, and vertically differentiated by around 5 ms TWTT, spaced at approximately 1 km intervals. Their downstream terminations are abrupt, occurring against the N320°-oriented progradations. Type 3 channels are abundant only along the topsets of the first clinoform, absent in subsequent clinoforms, which are narrower and exhibit gentler slopes.

Figure 3 also reveals depressions (Feature 2) in the most proximal part of the seismic block, upstream of the progradations. These depressions are about 50 ms TWTT deep, filled with clinoforms with stronger seismic amplitudes than surrounding reflectors, aligned along a N320° axis, and measuring 2-4 km in width and 2-6 km in length.

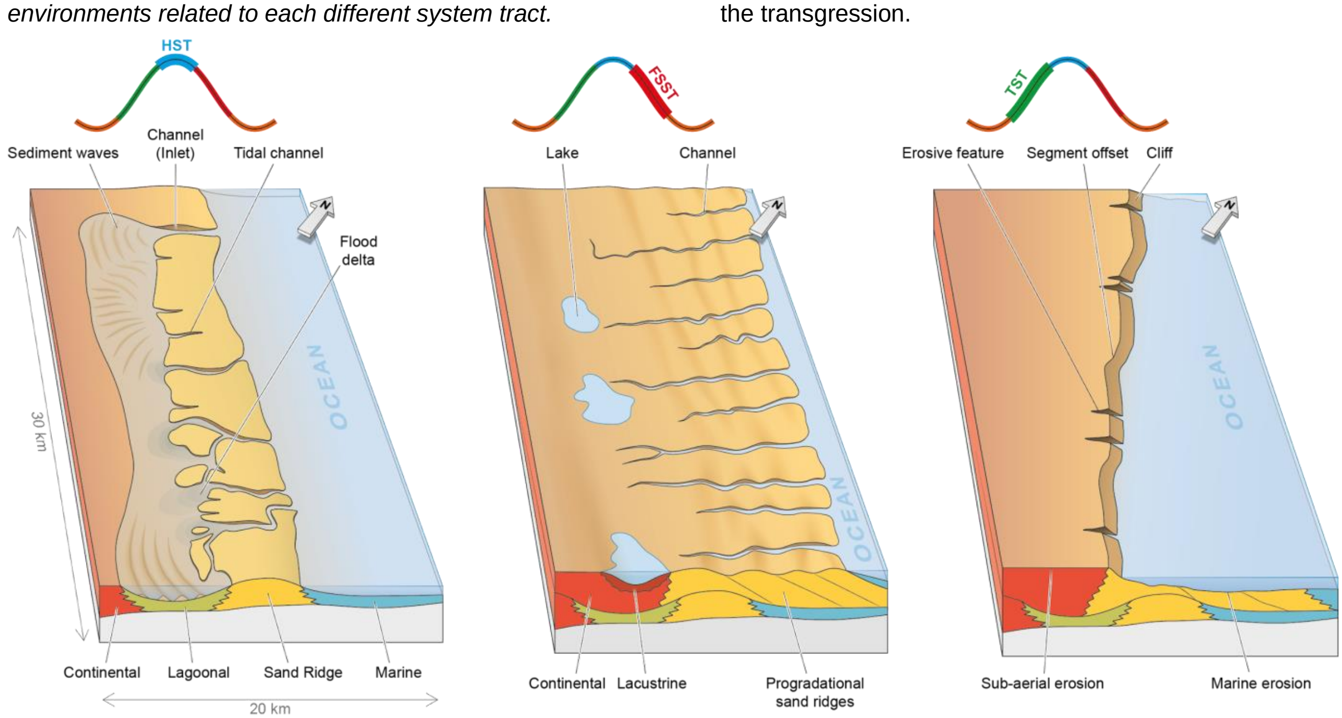
Figure 4 discloses a principal structure (Feature 4) delineating the boundary between two seismic amplitude domains. The proximal domain is flat with strong seismic amplitudes, while the distal domain is highly eroded, with low-amplitude reflectors. The eroded zone in the distal domain has lost approximately 57 ms TWTT of sedimentary deposits, filled by layers of continuous, subparallel reflectors with moderate amplitude. Feature 4 marks a significant slope change, representing an erosive front, predominantly maintaining a linear orientation of N320°, although segmented with lengths of 8-10 km and minor eastward offsets.

In the distal domain, at the base of the slope break, Feature 5 structures are less than 1000 m long and 100 m wide, displaying strong seismic amplitudes. These structures are part of a transgressive assemblage filling the erosive embayment in Figure 4, asynchronous with Feature 4.

Discussão e Conclusões

Our analysis of the northern Brazilian Equatorial Margin, based on 3D seismic data, reveals significant coastal morphological changes during the upper Pliocene and lower Pleistocene periods. The study identifies three distinct environments: barrier-lagoon, strand plain, and abrasion coastlines. In Figure 2, we observe sand ridges or barrier islands with rectilinear channels (Channel type 1) linking the ocean to a lagoon. Feature 1 corresponds to sediment waves within the lagoon. Figure 3 displays beach ridges indicative of a sea-level fall, with deeper, more erosive channels suggesting intermittent streams (Channel type 2) draining the coastal area. Additionally, Feature 3 may represent lakes located behind the beach ridges at the former position of the lagoon. In Figure 4, Feature 4 signifies abrasion coastlines with substantial erosion caused by wave action, and Feature 5 indicates potential carbonate buildups developing at the onset of the transgression.

Figure 11: Simplified drawing of the different depositional environments related to each different system tract.



The study highlights how these geomorphological features align with sea-level changes and sediment supply variations. The progradational beach ridges and abrasion coastlines reflect dramatic sea-level falls and transgressive phases, respectively.

We propose that these coastal changes are linked to 405 kyr eccentricity cycles, correlating with major sea-level falls during low eccentricity periods. The data suggest the Amazon River's increased sediment supply during glacial intervals facilitated coastline progradation to the outer shelf. The observed abrasion coastlines' preservation indicates a significant sediment influx during subsequent sea-level rises, reestablishing the modern current pattern and sediment transport. This study provides a comprehensive model of coastal evolution influenced by sea-level fluctuations and sediment dynamics over geological timescales.

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