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Sedimentary Patterns on the Continental Slope of the Pará-Maranhão Sedimentary Basin (Brazilian Equatorial Margin)

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Abstract: The Brazilian equatorial margin has attracted growing economic and environmental interest. Although studies on the continental slope exist for the Northeast and South regions of Brazil, knowledge gaps remain regarding the sedimentological processes related to sediment composition, deposition, and source on the Upper continental slope of the Pará-Maranhão sedimentary basin (PAMA). This article aims to analyze the dynamics of recent sediments on the continental slope of the PAMA sedimentary basin, based on two piston cores. Core preparations involved cutting and sectioning at 10 cm intervals, followed by homogenization, washing, oven drying, maceration, and labeling. Analyses included stratigraphic description, grain size analysis, and quantification of calcium carbonate (CaCO₃) and organic matter (OM) contents. The results showed an abundance of muddy sediments, with a predominance of the silt fraction (80%) in T1, followed by sand (19%) and clay (1%). In T2, the silt fraction reached 91%, followed by sand (8%) and clay (1%). CaCO₃ content ranged from 13% at the base to 11% at the top, with a mean of 6% in T1, and in T2 from 1% at the base to 5% at the top, with a mean of 2%. OM content reached a mean of 15% in T1 and 13% in T2. The sediment source of the Pará-Maranhão continental slope is of Andean origin (90%), controlled by the solid discharge of the Amazon River, the North Brazil Current (NBC), and the North Atlantic Deep Water (NADW), all modulated by the trade winds and the Intertropical Convergence Zone (ITCZ).

Key-words: continental slope; depositional dynamics; sedimentology; source

INTRODUCTION

Sedimentology and stratigraphy are of great importance for acquiring information related to the regional distribution of sediments, enabling the reconstruction of sedimentological changes in the marine environment (Restrepo et al. 2020). The composition and quality of terrigenous sediments transported across the continent via rivers/estuaries, winds, and glaciers are linked to the nature of source rock erosion and to climatic conditions within drainage basins (Kissel et al. 2020).

Terrigenous sediments are deposited on continental shelves and dispersed by ocean currents subject to waves and bottom flows (Garcia et al. 2024). The transport of terrigenous sediments deposited on continental margins occurs by traction or suspension; on the continental slope, fine sediments (silt and clay) are predominant, derived from gravitational processes (De Castro et al. 2020; Zavala, 2020; Lopes et al. 2017; Calazans & Griep, 2015).

These sediments are deposited on the continental slope and in deep oceanic basins; the most characteristic transport processes include mass deposition, pelagic and authigenic sedimentation, and bottom currents (Oliveira et al. 2023; Chiang et al. 2022; Kissel et al. 2020).

In most ocean settings, sediment accumulation rates on the continental slope and abyssal plains are low, taking thousands of years for significant deposition to occur (0.1 to 1 mm/ys) (Ozerova et al. 2023). The distribution of sediments in deep water is subject to natural physical disturbance that mobilize sediments, such as extreme storm events, sediment transport triggered by slope failures on continental slopes, and benthic storms that remobilize sediments at abyssal depths (Zhu et al. 2024; Harris, 2014).

In general, the continental slope is incised by submarine canyons, depressions, ridges, channels, rock outcrops, gullies, terraces, and escarpments, with depths ranging from 100-200 m to 1,300 – 3,200 (abyssal plain), where turbidity currents, reaching flow velocities of up to 40 km/h, transport large volumes of sediments and organic matter (OM) (Bigham et al. 2023; Bluhm et al. 2020; Almeida et al. 2017; Calazans & Griep, 2025).

The occurrence of submarine landslides driven by external forces (earthquakes) and internal forces (sediment accumulation and overpressure) is responsible for sedimentological changes on the continental slope. These large sediment masses are transported at velocities ranging from millimeters to centimeters per year up to 10-30 km/h, depending on the type of mass movement (slides, turbidity currents, debris flows, mud flows), resulting in substantial displacement along the continental slope (Wang et al. 2024).

In the study region, the following investigations have been conducted: the Brazilian Continental Margin Global Reconnaissance Program – REMAC (1968-1978), followed by research projects and programs including the Amazon Shelf Sediment Study (AmaSeds, 1989-1992), the Brazilian-German Joint Oceanographic Projects (JOPS-I, 1990-1991), the Program for the Sustainable Potential Assessment of Living Resources in the Exclusive Economic Zone (REVIZEE, 1990-2005), the Costa Norte Project (2016-2020), the Program for the Assessment of Mineral Potential of the Brazilian Legal Continental Shelf (REMLAC, 1997-present), and the Brazilian Continental Shelf Survey Plan (LEPLAC, 1987-present).

There is growing environmental and economic interest in the exploration of the Brazilian equatorial margin (Gualberto & El-Robrini, 2005; Pellegrini & Ribeiro, 2018; Francini-Filho et al. 2018; D'Almeida et al. 2019; Soares, 2021; Santos et al. 2022; Guimarães, 2023), as well as studies on the continental slope of the Northeast and South regions of Brazil (de Almeida et al. 2015; Fadina et al. 2019; de Leo et al. 2020; Korotkova et al. 2021; Souza et al. 2022; Hercos et al. 2023; Jovane et al. 2024).

Despite this, knowledge gaps remain regarding the sedimentological processes related to the deposition, composition, and source of sediments on the upper continental slope of the Pará-Maranhão sedimentary basin (PAMA) (Pellegrini & Ribeiro, 2018). This article aims to analyze the dynamics of recent sediments on the continental slope of the PAMA sedimentary basin.

MATERIALS AND METHODS

Study Area

Geological and Morphological Context

The continental slope of the PAMA basin is situated on the Brazilian continental margin (Fig. 1). The PAMA basin covers a surface area of 48,000 km², with the continental slope extending from depths of 100 m to 3,400 m and featuring canyons-oriented SW-NE at dip angles between 3° and 16° (Nogueira et al. 2021; Conte & Chira, 2021; Cruz, 2009).

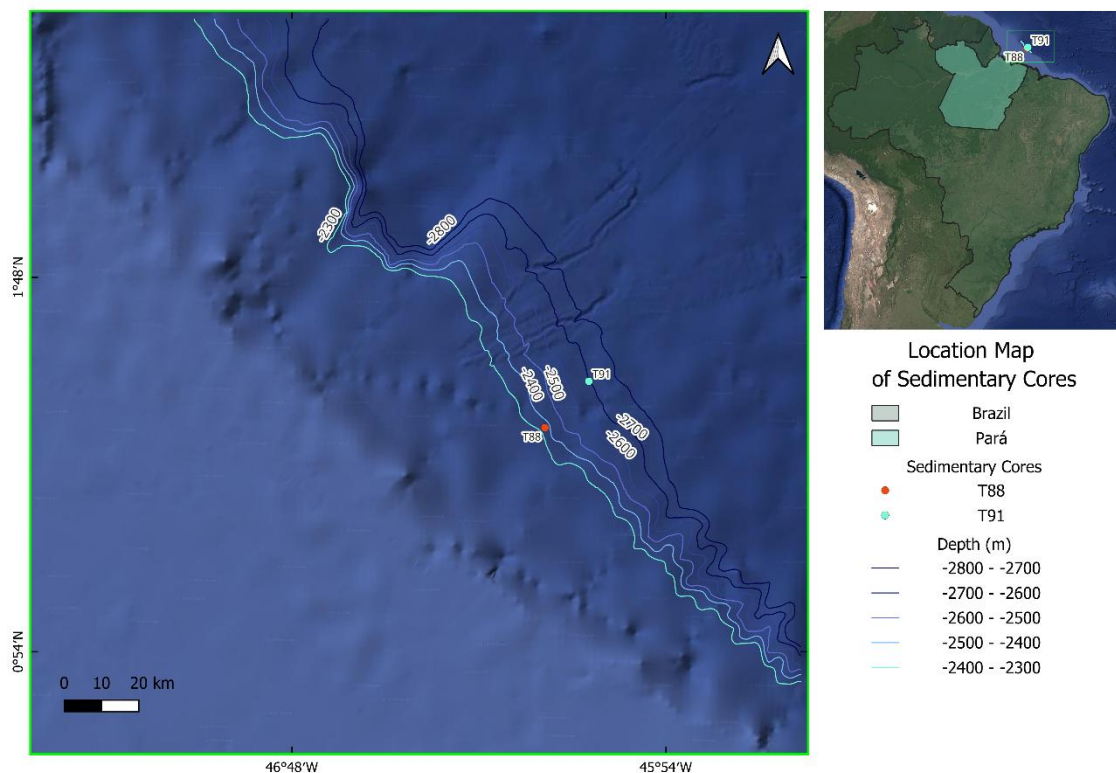


Fig. 1 Location map of sediment cores on the continental slope of the Pará-Maranhão Basin. Source: Author.

With the occurrence of gravitational fold-and-thrust belts, the continental slope is characterized by sedimentary successions exceeding 10 km in thickness and a structural system divided into three tectonic domains linked by a décollement surface. These domains comprise: (i) the extensional domain, associated with the upper slope, marked by listric normal faults accommodating the initial collapse of the rocks; (ii) the translational domain, corresponding to the intermediate zone, where strata slide along the décollement surface without internal deformation; and (iii) the compressional domain, located at the slope toe, characterized by imbricated thrust faults and foils resulting from sediment displacement (Soares, 2021).

The geomorphology of the ocean floor is controlled by regional neotectonics and the sediment supply derived from the Amazon Cone. The study area features superimposed channels and paleochannels with relief differences exceeding 200 m, as well as sedimentary barriers responsible for deflecting or blocking sediment transport toward deeper areas. Volcanic intrusions and submarine mountain chains are also observed acting as accelerators and/or baffles for local sedimentation (Azevedo, 2014).

Due to contractional tectonics, the basin exhibits a large-scale gravitational fault with an upward-dipping downslope inclinations. The general deformations system caused by gravity has an overall width of 38 km, comprising a 19 km-wide zone and a 16 km-wide zone with a gentle seaward dip, composed of overpressure mudstone (Yang et al. 2020)

Climate and Climatic Variability

The South Atlantic Ocean influences climate at both global and regional scales through its participation in thermohaline circulation and sea surface temperature (SST) patterns, which interact with the atmosphere and drive precipitation variability in adjacent countries (Colberg et al. 2004). Atmospheric circulation is predominantly controlled by the trade winds, which blow toward the tropics in the direction of the equator, forming the Intertropical Convergence Zone (ITCZ). During winter, the northeast trade winds prevail, while during summer in the southeast (SE) trade winds dominate (Aguar et al. 2022).

In addition, the Atlantic Ocean exhibits the Atlantic Multidecadal Oscillation (AMO), characterized by significant variations over multidecadal and decadal periods, as well as on shorter

timescales (>7 years), including the El Niño phenomenon, which affects SST and contributes to changes in precipitation patterns across various regions (Gomes et al. 2024).

Another important climatic variability mechanism is the Atlantic Dipole (AD), related to ocean-atmosphere variability. It directly influences the South Atlantic Ocean, with greater intensity from June to August in the Northeast and affects SST and the precipitation regime in costal and oceanic zones of the Southeast (Nworgu et al. 2024).

Hydrology and Continental Supply

In the coastal zone, the Amazon River discharges approximately $2 \times 10^5 \text{ m}^3 \text{ s}^{-1}$ of freshwater into the Atlantic Ocean (Shi & Wand, 2024; Espinoza et al. 2022). Variations in the discharge and hydrograph (ENSO), the tropical Pacific climate cycle, Northern Hemisphere climate, and interactions with the Hadley cell and meridional atmospheric cells such as the North Atlantic Oscillations (NAO), underscoring its importance within the oceanic and atmospheric hydrological cycle (Shi & Wand, 2024).

The Amazon and Pará river systems regulate freshwater transport and are also fundamental to the regional sediment budget (Costa et al. 2025). The Amazon River plume transports and annual solid discharge of suspended sediments reaching $8\text{-}9 \times 10^8 \text{ tonner yr}^{-1}$ (Shi & Wang, 2024).

Oceanographic aspects

Ocean wave conditions are influenced by the trade winds and the migration of the ITCZ. During winter, higher waves are generated, reaching 1.5 to 1.8 m offshore, while during summer, as the ITCZ shifts northward, waves are generated by local winds, with height variations between 1.2 and 1.5 m (Botelho & El-Robrini, 2026). A wave bimodality occurs in the area: 59% of the time sea conditions are characterized by swell waves, generated by storms in the North Atlantic (reaching peaks of 3.32 m) and during austral summer and autumn. Wind-sea waves dominate approximately 41% of the time, during spring conditions and during the intensification the southeast trade winds (reaching up to 2.94 m) (Dos Reis et al. 2024).

Sampling

For the study of the local geological formation, stratigraphic surveying was carried out using a piston corer for the collection of stratigraphic sections of sedimentary packages from the ocean sub-bottom (Griep, 2011). Sampling (Table 1) was conducted on board the vessel *Geoexplorer*.

Table 1. Core samples, with geographic coordinates and water depth.

<i>Core</i>	<i>Latitude</i>	<i>Longitude</i>	<i>Water Depth (m)</i>
<i>T1</i>	N 01° 26' 20"	W 46° 10' 88"	2.350 m
<i>T2</i>	N 01° 32' 61"	W 46° 04' 67"	2.700 m

Laboratory methods

Core opening and textural description

The sediment cores collected in 2014 were marked and opened using an electric cutting saw and a PVC support tray designed to hold the sediment cores and allow parallel sectioning on both sides for core opening. This procedure produces two longitudinal sections: one commonly used for analytical processing and the other preserved as an archive.

The working section was photographed in its entirety to assist in the overall visualization of the vertical profile, including sediment color classification according to Color (2009), lithology, sedimentary structures, and the possible presence of biogenic material. Subsamples were collected from the sediment core at 10 cm intervals.

Grain-size distribution

The sediment samples were subjected to the wet sieving method (Martins et al. 2017; Suguio, 1973). Initially, an aliquot of sediment from each subsample was placed in an oven at 60°C for drying. After drying, the samples were gently disaggregated, and a 10 g aliquot of sediment was used for grain-size analysis.

In a beaker, the sediment was homogenized with distilled water using a glass rod and subsequently transferred to a 63 µm mesh sieve to separate the sand, silt, and clay fractions. The sand fraction retained on the sieve was collected, dried again in an oven, and then weighed.

The fraction composed of silt and clay was also dried, disaggregated, and subsequently subjected to centrifugation. Afterwards, 10 g of sample from each sediment core subsample was placed into test tubes, homogenized with distilled water, and weighed using an analytical balance to ensure equivalent masses among samples. The samples were then centrifuged at 1500 rpm for 5 minutes, allowing the separation of the silt fraction at the bottom of the tube and the clay fraction remaining in suspension.

After this process, the clay and silt fractions were transferred to properly identified beakers and dried in an oven at 60°C. Finally, the obtained fractions were subjected to statistical treatment for grain-size data analysis

Statistical treatment

The sediments were classified based on statistical parameters using the following indicators: sorting (standard deviation), kurtosis, and skewness (Fernandes and Castro, 2020). Additionally, triangular diagrams proposed by Folk and Ward (1954) and Shepard (1954) were used for textural classification based on sand, silt, and clay fractions. The Pejrup (1988) diagram was applied to interpret hydrodynamic conditions, in this diagram, groups A to D represent increasing hydrodynamic energy levels based on sand and silt proportions, while groups I to IV reflect clay content, indicating depositional energy conditions.

Quantification of organic matter and calcium carbonate

The contents of organic matter (OM) and calcium carbonate (CaCO₃) were determined through the loss on ignition (LOI) (Catianis et al. 2020; Kralik, 1999). Initially, 1 g of sediment was weighed in previously identified porcelain crucibles corresponding to the respective subsample sections. The crucibles were then weighed using an analytical balance to obtain the initial weight (P1).

Subsequently, the crucibles were placed in a muffle furnace at 600°C for 2 hours to remove the OM through combustion. On the following day, the crucibles were weighed again to obtain the final weight (P2). The difference between these values was used to determine the organic matter content present in the sediment:

$$OM (\%) = (P1 - P2) \times 100 \quad (1)$$

Afterwards, the crucibles were returned to the muffle furnace for CaCO₃ combustion at 800°C for 2 hours. On the following day, the samples were weighed again, and the difference between the previous weight and the weight obtained after the second combustion was used to determine the CaCO₃ content:

$$CaCO_3 (\%) = (P1 - P2) \times 100 \quad (2)$$

Larsonneur classification

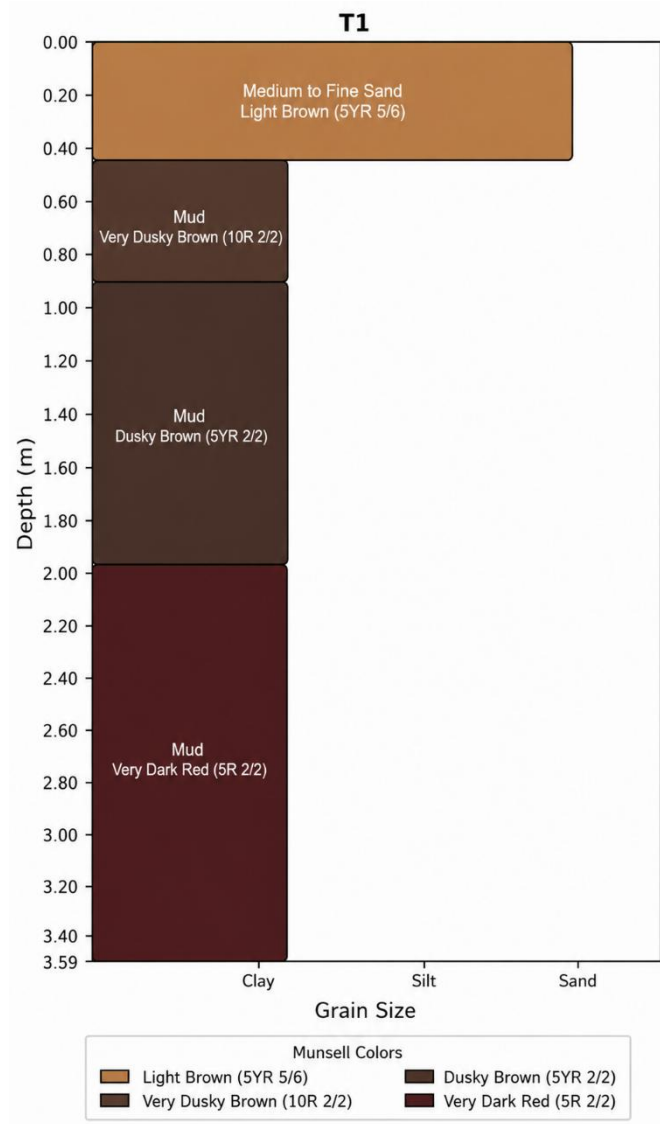
The Larsonneur (1977) classification was applied to determine the carbonate content and classify marine sediments as follows: lithoclastic sediments contain less than 30% CaCO₃; lithobioclastic sediments contain more than 30% and less than 50%; biolithoclastic sediments contain between 50% and 70%; and sediments with values above 70% are classified as bioclastic.

RESULTS

Grain-size distribution

Core T1 (Fig. 2) measured 3.59 m in length and consisted of four sections (A, B, C, and D). The core was considered massive, with no occurrence of sedimentary structures or stratigraphic markings. From 0 to 46 cm, it presented a fine to medium sand layer with a Light Brown color (5YR 5/6), while from 47 to

194 90 cm, the sediment exhibited a Very Dusky Brown color (10R 2/2) with a muddy texture. From 91 cm to
 195 1.94 m, the sediment color changed to Dusky Brown (5YR 2/2), while maintaining a muddy texture. From
 196 1.95 m to 3.59 m, the color changed to Very Dark Red (5R 2/2), continuing with a muddy texture.



197

198 Fig. 2 – Sedimentary sections of core T1. Source: Author.

199 The predominant grain-size fraction was silt, followed by sand and clay (Fig.3). In core T1 the
 200 sand fraction ranged from 15% to 1% at depths of 2.30 m and 1.60 m, respectively. The silt fraction varied
 201 from 98% at the top to 83% at the base, whereas the clay fraction ranged from 2% at the top to 0.2% at the
 202 base.

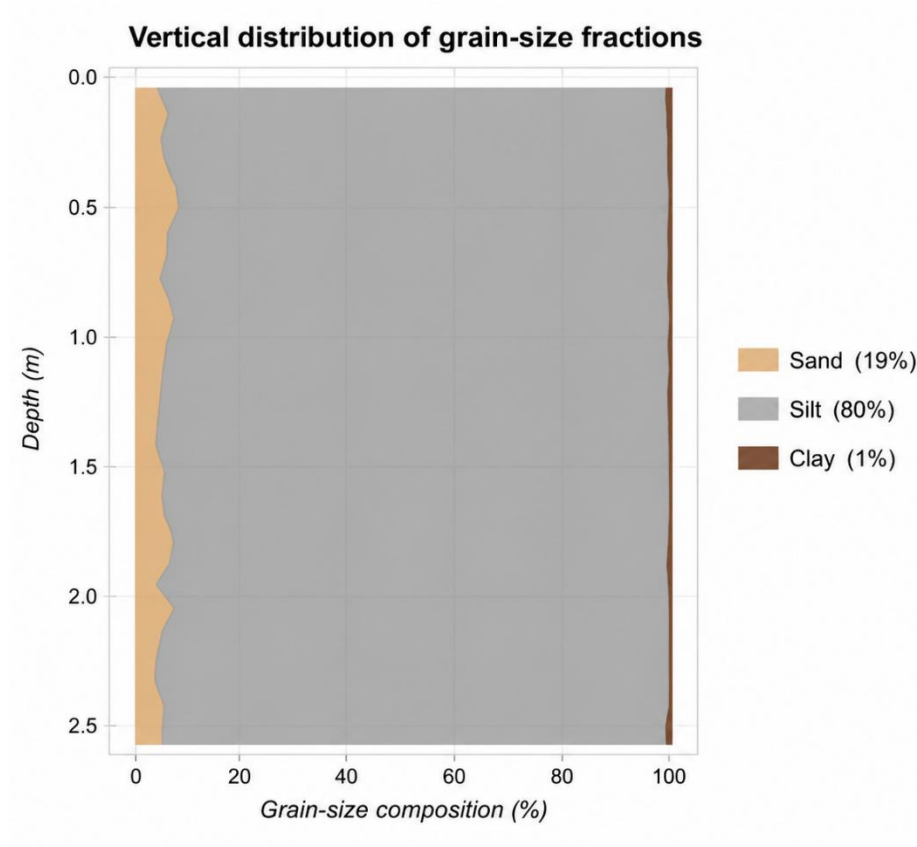


Fig. 3 – Distribution of grain-size fractions of core T1. Source: Author.

Core T2 (Fig. 4) measured 3.0 m in length and was divided into sections A to C. From 0 to 96 cm, the sediment exhibited a Dark Reddish-Brown color (10R 3/4) with a muddy texture. From 0.97 m to 1.26 m, the color changed to Grayish Brown (5Y 3/2), and from 1.27 m to 1.93 m, it changed again to Dark Reddish Brown (10R 3/4), maintaining a muddy texture. From 1.94 to 2.25 m, the sediment color changed to Grayish Red (10R 4/2), and finally, from 2.26 to 3.0 m, it changed to Moderate Brown (5YR 4/4).

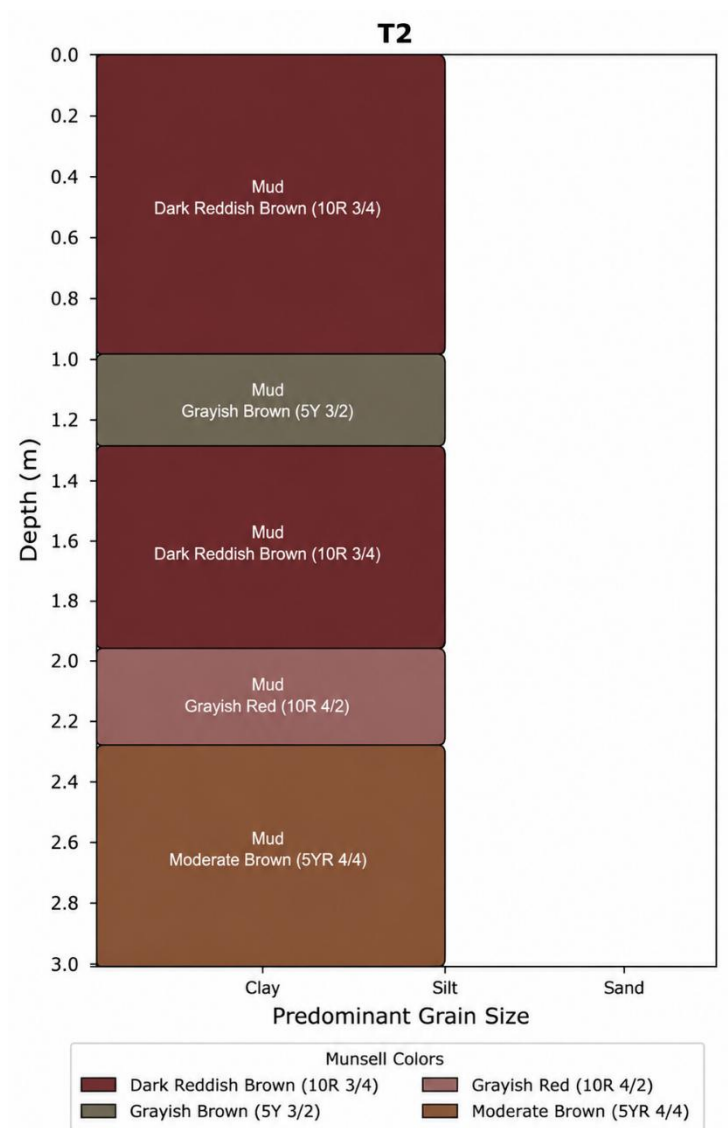


Fig. 4 – Sedimentary sections of core T2. Source: Author.

No sedimentary structures or stratigraphic markings were observed, and the grain-size classification consisted of silt, clay, and sand fractions (Fig 5). The sand fraction ranged from 15% at the top to 1.13% at the base, the silt fraction varied from 86% at the top to 57% at the base, and the clay fraction ranged from 2% at the top to 0.21% at the base.

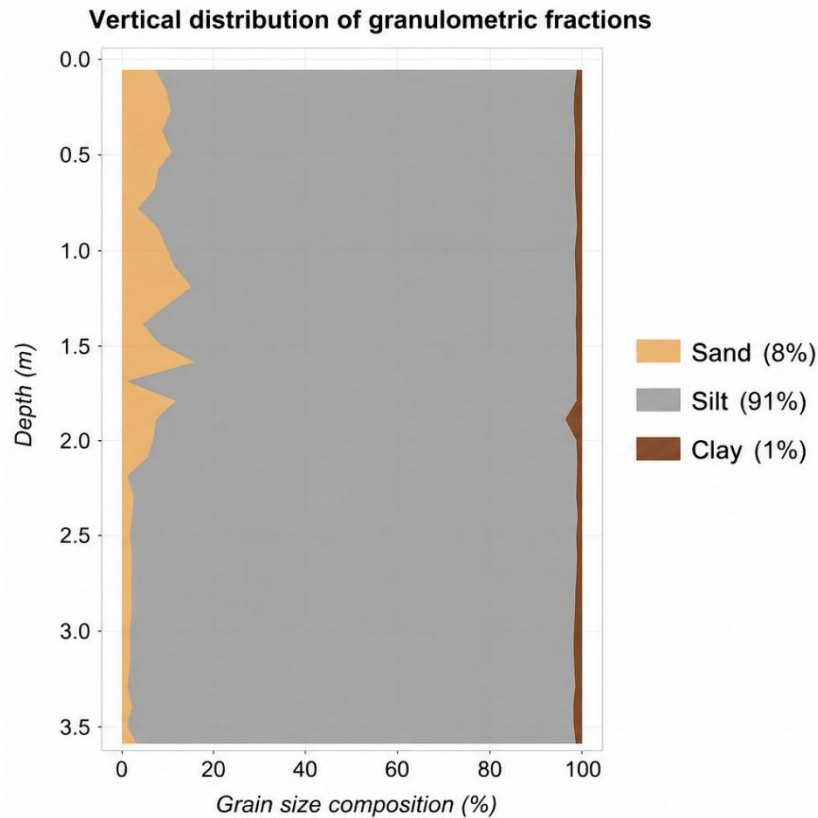


Fig. 5 – Sedimentary sections of core T1. Source: Author.

Statistical treatment

The Folk and Ward (1957) classification indicates that core T1 consists of coarse silt, very well sorted, with approximately symmetrical skewness and platykurtic kurtosis. According to the Shepard (1954) classification, T1 sediments were classified as silt or siltstone and sandy silt. However, based on the Pejrup (1988) classification, T1 represents the deposition of silt and sandy silt sediments under very high hydrodynamic conditions (Fig. 6).

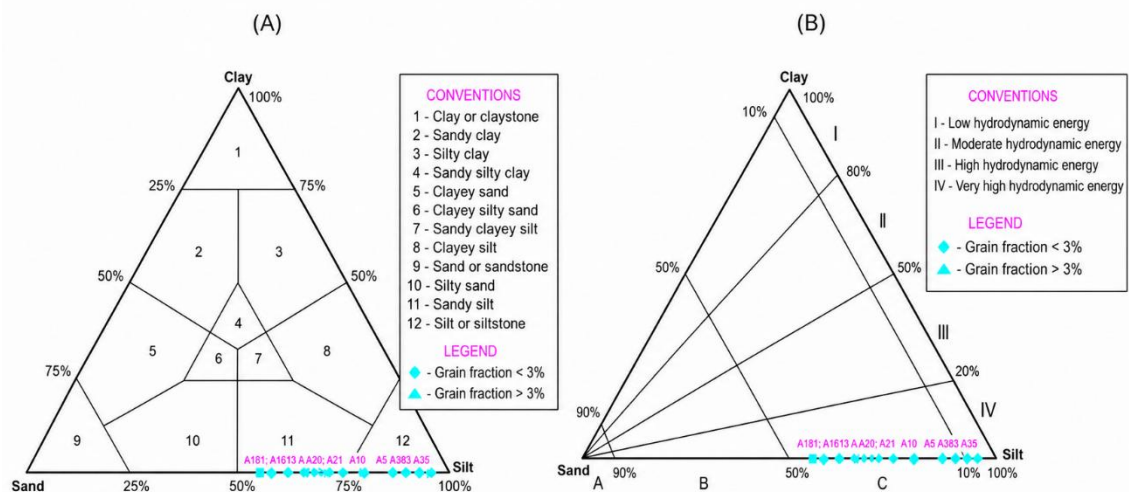


Fig. 6 – Sediment classification of core T1 according to Shepard (1954) (A) and Pejrup (1988) (B). Source: Author

For core T2, the Folk and Ward (1957) classification indicates coarse silt, ranging from very well sorted to well sorted, with approximately symmetrical skewness and platykurtic kurtosis. According to the Shepard (1954) classification, T2 was classified exclusively as silt (Fig. 7). However, the Pejrup (1988)

classification indicates the deposition of T2 sediments as silt and sandy silt under very high hydrodynamic conditions (Fig. 7).

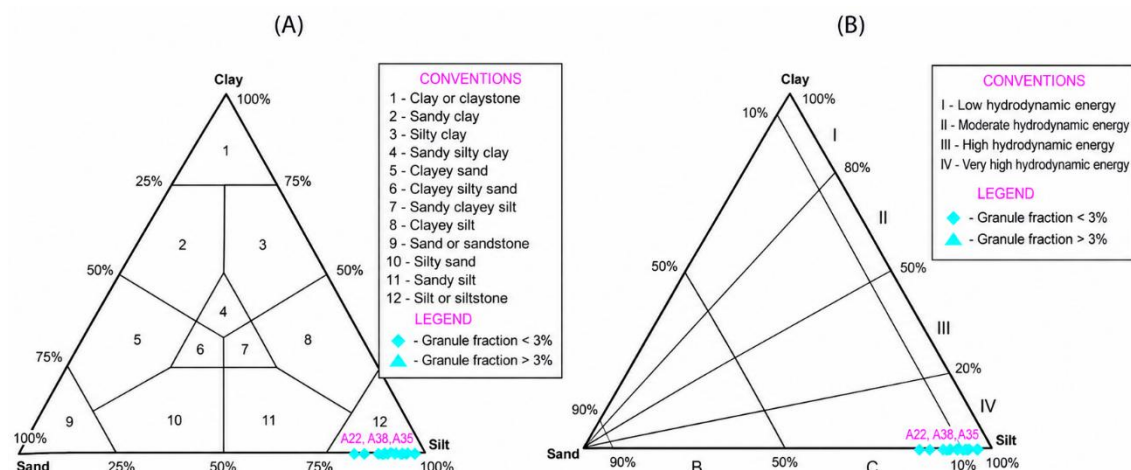


Fig. 7 – Sediment classification of core T2 according to Shepard (1954) (A) and Pejrup (1988) (B). Source: Author.

Quantification of organic matter and calcium carbonate

In core T1, the OM content reached 22% at the top and 11% at the base, with an average value of 15% (Fig. 8). The lowest OM content was 8% at 2.0 m depth, while the highest value reached 23% at 1.80 m. The CaCO_3 content was 11% at both the top and base, with an average value of 6%. The highest CaCO_3 content was recorded at 2.20 m depth, reaching 22%, whereas the lowest value was observed at 1.70 m, with 1%.

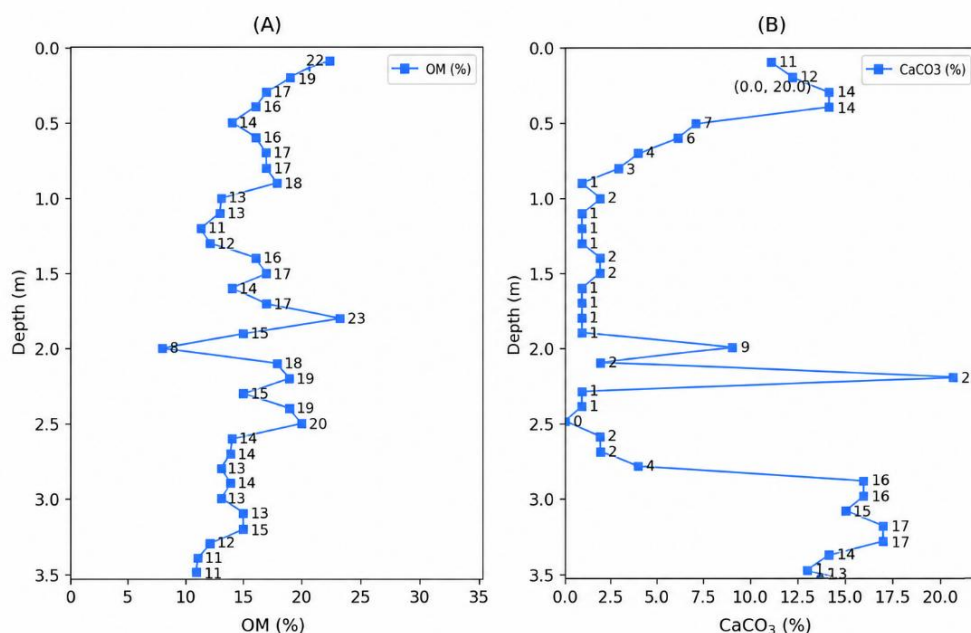


Fig. 8 – Organic matter content (A) and calcium carbonate (B) graphs for core T1. Source: Author

For core T2, the OM content was 10% at the top and 9% at the base, with an average value of 13% (Fig. 9). The lowest OM content was observed at 1.90 m depth, with 5%, while the highest value was recorded at 0.30 m depth, reaching 33%. In T2, CaCO_3 contents ranged from 2% at the top to 2% at the base, with an average value of 2%. The highest CaCO_3 content was 5% at 2.10 m depth, and the lowest was 1% at 0.30 m.

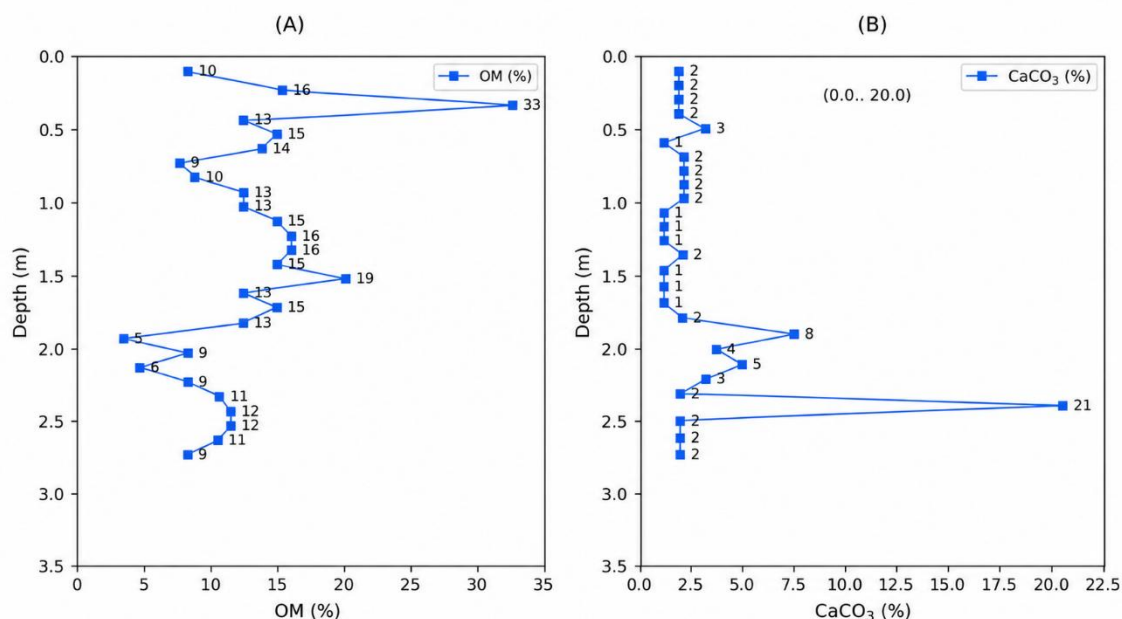


Fig. 9 – Organic matter content (A) and calcium carbonate (B) graphs for core T2. Source: Author.

Larsonneur classification

According to Larsonneur (1997), core T1 was classified along its entire length (3.59 m) as lithoclastic terrigenous mud, presenting CaCO₃ contents below 30% (ranging from 1% to 22%). Similarly, core T2 was also classified as terrigenous mud, with CaCO₃ contents below 30% (ranging from 1% to 21%).

DISCUSSION

Texture and Grain Size

Lins (2022) conducted a study of sediment cores from the continental slope of the Ceará Basin at depths greater than 2000 m. In this area, muddy sediments with olive-gray tones were identified, associated with minerals such as calcite, siderite, and magnetite. According to the classification proposed by Larsonneur (1977), these sediments were characterized as bioclastic, presenting bioturbation throughout their entire length. The predominant grain-size fractions in the cores were silt (81%), clay (9%) and sand (10%).

The analyzed grain-size statistical parameters included sorting, which is influenced by flow velocity and turbulence conditions in the depositional environment (Ponçano, 1986) and was determined through standard deviation (Folk and Ward, 1957). Kurtosis is related to sedimentary environments dynamics, with platykurtic values indicating low-energy conditions. Skewness, in turn, allows the identification of environments dominated by erosion (negative skewness) or deposition (positive skewness) of grain-size fractions (Duane, 1964).

When comparing the data obtained from the two continental slopes, the predominance of the silt fraction indicates a low-energy depositional environment, favoring the accumulation of finer sediments. In both continental slope areas, the results showed platykurtic and very platykurtic distributions, supporting the interpretation of low-energy depositional environment characterized by reduced sediment transport and a greater tendency toward sediment deposition. Furthermore, the observed positive skewness values are associated with the presence of fine particles and depositional conditions within the environment.

Yamashita et al. (2023) associate variations in mean grain size with hydrodynamic conditions in the depositional environment. According to the same authors, silt particles between 10 and 63 μm are transported by bottom currents with velocities of approximately 0.2 m s⁻¹ or higher. In this context, it can be hypothesized that part of the silt fraction deposited in the study area- whose provenance is associated with the Amazon River system (Andean origin), may be subject to reworking and transport by bottom currents. Furthermore, the occurrence of the North Atlantic Deep Water (NADW), whose upper portion

(2,000 – 3,000 m depth) corresponds to the depth range of cores T1 and T2, presents flows velocities compatible with those described by Yamashita et al. (2023) (de Freitas Assad et al., 2020).

MO and CaCO₃

Murray (2006) and Ransom (1998) highlighted the relationship between fine-grained sediments, particularly clay mineralogy, and the capacity for OM retention and preservation when compared to sandy sediments. Due to this association, lower-energy depositional environments tend to exhibit higher OM concentrations, as these settings favor the deposition and accumulation of fine sediments (Soares, 2014). In addition, terrigenous sediments derived from fluvial input and coastal erosion transport OM into marine environments, with its fraction decreasing as water depth increases (Bell et al. 2016).

The main sources of OM are related to terrestrial (allochthonous) OM transported by fluvial discharge, in which the Amazon River and Vermelho River are considered major contributors of detrital material and OM to their respective sedimentary basins (Romankevich, Vetrov and Ulyantsev, 2023; Tong et al. 2024). Another important source of OM is marine (autochthonous) OM, produced by primary marine producers (phytoplankton) within the euphotic zone. The nature of buried OM in marine environments is controlled by factors such as terrestrial sediment input, aquatic productivity, and coastal hydrodynamics (Tong et al. 2024).

Once available in the aquatic benthic environment, terrestrial OM may undergo remineralization, in which it is decomposed and recycled for reuse by primary producers. Another process is bioturbation, characterized by sediment remobilization caused by bioirrigation activities of benthic fauna (Kauppi and Villnas, 2022).

Terrestrial OM plays an important role in marine environments due to its contribution to interactions between fauna and the surrounding environment by acting as an energy source. The composition of terrestrial OM consists of a mixture of vascular plant material, black carbon, and eroded carbonate rocks. A considerable amount of this material is deposited in aquatic benthic environments, forming reservoirs for sedimentation and contributing to carbon and nutrient accumulation (Pardo et al. 2023; Bianchi, 2011).

The OM contents obtained in this study, ranging from 24% to 33%, differ from those expected based on previous studies, such as Coimbra (2018) and Martins (2019), considering the distance of sediment cores from the coast and the OM values reported. Reis et al. (2016) associated the high OM values with mass-transport events and/or the displacement of sediment deposits from the continental shelf to the continental slope. This interpretation is supported by the OM profiles obtained along the cores, which show variation between lower and higher values from the base to the top. Similar patterns were observed by Salimos (2018) and Campos (2017) regarding OM distribution on the continental slope of the PAMA basin.

Continental shelves and slopes are environments characterized by the mixing of allochthonous and autochthonous material. The continental slope is affected by several physical processes, including sediment gravity flows, unidirectional currents, and oscillatory flows, which promote sediment remobilization and reworking. Variations in sedimentation processes result in the mixing of autochthonous material (biogenic compounds, fecal pellets, and authigenic substances) and allochthonous material (terrigenous sediments, including lithogenic and biogenic components) (Tomassetti and Benedetti, 2020; Guli et al. 2014).

A relationship exists between terrigenous and carbonate sedimentation, influencing sediment distribution, with stronger continental influence occurring when CaCO₃ values are low (Knoppers et al. 1999). Studies conducted by Lopes (2018) and Lins (2022) reported average CaCO₃ contents ranging from 33.46% to 62%, with increasing CaCO₃ concentrations associated with greater distance from the coastline.

The average CaCO₃ content found on the continental slope of the PAMA basin was 6%, classifying the sediments as lithoclastic, composed mainly of terrigenous mud according to the classification of Larssonneur (1977). This indicates a strong influence of terrigenous sediment deposition. Vasconcelos (2018) highlighted the mixing process between autochthonous and allochthonous sediments, relating CaCO₃ concentrations in transported sediments to tidal oscillations, which contribute to the displacement of bioclastic sediments from the continental shelf. These sediments can subsequently be transported to the continental slope by turbidity currents and bottom currents. Turbidity flows transport large volumes of sediments and OM from the continental slope to the abyssal plain (Bigham et al. 2023).

Sediment sources

Physical weathering (caused by temperature variations, water, ice, and pressure) and chemical weathering promote the disaggregation and alteration of rocks, in which particles are eroded, removed, and transported. Rainfall and surface runoff contribute to soil erosion, while fluvial systems are responsible for riverine erosion, transporting the collected material to different depositional sources. The transport of finer grains is favored by the decrease in transport energy and channel slope along river courses (Ouillon, 2018).

Approximately 13.5 billion tons of sediments are transported annually through fluvial systems worldwide. In the case of the Amazon River, considered a mega-river, sedimentation rates reach $\sim 3\text{--}8\text{ cm yr}^{-1}$. Its extensive continental shelf contributes significantly to the input of terrigenous sediments into the seafloor (Nittrouer et al. 2021; Wittmann et al. 2011; Ouillon, 2018; Rijn et al. 2013; Restrepo et al. 2020).

From the Andes Mountains to the mouth of the Amazon River, the sediments transported along a 4,00 km course undergo transformations in their physical characteristics (grain size and shape) and chemical composition (mineralogy). The main drainage systems in the Andean headwaters include the Marañón, Ucayali, Napo, Beni, and Mamoré rivers, which, upon converging into the main tributaries of the Amazon, give rise to a discharge of “white waters” (turbid and rich in suspended sediments), carried by the Solimões and Madeira rivers. Along this course, part of the sediment load is retained in marginal floodplains, while the remainder continues downstream to Óbidos, located 800 km from the mouth, where the final stretch is marked by the interaction between Andean discharge, tidal oscillations, and oceanic influence (Nittrouer et al., 2020; Li et al., 2020; Wittmann et al., 2011).

The Andes Mountains are responsible for approximately 90% of the terrigenous material transported to the Atlantic Ocean through the Amazon Basin. The contribution of Andean sources to Amazon River sediment discharge is estimated to range from 2,300 to 3,100 Mt yr^{-1} , while the river’s water discharge is approximately 6,100 $\text{km}^3\text{ yr}^{-1}$. About 90% of the transported material is carried as suspended load, with 85–95% of the sediment mass consisting of silt and clay fractions (illite and chlorite associated with the Andean signal, and kaolinite related to intense weathering), while the remaining fraction consists mainly of quartz-rich sand (Queiroz and Marinho, 2026; Feng et al. 2025; Govin et al. 2015).

Coastal zones with high sedimentation rates are susceptible to the development of continental slope instability, resulting in landslides and/or megaslides, as well as gravitational flows toward areas with lower slope gradients (Restrepo et al. 2020). The continental slope is characterized by the deposition of fine-grained sediments (sedimentation rate of $\leq 0.003\text{ cm yr}^{-1}$) and weaker hydrodynamic conditions due to the transport and deposition of material originating from the continental shelf (Lacerda et al. 2023).

The results obtained by Azevedo (2014) support the contribution of Amazon River-derived sediments, particularly those deposited in the Amazon Cone, which are associated with the lower branch of the North Atlantic Deep-Water overflow and contribute to the sedimentary formation of the continental slope in the PAMA Basin. The total or partial loss of shear strength is responsible for most mass movements observed on continental slopes. This loss of strength is related to factors such as slope gradient, high sedimentation rates, high biological productivity, and gas generation (Stow et al. 1996).

CONCLUSION

The results indicate the predominance of fine-grained sediments, typical of low-energy depositional environments, with a tendency toward sediment deposition and preservation over time. The OM content on the continental slope of the PAMA was higher than expected for the area, corroborating previous studies that associate this enrichment with sediment mass movements from the continental shelf to the continental slope. In contrast, the low CaCO_3 contents observed may be attributed to the influence of terrigenous sediments transported from the shelf to the continental slope through the combined action of tidal oscillations and turbidity currents, which are responsible for downslope sediment transport.

The origin of the sediments deposited on the continental slope is directly influenced by the transport of terrigenous material from the Andes, controlled by variations in the sediment discharge of the Amazon River, the action of the North Brazil Current, the North Atlantic Deep Water, which flows at the depth investigated, and the trade winds. This interpretation is supported by the similarity between the results obtained for the PAMA basin study area and previous sedimentological studies conducted in the Amazon Cone.

These findings contribute to a better understanding of sediment deposition and redistribution processes on the continental slope of the PAMA sedimentary basin. They also highlight the influence of the Amazon River on the sedimentary dynamics of the Brazilian Equatorial Margin through the transport

of Andean-derived sediments, as well as the distribution of the sediments, OM, and CaCO₃ in the deep marine environment.

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