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Tectono-Stratigraphic Evolution of an Incised Valley in a Narrow and Shallow Continental Margin: Insights from High-Resolution Seismic Imaging in Lagoa Encantada, Brazil

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Abstract Summary

Incised valleys are critical stratigraphic features for understanding coastal evolution and hydrocarbon potential. This study investigates the Lagoa Encantada Incised Valley (VILE), located in a narrow (14 km) and shallow passive margin in northeastern Brazil. High-resolution seismic data (CHIRP and Sparker), sediment cores, and radiocarbon dating were integrated to reconstruct the geomorphological evolution of VILE since the Last Glacial Maximum. Structural inheritance from the Itabuna-Itaju da Colônia Shear Zone and limited accommodation space due to the São Francisco Craton influenced the valley's unique rhomboid shape. Results indicate a two-phase sedimentary infill (Pleistocene and Holocene), with the submerged portion still acting as a sediment trap. The findings link sea-level variations, tectonic activity, and sedimentary processes in passive margin settings and contribute to coastal zone management and exploration strategies.

Introduction

Incised valleys are erosional features formed during sea-level lowstands and filled during subsequent transgressions. These valleys are key elements in sequence stratigraphy and are often hydrocarbon-bearing. The Lagoa Encantada Incised Valley (VILE), located on Brazil's northeastern margin, is carved into a narrow and shallow shelf, 14 km wide, with a shelf break at approximately -100 meters depth (Figure 1).

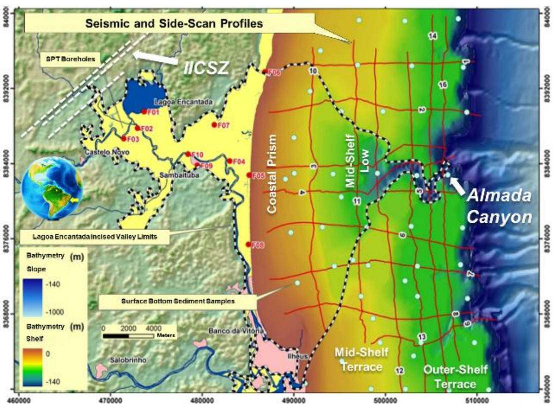
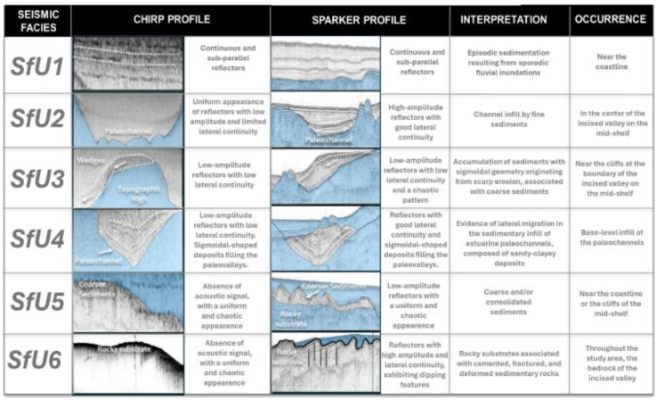


Figure 1: Location of Chirp, Sparker, and side-scan sonar imaging profiles in the submerged portion of the study area. The location of the SPT boreholes is plotted on the coastal plain.

This valley exhibits a unique rhomboid geomorphology, controlled by two main factors: the limited accommodation space generated by the São Francisco Craton and the tectonic influence of structural lineaments in the Almada Sedimentary Basin, particularly the Itabuna-Itaju da Colônia Shear Zone. The VILE's outlet directly connects to the Almada submarine canyon, forming an important depositional system. This study investigates the formation, evolution, and sedimentary infilling of the VILE through an integrated approach combining geophysical and geological methods. High-resolution seismic analyses (CHIRP and SPARKER), sedimentological cores, and radiocarbon dating were employed. The research enabled the reconstruction of the valley's geomorphological evolution since the Last Glacial Maximum (LGM), showing that its formation was strongly influenced by eustatic sea-level variations and regional tectonic structures.

Method and/or Theory

This research combines high-resolution CHIRP and Sparker seismic profiles, side-scan sonar, sedimentological data, and radiocarbon dating (Figure 1). Profiles were processed using SonarWiz and Meridata MDPS software, and seismic interpretation followed sequence stratigraphy and seismic facies models from Catuneanu (2006) (Figure 2). Integration with borehole and core data allowed correlation between emerged and submerged valley segments.



SEISMIC FACIES	CHIRP PROFILE	SPARKER PROFILE	INTERPRETATION	OCCURRENCE
SfU1	Continuous and sub-parallel reflectors	Continuous and sub-parallel reflectors	Episodic sedimentation resulting from sporadic fluvial inundations	Near the coastline
SfU2	Uniform appearance of reflectors with low amplitude and limited lateral continuity	High-amplitude reflectors with good lateral continuity	Channel infill by fine sediments	In the center of the incised valley on the mid-shelf
SfU3	Low-amplitude reflectors with low lateral continuity	Low-amplitude reflectors with low lateral continuity and a chaotic pattern	Accumulation of sediments with sigmoidal geometry originating from scarp erosion, associated with coarse sediments	Near the cliffs at the boundary of the incised valley on the mid-shelf
SfU4	Low-amplitude reflectors with low lateral continuity. Sigmoidal-shaped deposits filling the paleovalleys.	Reflectors with good lateral continuity and sigmoidal-shaped deposits filling the paleovalleys.	Evidence of lateral migration in the sedimentary infill of estuarine paleochannels, composed of sandy-clayey deposits	Base-level infill of the paleochannels
SfU5	Absence of acoustic signal, with a uniform and chaotic appearance	Low-amplitude reflectors with a uniform and chaotic appearence	Coarse and/or consolidated sediments	Near the coastline or the cliffs of the mid-shelf
SfU6	Absence of acoustic signal, with a uniform and chaotic appearance	Reflectors with high amplitude and lateral continuity, exhibiting dipping features	Rocky substrates associated with cemented, fractured, and deformed sedimentary rocks	Throughout the study area, the bedrock of the incised valley

Figure 2: Seismic facies identified in CHIRP and Sparker records. The seismic facies can be divided into two groups: (i) sedimentary infill units (sfU1, sfU2, sfU3, sfU4, and sfU5), and (ii) bedrock substrates (sfU6).

Results

Seismic analysis revealed five stratigraphic units and six seismic facies (Figure 2). Erosional terraces at distinct depths (-100 to -27 m) reflect stillstands during sea-level rise (Figure 3). The Pleistocene sequence includes platformal clays and fluvial sands, while the Holocene sequence features bioclastic deposits and marine muds.

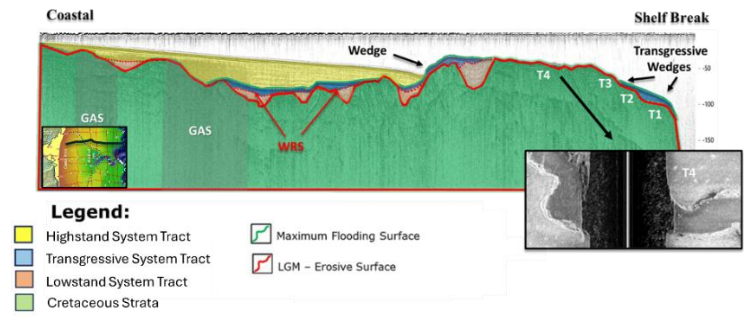


Figure 3: Dip profile using Sparker acoustic source, interpreted. Notable near the shelf break are terraces T1 to T4 and the incipient drainage present in the bedrock of T4 on the side-scan image. WRS = Wave Ravinement Surface.

A key erosional surface marks the Last Glacial Maximum (LGM) (Figure 5). The submerged valley functions as a modern sediment trap, contrasting with the fully infilled coastal plain. Knickpoints, faults, and fractures derived from pre-existing structures shaped the valley and its depositional patterns (Figure 4).

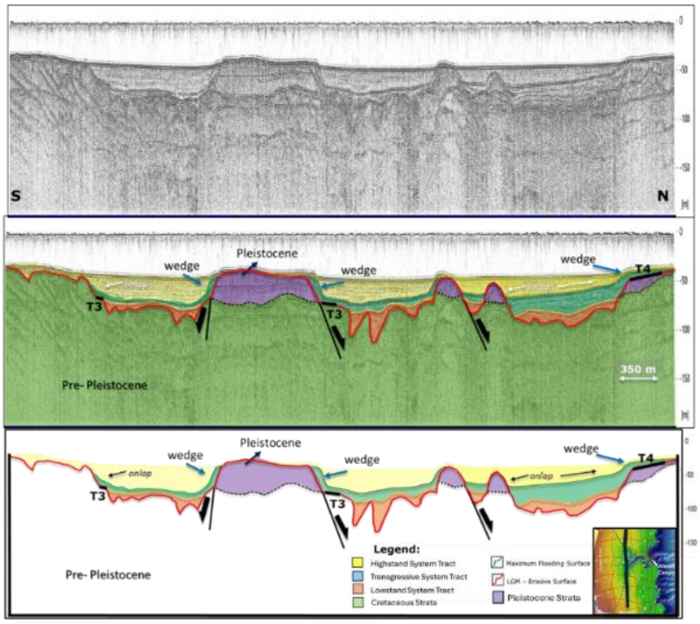


Figure 4: Sparker acoustic source profile. Uninterpreted (A) and interpreted (B and C), showing the three seismic units that fill the incised valley. Note the purple unit as a remnant of the Pleistocene sequence preserved on the bathymetric highs of the VILE. T3 and T4 correspond to abrasion terraces.

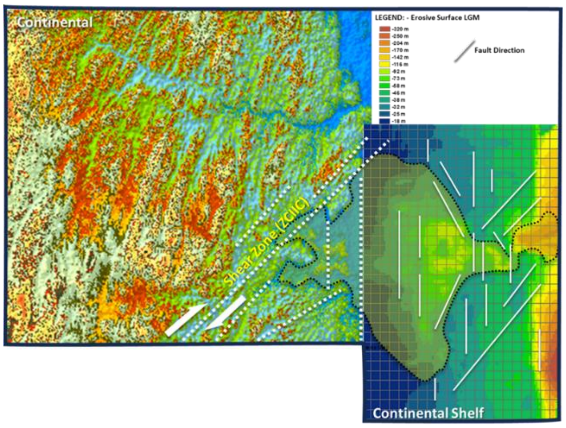


Figure 5: Map of the erosional unconformity of the LGM overlain on the digital elevation model of the continental portion of the study area. Warm colors on land indicate higher altitudes. In the submerged portion, the distribution of the main mapped structural trends is shown.

Conclusions

During marine transgressions, the valley was progressively filled with marine and fluvial sediments, displaying significant differences between its emerged portion (coastal plain) and submerged portion (continental shelf). The results indicate that, while the coastal plain is fully filled, the submerged section still functions as a sediment trap, accumulating fine suspended sediments since the Cretaceous. Marine terraces and clastic wedges developed during stillstand periods throughout these transgressive events since the LGM (Figures 6 and 7). Knickpoints played a crucial role in shaping the valley's geometry, influencing both fluvial incision and sediment transport dynamics. The migration of these knickpoints and their interaction with varying substrates were key factors in the development of the valley's distinct morphology.

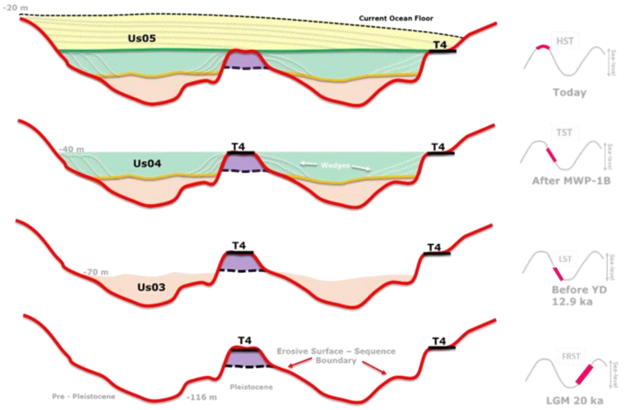


Figure 6: Schematic strike profile of the VILE showing the summarized infill history since the LGM and its respective Systems Tracts. The orange line represents the Transgressive Surface, and the green line represents the Maximum Flooding Surface. HST – Highstand System Tract (US05), TST -Transgressive System Tract (US04), LST – Lowstand System Trac (US03), FRST – Forced Regressive System Tract.

This study reconstructs the evolution of the Lagoa Encantada Incised Valley and emphasizes the importance of integrating geophysical and geological data into passive margins. Structural inheritance and sea-level dynamics play central roles in the geomorphology and sedimentation of incised valleys. The approach presented provides a model for similar systems globally and offers insights into environmental and resource management.

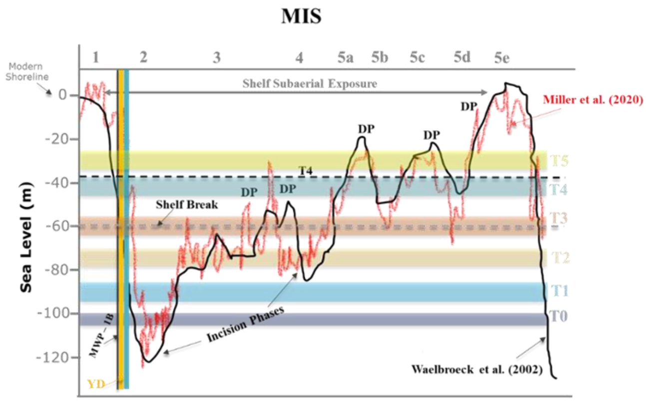


Figure 7: Bathymetric positions of the abrasion terraces in relation to sea-level curves for the last 130 ka from Miller et al. (2020) and Waelbroeck et al. (2002).

Acknowledgments

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