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FACIES AND STRATIGRAPHY OF PORTO DA BARRA GRANDE TIDAL CHANNEL, ICAPUI – CE

Ian Cerdeira de Oliveira Souza[1]; Guilherme Augusto Mendonça Maia[2]; Narelle Maia Almeida[3]; João Capistrano Abreu Neto[4]; George Satander Sá Freire[5]; Luana Nascimento Albuquerque[6]; Antônio Daniel da Silva Silveira[7]

[1]Mestrando em Geociências, Departamento de Geologia e Recursos Naturais, Universidade Estadual de Campinas (UNICAMP), Campinas/SP, Brasil.
ORCID: https://orcid.org/0000-0002-7867-0595
Email: cerdeiraian@gmail.com

[2]Mestrando em Geociências, Departamento de Geologia, Universidade Federal de Pernambuco (UFPE), Recife/PE, Brasil.
ORCID: https://orcid.org/0000-0002-2776-0240
Email: guilherme.maiageo@gmail.com

[3]Doutora em Geologia, Departamento de Geologia, Universidade Federal do Ceará (UFC), Fortaleza/CE, Brasil.
ORCID: https://orcid.org/0000-0003-2586-4502
Email: narelle@ufc.br

[4]Doutor em Geologia, Departamento de Geologia, Universidade Federal do Ceará (UFC), Fortaleza/CE, Brasil.
ORCID: https://orcid.org/0000-0002-4601-9386
Email: joaoabreuneto@gmail.com

[5]Doutor em Geologia, Departamento de Geologia, Universidade Federal do Ceará (UFC), Fortaleza/CE, Brasil.
ORCID: https://orcid.org/0000-0001-8850-7225
Email: satanderfreire@gmail.com

[6]Graduanda em Geologia, Departamento de Geologia, Universidade Federal do Ceará (UFC), Fortaleza/CE, Brasil.
ORCID: https://orcid.org/0000-0002-9798-6042
Email: lalalbuquerque855@gmail.com

[7]Graduando em Geologia, Departamento de Geologia, Universidade Federal do Ceará (UFC), Fortaleza/CE, Brasil.
ORCID: https://orcid.org/0000-0001-8213-777X
Email: danielsilver273@gmail.com

Abstract

The Icapuí coastal plain is composed by overlapping sea terraces, coastal strands, lagoons and wind deposits, bordered in the south by the cliffs of Barreiras Formation, and is morphologically cut by tidal channels where is located the Barra Grande Port. In general, the area presents regressive features during the Upper Holocene. However, tidal flats and channels can be formed under completely different conditions, providing important information about the evolution of this depositional environment. In order to characterize the Barra Grande Port tidal channel in a faciological and stratigraphical aspects, highlight the relationship between factories and understand how the short and long term changes occur in the region, it were stablished 16 facies grouped into three sedimentation stages (lower, intermediate and upper portions) based on six cores sampled in the area of study. The lower portion is basically composed of mud and fine sand. The intermediate portion is composed of medium to coarse sediments, high amount of shells and gravels, high ZTR index, moderate $CaCO_3$ content and low amount of organic matter. The upper portion is composed of fine to medium sediments, with roots and preserved shells, low ZTR index, $CaCO_3$ and organic matter contents. The sedimentary succession was interpreted as lagoon sediments, followed by transgressive and regressive deposits.

Keywords: Core; Tidal Flat; Sea Level Variations.

FÁCIES E ESTRATIGRAFIA DO CANAL DE MARÉ DO PORTO DA BARRA GRANDE, ICAPUÍ – CE

Resumo

A planície costeira de Icapuí é composta pela sobreposição de terraços marinhos, cordões litorâneos, lagunas e depósitos eólicos, limitados a sul por uma linha de falésias da Formação Barreiras e cortado, morfologicamente, por canais de maré, situado o Porto da Barra Grande. No geral, a região apresenta caráter regressivo durante o Holoceno Superior, contudo as planícies e os canais de maré podem ser formados em condições completamente distintas. A fim de caracterizar o canal de maré do Porto da Barra Grande diante dos aspectos estratigráficos e faciológicos, destacar a relação entre as fácies e compreender as mudanças de curto e longo prazo que ocorreram na região, foram estabelecidas 16 fácies agrupadas em três estágios de sedimentação (porções inferior, intermediária e superior) a partir de seis testemunhos retirados na área de estudo. A porção inferior é composta por pacotes lamosos e arenosos muito finos, a intermediária é dominada por sedimentos médios a grossos, alta quantidade de conchas e cascalhos, alto índice ZTR, teor de $CaCO_3$ moderado e baixo de matéria orgânica. A porção superior é composta por areia fina a média, presença de raízes, conchas preservadas, baixo índice ZTR e baixo teor de $CaCO_3$ e matéria orgânica. Interpretou-se a sucessão sedimentar como sendo inicialmente lagunar, seguido por depósitos transgressivos e regressivos.

Palavras-chave: Testemunho; Planície de Maré; Variação do Nível do Mar.

FACIES Y ESTRATIGRAFÍA DEL CANAL DE MAREAS DEL PUERTO DE BARRA GRANDE, ICAPUÍ – CE

Resumen

La llanura costera de Icapuí se compone de terrazas marinas superpuestas, arroyos costeros, lagunas y parques eólicos, limitados al sur por una línea de acantilados de la Formación Barreiras y cortados, morfológicamente, por canales de marea, ubicados en el Puerto de Barra Grande. En general, la región tiene un carácter regresivo durante el Holoceno superior, sin embargo, las llanuras y los canales de marea pueden formarse en condiciones completamente diferentes. Para caracterizar el canal de la marea de Porto da Barra Grande frente a los aspectos estratigráficos y faciológicos, para resaltar la relación entre las facies y comprender los cambios a corto y largo plazo que ocurrieron en la región, se establecieron 16 facies agrupadas en tres etapas de sedimentación. (porciones inferior, intermedia y superior) de seis núcleos tomados del área de estudio. La porción inferior está compuesta de paquetes muy finos de barro y arena, la del medio está dominada por sedimentos medianos a gruesos, gran cantidad de conchas y esquejes, alto índice ZTR, contenido moderado de CaCO3 y baja materia orgánica. La porción superior está compuesta de sedimentos finos a medios, presencia de raíces, conchas preservadas, bajo índice ZTR y bajo contenido de CaCO3 y materia orgánica. La sucesión sedimentaria fue interpretada como inicialmente laguna, seguida de depósitos transgresivos y regresivos.

Palabras-clave: Hoyo; Llanura de marea; Variación en el nível del mar.

1. INTRODUCTION

In shallow marine environments, tidal channels appear as a path for the tide flow, being the main sedimentation and morphology control of these environments. Bidirectional and gravity flows of nearby sediments are also common in tidal channels. In general, the sedimentation and morphology of tidal channels are highly sensitive to local variation in sea level, where the main records are found preserved in sandy banks and lateral accretions in meanders (Davis Jr. & Dalrymple, 2012).

Some authors have successfully published researches about the sedimentological and morphological dynamics in tidal channels (Féniès & Faugères, 1998; Lanzoni, 2002 and Perillo, 2003). However, the thematic was rarely approached in Brazil and in tropical regions. One of the main papers, produced by Vital et al. (2008), highlighted the morphodynamic effects in a tidal channel of the Rio Grande do Norte coast and identified three cycles of granodescence in a core, contributing to the understanding of the long and short term changes in these channels. However, in the State of Ceará, there are no studies that address this theme, with a gap of data for comparison with similar deposits or discussion about the genesis and evolution of the channels in that region.

The coastal plain of Icapuí, a unit of great ecological and geological diversity, is limited to the south by a line of cliffs, composed of Barreiras Formation, and extensive coastal strands overlaid by lagoons, marine terraces, wind and beach deposits where the Porto da Barra Grande tidal channel is morphologically discordant (figure 1). The quaternary evolution of the region was controlled by the action of different processes, whose chronological occurrence is difficult to pinpoint due to the great complexity of the associated morphostratigraphic units, with intercalations of different deposits (Maia, 2017).

Meireles (1991) discussed the sedimentary aspects of the coastal plain of Icapuí, proposing a model of evolution for the last 5100 years, explaining the formation of the main components present in this plain, where, in general, it is considered that regressive events were responsible for the formation of coastal strands and sand spurs, formed on the Pleistocene marine terrace deposited in very different conditions from the current ones.

Sea level variations were limited by the cliffs of Barreiras Formation, occurring construction stages of Pleistocene, Holocene and transgressive marine terraces, responsible for the erosion of this Formation (Souza et al., 2008). Other authors, through core analysis and other methods, also studied the Icapuí Plain (figure 02), such as Maia (2017) who proposed five stages for the evolution of Icapuí region focusing on the formation of the coastal strands, suggesting the beginning of the sedimentation from the southeast to the northwest in a prograding environment and strongly controlled by neotectonic events. Then, the advancement of the coastal strands is interrupted, causing a hydraulic busbar for the drift current and the generation of the tidal channel.

Thus, this study aims to characterize the Porto da Barra Grande tidal channel in both stratigraphic and faciological aspects, highlighting the relationship between the sedimentary facies and the short and long-term changes that occurred in the region, thus, contributing to sedimentary evolution of the Icapuí Coastal Plain.

2. MATERIALS AND METHODS

2.1. Study area

The study area, located in Icapuí, the far east city of Ceará State, is within the limits of environmental protection of the Barra Grande area, promulgated by the Municipal Law No. 298/2000 (CEARÁ, 2000), established on May 12, 2000. The Barra Grande tidal channel is located in a mangrove region and is characterized by little branching and only three shallow secondary channels, approximately four meters deep during high tide.

The region has predominance of SE, ESE, E and NE directions of wind, with average speeds of 4.5 m/s and peaks of 11 m/s (Meireles, 2013), remobilizing a large amount of sediments. According to Monteiro Neto (2003), Ceará coast has a straight profile, favoring the occurrence of waves, which in Icapuí have low energy and break towards SW. The tide, the main transport agent in the study area, is classified as semi-diurnal and ranges between 0.2 and 3.7 meters.

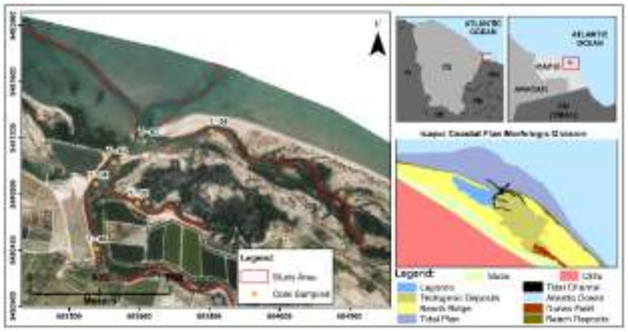

Figure 1 – Map of the study area and the sample points in Porto da Barra Grande tidal channel, Icapuí - CE. Source: Authors (2020).

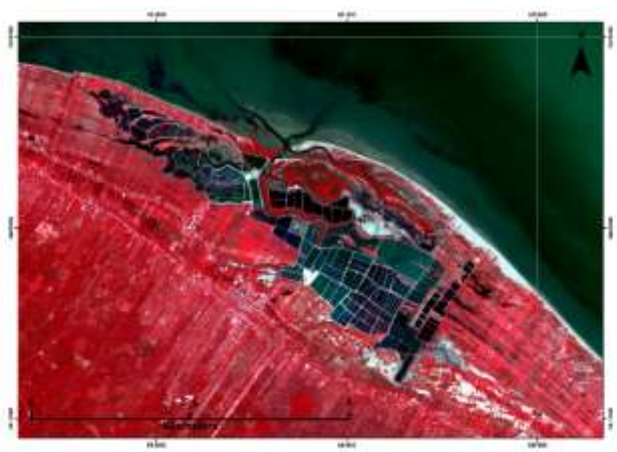

Figure 2 - NW-SE coastal strands limited to the south by a cliff line and cut by lagoons, tectogenic deposits and tidal channels, with a small overlap of eolian and coastal deposits of Icapuí Tidal Plain (RapidEye image, composition R5G1B4). Source: Authors (2020).

2.2. Methodology

The current study was divided into two stages, comprehending the sample colletion in the field and the samples analysis in the laboratory. Initially, the fieldwork aimed to collect six cores in PVC pipes with two meters length approximately and ten centimeters of diameter, using a vibrating hammer that consists of a two-stroke engine, responsible for producing repeated mechanical pulses, capable of insert the pipe into the deposit in question. In total, four cores were collected in the main channel and two in the branches (figure 1).

The second stage consisted of processing the data in the laboratory. The cores were described according to the Figueiredo Junior (1990) methodology, highlighting textures, contacts between layers, structures and apparent coloring. The cores were compartmentalized into facies, which were separated, dried and sieved, following the nominal classification proposed by Wentworth (1922). In total, 54 samples were analyzed. The fractions of fine and very fine sand (total of 10 facies) were submitted to the densimetric separation by bromorphorm ($CHBr_3$) isolating heavy minerals that were analyzed by the strip counting method in thin sections impregnated with balsam from Canada (Galehouse, 1971), identifying 50 minerals in each section. Initially defined by Hubert (1962), the ZTR index consists of counting the minerals zircon, tourmaline and rutile, indicating the degree of transport or mechanical rework, disregarding effects after deposition, such as dissolution, as these minerals are classified as ultra-stable. After the strip counting, the percentage of the cited minerals in relation to the total counted was calculated, considering the highest values related to more energetic environments.

An aliquot of the samples was separated and macerated, until acquiring a granulometry smaller than 0.2 mm, in order to analyze the contents of calcium carbonate and organic matter. The carbonate content analysis was performed using the modified Bernard Calcimeter (Lamas et al., 2005) and the organic matter content was obtained following the modified Walkley & Black (1934) oxidation method.

In order to correlate the geodesic position of the cores, a topographic precision survey was performed, concomitantly with the core sampling, using a pair of Trimble R3 receivers, with 5 mm horizontal and vertical nominal precision. The ages presented in this work are considerably relative, considering the environments interpreted through the cores, expected sea level in relation to the channel position and sedimentary record of identified stages, using the sea level variation curve proposed by Bezerra and collaborators (2003).

3. RESULTS AND DISCUSSION

The tidal channel of Porto da Barra Grande presents muddy and sandy packages, all deposited under underwater conditions, with varied composition and structures. In order to facilitate the interpretation, the core facies were segregated into four groups (figure 03), which were subdivided according to the granulometry and total percentage of mud and gravel, following the division proposed by Nascimento Junior (2010).

Variations in energy and sediment supply are the main conditioning factors of the channel deposits, being controlled mainly by a transport agent represented by the tidal currents. Through the compilation of the interpreted facies (figure 03), three stages of sedimentation under different conditions stand out.

Table 1 – Grouping and description of the interpreted facies . Source: Authors (2020).

Group	Facies	Description
Terrigen without structure	AMF***T***l	Very fine sand with a predominance of terrigen, without structures, high percentage of mud (10 to 25%) and moderately sorted.
	AMF***T***	Very fine sand with a predominance of terrigen, without structures, low percentage of mud and gravel, well sorted.

	AF***T***l	Fine sand with a predominance of terrigen, without structures, high percentage of mud (10%) and poorly sorted.
	AF***T***	Fine sand with a predominance of terrigen, without structures, low percentage of mud and gravel, sorting ranging from moderate to poor.
Presence of more than 5% of vegetable fragments	AMF***V***l	Very fine muddy sand (contents between 10 to 15%), with the presence of oxidized vegetable fragments, which may present subhorizontal laminations and small preserved shells, moderately sorted.
	AF***V***	Fine sand with a low percentage of mud and gravel, with the presence of oxidized vegetable fragments, probably roots, and may present small shells of transported bivalves, but without preferential guidance, with moderate sorting.
Terrigen with structure	AMF***T***l	Silt and clay with sub-horizontal laminations, which may present shells of gastropods and bivalves, normally fragmented, and very poor sorting.
	AMF***SH***l	Very fine muddy sand (contents between 11% to 23%) with sub-horizontal laminations and very poor sorting.
	AF***SH***l	Fine muddy sand (contents above 15%) with sub-horizontal laminations and poor sorting.
Presence of more than 5% of carbonate compounds	AMF***C***l	Very fine muddy sand (5 to 18% mud) with emphasis on the accumulation of shells of fragmented mollusks and sorting ranging from moderate to good.
	AMF***C***	Very fine sand and low percentage of mud and gravel, high content of shells dispersed in the matrix, normally fragmented, with good sorting.
	AF***C***	Fine sand and low percentage of mud and gravel, high content of shells dispersed in the matrix, usually fragmented, with moderate sorting.
	AF***C***c	Fine gravel sand (above 6% gravel) and bioclasts, mainly molluscs, mostly preserved, moderately to poorly sorted.
	AM***C***	Medium sand with a mixture of carbonate compounds (shells and corals of the lithotaminium type), preserved and fragmented, with very poor sorting.
	AM***C***c	Medium gravel sand (6 to 10% of gravel) with carbonate compounds (shells and corals of the lithotaminium type) dispersed in the matrix.
	AG***C***c	Coarse gravel sand (11 to 15% of gravel) with a mixture of carbonate compounds (shells and corals of the lithotaminium type), with poor sorting.

The first stage, positioned at the base of the cores, stands out for presenting extensive muddy and sandy packages with a high percentage of mud and sub-horizontal laminations (LSH, AMFSHl, AFSHl), characterized by depositions in parallic environments (figure 4), with sedimentation by decantation. The section in question is characterized by the lowest levels of calcium carbonate, varying between 50 and 65%, with rare horizons presenting high content due to the accumulation of bioclasts. The contents of organic matter, however, are high, ranging from 0.6 to 2%. The ZTR index indicates mature sediments, with percentages between 4 and 16% (figure 5), and the poor sorting of sediments (LSH, AMFSHl, AFSHl) suggests contributions by gravitational transport. This stage was interpreted as a low-energy lagoon environment developed during a regressive event, which provided conditions propitious to a fine sedimentation with sub-horizontal lamination. Sporadic inputs due to gravitational fluxes justify the presence of fragmented shells and poor sediment sorting.

The second stage, located in the intermediate portions of the cores, is characterized by sedimentation under high energy conditions. It stands out from the other stages due to the coarser granulometry and predominance of shells in practically all facies (AFC, AFCc, AMC, AMCc, AGCc). The mud content is basically null, and the stage has a well-marked limit by abrupt contact with the lower portions, which belong to the first stage (figure 4). The second stage showed a high ZTR index, varying from 8 to 24%, indicating a sedimentary maturity even greater than the sediments of the first stage, and the carbonate contents are the highest among those analyzed, ranging from 60 to 95%. In contrast, the measured organic matter contents were low, varying from 0.1 to 1% (figure 5). This stage was interpreted as a deposit formed during a high energy transgressive system that caused great erosion and rework of past coastal strands.

The third stage, positioned at the top of the cores, was deposited in low energy conditions (AMFTl, AMFT, AFT) with decanting moments in parallic environments (LSH). It differs from the other stages by the predominance of fine and very fine sand with the presence of vegetable fragments (AMFVl and AFV), sometimes presenting thin strata with the presence of fragmented bioclasts, originally deposited at the bottom of the channel and reworked by episodic currents (AMFC, AFC, AFCc). In general, this stage is limited by a gradual contact at the bottom (figure 4). The levels of calcium carbonate and organic matter ranged from 30 to 80% and 0.1 to 1.4%, respectively (figure 5). The ZTR index presented low percentages, not exceeding 3%, indicating the immaturity of these sediments. Identified in all six cores, this stage was interpreted as having been deposited in an intertidal environment during a regressive system with a small water depth, as there are signs of continental vegetation, but it also allowed the development and deposition of aquatic organisms such as bivalves.

In general, the carbonate contents show thinning towards the continent, demonstrating a decrease in the marine contribution in this direction. The second sedimentation stage behaves in a very similar way, where the last record occurs in the T04 core (figure 4), indicating the maximum point of the transgression influence approximately. The deposition of the described facies had as the main controlling agent the relative variation of the sea level. The Porto da Barra Grande tidal channel was subjected to three sedimentation stages with different characteristics, where, initially, in a regressive system (first stage), a small coastal barrier system was able to isolate small bodies of water, forming lagoons and depositing sediments from the first stage. Subsequently, this system was eroded by a transgressive event (second stage) which caused a higher energy sedimentation composed of reworked sediments and, finally, a new marine regression was installed (third stage), lasting until today (figure 6), developing an intertidal environment.

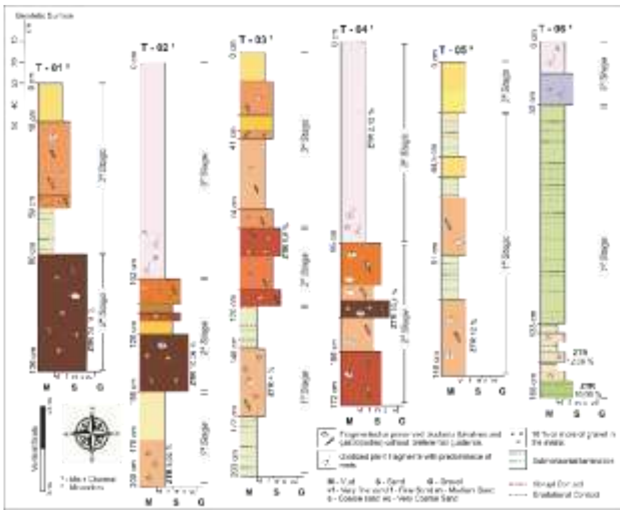

Figure 3 – Stratigraphic columns of the six cores described illustrating the stages of sedimentation and colored according to the interpreted facies. Source: Authors (2020).

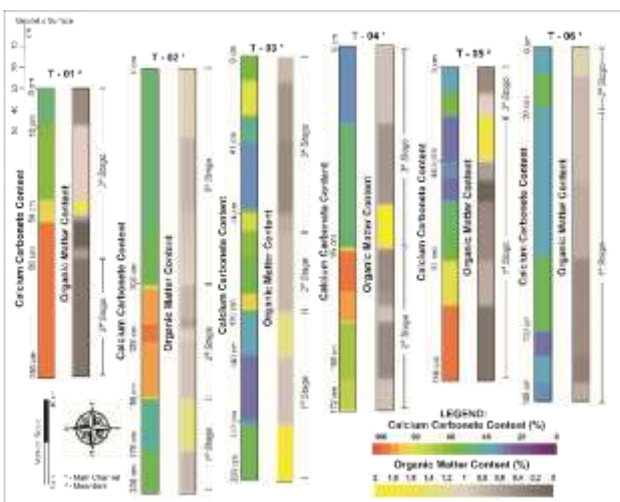

Figure 4 – Vertical sections of carbonate and organic matter contents analyzed in selected core samples. Source: Authors (2020).

According to the envelope curve of sea level variation proposed by Bezerra et al., (2003) constructed based on paleoindicators (figure 6), the sea level was approximately 2.5 to 4 meters higher than the current one in the coast of Rio Grande do Norte, extending from 5730 to 4630 years cal BP. Subsequently, there was a relative drop in sea level, followed by a positive oscillation that occurred from 2100 to 1100 years cal BP which was interpreted by the authors as a disturbance of the glacio-isostatic sea level trend predicted by Peltier (1998). Considering this curve, it is suggested that the three sedimentation stages interpreted in this study occurred, approximately, during the last 4630 years cal BP (figure 06). The first stage corresponds to a regressive system represented by the drop in sea level. However, it cannot be inferred when this stage started. The second stage was interpreted as a transgressive erosive system and occurred more quickly, starting 2100 years ago cal BP and lasting up to approximately 1550 years cal BP, when the third stage began with a relative sea level drop and lasting up to the present day.

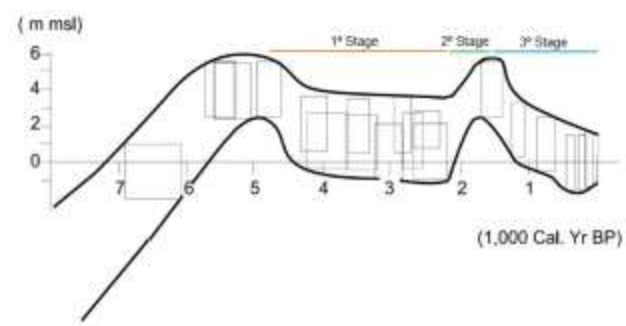

Figure 5 – Envelope curve of the Sea Level Variation of the northern coast of the Rio Grande do Norte state associated with the proposed sedimentation stages. Source: Modified by Bezerra et al. (2003).

In addition to the core data, the Icapuí Coastal Plain presents indicators of sea level variations that demonstrate a transgressive system, responsible for the generation of marine terraces and cliffs along the plain, with a progressive transition to a regressive system, responsible for forming coastal strands and lagoons.

4. FINAL CONSIDERATIONS

The interpretations of the Porto da Barra Grande tidal channel were based on 6 vibration cores collected over the study area, adding 54 analyzed samples, 16 described facies, 10 sections with a total of 500 identified minerals and 108 chemical analyzes, producing 6 stratigraphic columns and 12 vertical sections of calcium carbonate and organic matter contents.

The entire data set allowed the interpretation of three sedimentary stages, deposited under different conditions and controlled by sea level fluctuation. The first and third stages were deposited in regressive conditions at low sea level, and the second stage in transgressive conditions.

The sedimentation model of the Porto da Barra Grande tidal channel is in accordance with the curve of relative sea level, proposed in the literature and with the sedimentary dynamics commonly found on the northeastern Brazilian coast. Thus, the model can be used for comparison with other similar deposits and for the correlation space-time with the other sea level variation indicators present in the region. It is suggested for future work to date sedimentological samples to make possible the accurate tie of the evolutionary model throughout the Holocene.

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