Anuário do Instituto de Geociências - UFRJ
www.anuario.igeo.ufrj.br

Sedimentary Dynamic and Composition of a Tidal Channel in a Tropical Hot Semi-Arid Environment, NE Brazil

Composição e Dinâmica Sedimentar de um Canal de Maré em um Ambiente Tropical Quente Semi-Árido, NE do Brasil

Ian Cerdeira de Oliveira Souza[1]; Guilherme Augusto Mendonça Maia[2]; Narelle Maia de Almeida[3]; João Capistrano Abreu Neto[3] & George Satander Sá Freire[3]

[1]*Universidade Estadual de Campinas, Instituto de Geociências, Departamento de Geologia e Recursos Naturais, Rua Carlos Gomes, 250, 13083-855, Campinas, SP, Brasil*
[2]*Universidade Federal de Pernambuco, Centro de Tecnologia e Geociências, Departamento de Geologia, Avenida da Arquitetura, s/n, 50740-550, Cidade Universitária, Recife, PE, Brasil*
[3]*Universidade Federal do Ceará, Centro de Ciências, Departamento de Geologia, Campus do Pici, Blocos 912/913, 60440-554, Fortaleza, CE, Brasil*
E-mails: cerdeiraian@gmail.com; guilherme.maiageo@gmail.com; narelle@ufc.br; joaoabreuneto@gmail.com; satanderfreire@gmail.com
Recebido em: 14/04/2020 Aprovado em: 07/10/2020
DOI: http://dx.doi.org/10.11137/2020_4_144_155

Resumo

Canais de maré compreendem um ambiente peculiar e dinâmico. Este trabalho objetiva reconhecer a distribuição e composição sedimentar de um canal de maré localizado numa área de clima semi-árido para compreender a dinâmica sedimentar da região. Esta região tem importância econômica e ambiental tendo em vista que diversas atividades têm sido desenvolvidas na área, tais como, indústria salineira e aquicultura com criação de camarão. Os resultados e discussões aqui apresentados sobre o canal de maré do Porto da Barra Grande foram baseados em 43 amostras superficiais distribuídas ao longo da a área, nas quais foram determinadas granulometria e os teores de carbonato de cálcio e matéria orgânica. Os dados permitiram a caracterização e compartimentalização do canal de maré em cinco seções e a interpretação da dinâmica sedimentar da área. As seções apresentam uma importante variação na composição e seleção. A seção 1 está localizada na zona supramaré, enquanto as seções 02, 03, 04 e 05 estão na zona intermaré. O tamanho médio dos grãos tende a diminuir em direção ao final do canal bem como a porcentagem de cascalho e os teores de carbonato de cálcio e matéria orgânica. Diferentemente, o teor de lama e a seleção aumentam em direção ao final do canal bem como a assimetria se torna mais positiva. De uma forma geral, o teor de carbonato é alto ao longo de todo o canal variando de 20 a 98% enquanto o teor de matéria orgânica é baixo, variando de 0 a 3%. Interpretou-se que esta distribuição sedimentar ocorre devido ao desenvolvimento de um barramento hidráulico na seção 03, causando um crescimento morfológico desta barreira arenosa, que atua como uma barragem hidraulica natural que dificulta o acesso da maré e, consequentemente, reduz a efetividade do transporte, acarretando na deposição de sedimentos finos nas áreas mais protegidas do canal (seções 04 e 05). As altas temperaturas e baixa pluviosidade do clima tropical quente semi-árido permitiu o desenvolvimento da sedimentação carbonática bem como o desenvolvimento de atividades antrópicas como a extração de sal em salinas artificiais, nas quais podem ter influenciado os baixos teores de matéria orgânica encontrados.

Palavras-chave: *Sedimentologia; Planície de Maré; Icapuí*

Abstract

Tidal channels comprise a peculiar and dynamic environment. This paper aims to recognize the sedimentary distribution and composition of a tidal channel located in a semi-arid climate area in order to understand the sedimentary dynamics of the region. This region has economic and environmental importance considering that several activities are developed in the area such as; salt industry and aquaculture with shrimp farming. The results and discussion presented here on the Barra Grande Port tidal channel are based on 43 superficial samples distributed in the area, in which we analyzed the grain-size distribution and the calcium carbonate and organic matter contents. The data enabled the characterization and compartmentalization of the tidal channel on five sections and the interpretation of the sedimentary dynamics of the area. The sections present an important variation in the composition and selection. The section 1 is located in supratidal zone while sections 02, 03, 04 and 05 are in intertidal zone. The grain-size mean has a tendency to decrease toward the end of the channel as well as the gravel percentage, and the carbonate and organic matter contents. Differently, the mud content and the sorting increase toward the end of the channel and the skewness becomes more positive. In a general way, the carbonate content is high throughout the tidal channel ranging from 20 to 98% while the organic matter content is low ranging from 0 to 3%. This sedimentary distribution occurs due to the development of a hydraulic dam on section 3, causing a morphological growth of this sand bar, which acts as a natural hydraulic dam, hampering the access of the tide and consequently reducing the effectiveness of the transport, resulting in the deposition of fine sediments in the sheltered areas of the channel (sections 04 and 05). The high temperatures and low rainfall of the tropical hot semi-arid climate allowed the development of carbonate sedimentation as well as the development of anthropic activities such as salt extraction in artificial salt pans which may have influenced the low levels of organic matter.

Keywords: *Sedimentology; Tidal Flat; Icapuí*

1 Introduction

Tidal flats are integrated systems. All tidal flat system, except those in areas dominated by wind tides, are composed of three basic environments: supratidal, intertidal, and subtidal. The supratidal sediments are those deposited above normal or mean high tide and exposed to subaerial conditions most of the time because they are flooded only by spring and storm tides; spring tides occur twice each month, and storm tides, the largest of all, occur sporadically during certain seasons and are less frequent. This environment includes, in arid regions, the sabkhas. The intertidal sediments are those deposited between normal high tide and normal low tide. Many intertidal flats are dissected by complex system of tidal channels, and the subtidal sediments are those which are seldom, if ever, exposed to air (Shinn, 1983).

Tidal channels comprise a special and dynamic subenvironment. They become shallower in a landward direction to the point where they disappear. They produce complex flow interactions due the action of tidal stream on channel and other nearby components like sand bars, vegetated marsh plataforms, mangroves and tidal flats. The asymmetric systems are commom and they trend to develop sand-bars and meanders on channel, creating convoluted transport pathways and residence times (Hughes, 2012). Several authors realized researchers focusing on sediment flux within tidal channels (Settlemyre & Gardner, 1977; French & Stoddart, 1992; Rinaldo *et al.*, 1999; Mudd *et al.*, 2010), however, most of them studied temperate and cold climate areas (Ashley, 1980; Dalrymple *et al.*, 1991; Shi *et al.*, 1995; Adams, 1997; Allen & Duffy, 1998; Fenies & Faugères, 1998; Gabet, 1998; Cleveringa & Oost, 1999; Allen, 2000; Ginsberg & Perillo, 2004; Rieu *et al.*, 2005; Hood, 2006, 2010) and few studies were developed on tropical regions (Vital *et al.*, 2008). In addition, the diference between deposition and erosion on tidal channels is influenced by several factors such as energy, grain-size, vegetation, cohesion between particles, channel morphology, among others. These factors are directly influenced by the climate. Thus, tidal channels in tropical regions can develop different structures and dynamics from those in temperate and cold climates and they lack information. Even more specific are the tidal channels developed in semi-arid tropical climates, occurring in Brazilian Northeast, Australia and some countries in Africa (Barletta & Costa, 2009).

The study area is located in northeastern Brazil (Figure 1), more specifically in the Barra Grande tidal channel, Icapuí, northeastern Ceará. According to FUNCEME (2018), the Ceará State has five climate types: Semi-arid Warm Tropical Climate, Mild Semi-Arid Warm

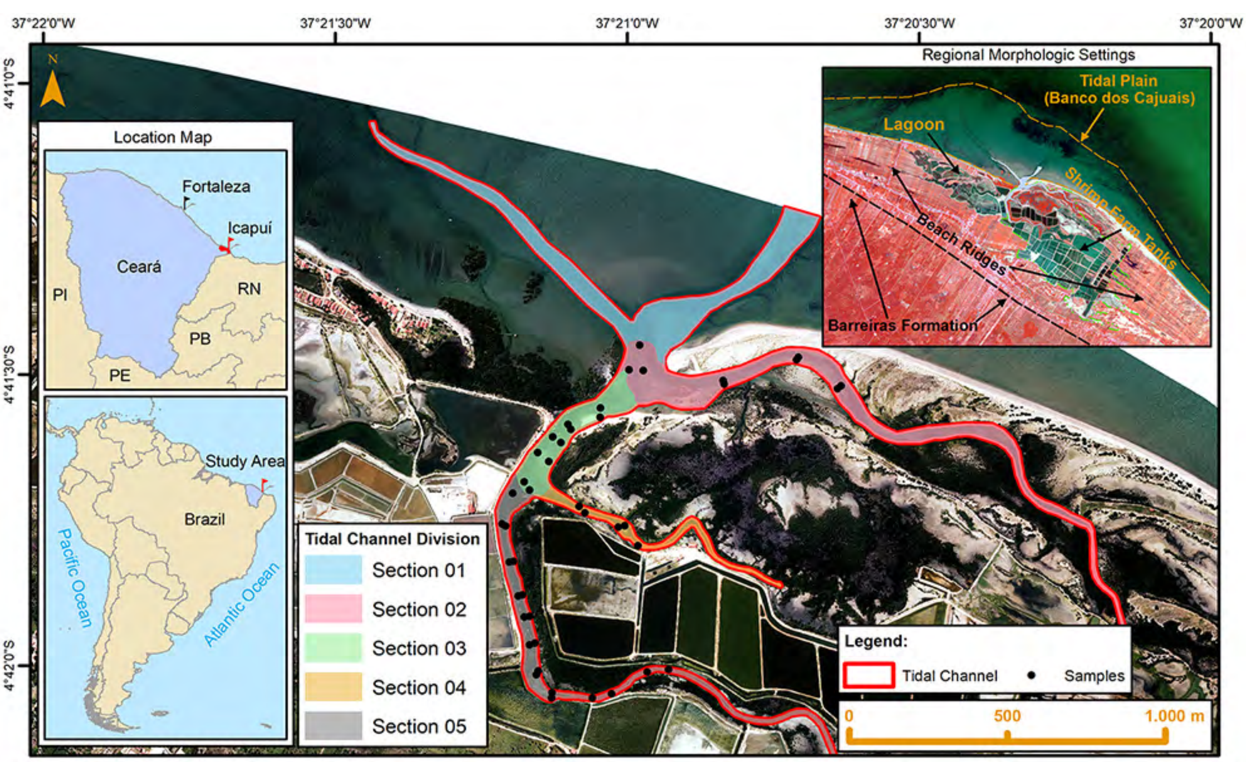

Figure 1 Location and section division map of Barra Grande Port Tidal channel showing the position of surface samples and simplified regional morphologic settings of the study area.

Tropical Climate, Sub-humid Warm Tropical Climate, Warm Humid Tropical Climate and Sub-warm Sub-humid Tropical Climate. The study area is located in a Mild Semi-Arid Warm Tropical Climate region. This climate is characterized by high temperatures, and irregularity and shortage of rainfall (*see regional settings*).

In general, in tidal channels there are inequalities between the magnitude of flood and ebb velocities or the respective periods over which they flow, that result from tidal range. Basically, there are two reasons to explain these inequalities. The first one is the finite amplitude effect which is directly linked to the water depth. The second cause is morphological. The presence of extensive intertidal regions has an impact on the timing of the flood and ebb. Particularly, channel with the presence of vegetation and anthropic structures have flows slower (Hughes, 2012). In the study area, both vegetation and anthropic structures are observed.

Historically, the municipality of Icapuí has its economy strongly associated with fishing and saline activity (Casemiro, 2017) where the Barra Grande port in the 60's emerged as an option for the exportation of salt production due to the ease of maneuver boats within the channel and the proximity of the salt flats to the channel margins. In addition, from 2000, shrimp farming activities began with the construction of tanks on the edge of the channel (Silva, 2012). Currently, the importance of the port has been minimized, being used only as a mooring and shipyard during the low tide due to the great variation of the tide in the region which in low periods leaves the channel surface partially exposed allowing the boats to leave only during the high tide. Faced with this problem, the fishing community exerts public pressure for possible dredging of the channel in order to restart the circulation of larger boats as occurred in the 60s.

Thus, the present study aims to analyze the particle size distribution within the Barra Grande Port tidal channel and recognize the calcium carbonate and organic matter contents in order to understand the sedimentary dynamics of the region and the possible causes of the progressive siltation that occurs in the area. In addition, this work aims to contribute to future environmental studies that may be developed in the area, providing a sedimentological characterization of the tidal channel in study.

2 Regional Setting

The Icapuí Coastal Plain is predominantly made up of deposits formed in regressive systems that are limited to the south by a line of cliffs formed by the Barreiras Formation formed during the last maximum sea level, followed by the deposition of coastal strands, marine terraces, dunes and lagoons (Meireles, 1991; Maia, 2017; Souza *et al.*, 2020). However, over the last 15 years the Icapuí coast has been subjected to intense transgressive events leading to erosion of natural deposits and anthropic buildings, followed by progressive sea level fall (Portela *et al.*, 2014; Braga & Medeiros, 2015; Barros, 2018).

The region also presents a great biological complexity with development of mangroves and tidal channels which shelter a wide diversity of fauna and flora (Silva, 2012; Ciarlini, 2014; Meireles *et al.*, 2017). The APA Manguezal da Barra Grande (Environmental Protection Area Barra Grande Mangrove created by the Municipal Law No. 298/00 of May 12,2000) is a sustainable use protected area that covers an area of 1,260.31 ha. This extensive and diverse area includes a variety of mangrove, estuary, beachfront, cliffs and salt flat habitats, but many locations have also been heavily impacted by salt evaporation and shrimp aquaculture activities. In particular, shrimp farming has increased rapidly in northeastern Brazil over the past several decades, resulting in a significant loss and alteration of mangrove and salt flat areas available (Carlos *et al.*, 2010; Burger *et al.*, 2019).

According to Meireles *et al.* (2013) the region presents winds in the SE, ESE, E and NE direction, with average speeds of 4.5 m/s and peaks of 11 m/s, remobilizing a large amount of sediment. During the first semester the N and NE directions prevail and during the second semester SE, E and ESE direction occur (Barros, 2018).

During flood periods the tidal presents velocity aproximally 2.76 m/s with 18.79 mg/l of suspended material (Maia *et al.*, 2019). The channel of Barra Grande Port presents an approximately rectilinear coastal profile where there is a predominance of low energy waves with breaking direction to SW (Monteiro Neto *et. al*., 2003), they are classified as semi-diurnal and with amplitudes ranging from 3.7 to 0.2 m with mid range of 8.2 s and the highest values were recorded between April and December.

The Banco dos Cajuais (BC) (Figure 1) covers approximately 540 ha and is 6 km wide. The BC is part of the Barra Grande tidal channel system, that flows through a tidal delta that may reach up to 3 km wide at low tide. In this area, low tide reveals extensive sand/mud banks, the largest tidal flat in the Ceará State (Carlos *et al.*, 2010).

Tropical semi-arid climate is characterized by high temperatures, irregularity and rainfall shortage. At Icapuí the principal precipitation rate occurs during February to May with historical average of 179.12 mm per month between 1988 to 2016 (Barros, 2018). During the rest of the year, between June to January considering the same range of years, the precipitation rate is about 27.89 mm per month (Barros, 2018). The average temperature is between 26ºC and 28ºC. However, the tropical semi-arid climate presents a thermal amplitude of 5ºC and commonly the temperature can reach 32ºC to 35ºC.

3 Material and Methods

This research was developed in two stages. Initially, the surface samples were collected along the tidal channel with a spacing of approximately 50 m, totalizing 43 samples. The samples were taken in the deepest part of the channel and in the margin, using an acrylic sampler. The collectiong was conducted during the low tide period as the channel is partially exposed during this period.

The second stage consisted of processing the samples in laboratory being analyzed for particle size, calcium carbonate and organic matter contents. The particle size analysis was performed by sieving the sample by agitating the set of sieves of specific sizes, following the Wentworth classification (Wentworth, 1922), from which the mean, skewness and standard deviation of each sample were calculated in order to assist the data interpretation. Calcium carbonate ($CaCO_3$) content was determined using an adapted Bernard calcimeter which basically consists of measuring the volume of carbon dioxide generated by the reaction of the sample with hydrochloric acid (Lamas *et al.*, 2005). Finally, the organic matter content was calculated by oxidation of the sample by reaction with phosphoric acid, following the procedures proposed by Walkley & Black (1934).

The environmental geodatabase was managed and interpreted using ArcGIS® ESRI software. In order to aid the data interpretation, the Inverse Distance Weighting (IDW) interpolation method was used to estimate values for areas that were not sampled. Basically, this deterministic method consists of calculating a certain value where the points with defined values influence the value of the nearest spaces, in other words, points closer to the empty space contribute more to the final value than the most distant points (Tomczak, 1998).

4 Results

The distribution of the sedimentary parameters along the Barra Grande Port tidal channel varies greatly (Table 1). The channel was compartmentalized in five distinct sectors according to the sedimentary patterns as well as the morphological and geographical characteristics (Figure 1). The section 01 is in subtidal zone and is morphologically composed of two channel branches with NW and NE directions, and between these branches there is an ebb tidal delta (Figure 1 and 5).

The section 02 extends from the mouth of the channel to the end of the first W-E branch and is bounded to the north by the beach barrier and to the south by the mangrove (Figure 1). In this section the grain-size mean ranges from coarse to very fine sand with a small area of mud (Figure 2A), the swekness varies from positive to very positive values (Table 1, Figure 2B) and the sorting is very poor. Regarding the composition, the section 2 presents 15 to 30% of mud and 15 to 25% of gravel (Table 1, Figure 3), while the analysis of $CaCO_3$ and organic matter evidenced 60 to 90% and 2 to 3%, respectively (Figure 3).

The section 03 (Figure 1) comprises a transition area between the subtidal and intertidal zones. The northern portion of this section is represented by a predominant grain size of medium to coarse sand and poor sorting (Figure 2). The gravel percentage is between 12% and 25% and the highest gravel rates are found downstream of the channel (Figure 3). In the southern portion, fine sand is the main grain size and the sediments are moderately sorted. Lower gravel rates (0% to 9%) were identified in this portion. The mud concentration showed slight variations across the section, between 0% and 5% and the skewness is negative to very negative (Table 1). Calcium carbonate content showed an important variation of impoverishment in the south of the section, with rates of 85% to 98% in the northern portion and 50% to 70% in the southern portion, while the organic matter content is close to 0%, except for a local area in the southern sector, which presented percentages around 1.7%.

The fourth section is configured as a branch of approximately 800 m and has W-E orientation. The granulometry presented a variation of mud to very fine sand, with mud percentage up to 30%, positive to very positive skewness and poor to very poor sorting. The percentage of calcium carbonate presented an average of 40% and the organic matter between 1.5% and 3%.

The fifth section is located in the intertidal zone and has two orientations: N-S in the initial portion and W-E in the final portion of the channel. The majority grain size is very fine sand with a percentage of gravel fraction close to 0% and a positive to very positive skewness. Some parameters, such as sorting and organic matter and mud contents presented clear variations when the channel orientation changes from N-S to W-E. The sediments in the N-S segment are moderately to well sorted and the organic matter content is close to 0%. Differently, in the W-E segment the sediments are poorly sorted and the organic matter content is around 3%. Besides that, the clay content decreases from the first to the second segment, ranging from 15% to 30% and 0% to 20%, respectively. In addition, the calcium carbonate content showed a low average (~ 25%) throughout the sector, as well as the percentage of gravel, close to 0%.

In order to better understand the depositional dynamics and transport processes inside the tidal channel it was calculated the correlation coefficient of the samples using the main statistical parameters. In general, the values indicate a linear correlation demonstrating that the characteristics of the deposit are directly related to the transport agent in question, disadvantaging the possibility

Section	Sample	Gravel (%)	Sand (%)	Mud (%)	Mean	Sorting	Skewn.	$CaCO_3$ (%)	O.M. (%)
Section 02	1	3.91	71.83	24.26	5.23	4.66	0.51	60.93	0.70
	2	7.14	85.78	7.08	1.79	2.74	0.27	85.58	1.80
	3	12.95	78.91	8.14	1.24	3.11	0.35	86.05	2.10
	4	6.88	91.54	1.58	0.51	0.94	-0.10	97.12	1.30
	5	5.48	83.99	10.53	3.07	2.43	0.01	66.05	1.70
	6	14.73	76.09	9.18	0.80	2.90	0.18	47.73	1.60
	7	6.60	93.40	0.00	1.65	1.53	-0.14	94.25	0.70
	8	0.00	90.93	9.07	3.36	0.53	0.15	54.37	0.30
	9	0.32	94.86	4.82	3.01	0.66	-0.40	72.96	1.00
Section 03	10	1.06	96.92	2.02	1.97	0.18	0.03	88.64	1.10
	11	0.34	95.74	3.92	3.03	0.70	-0.47	79.04	0.60
	12	0.26	96.62	3.11	3.08	1.59	-0.39	74.67	1.70
	13	1.80	95.60	2.60	2.71	1.01	-0.56	97.81	1.10
	14	2.44	95.78	1.78	2.16	1.19	-0.17	95.15	0.30
	15	16.86	82.72	0.42	0.04	1.04	-0.27	94.62	0.00
	16	3.50	94.34	2.16	1.30	1.15	0.10	98.34	0.60
	17	23.14	74.72	2.14	0.02	1.62	-0.16	95.56	0.30
Section 04	18	0.02	78.29	21.69	5.85	3.55	0.90	33.22	2.20
	19	0.23	91.33	8.44	3.36	1.59	0.53	28.89	0.90
	20	4.54	89.04	6.42	2.90	2.21	-0.10	42.37	0.80
	21	1.41	90.71	7.89	3.11	1.74	0.23	49.59	0.90
	22	0.61	81.16	28.23	5.68	3.34	0.91	29.30	3.00
Section 05	23	0.00	93.76	6.24	3.37	0.44	0.14	27.61	0.40
	24	0.00	91.54	8.46	3.40	0.50	0.18	28.54	0.50
	25	0.00	92.88	7.12	3.37	0.46	0.17	24.51	0.80
	26	0.15	88.21	11.65	3.49	0.44	0.34	32.98	0.30
	27	0.25	89.38	10.37	3.44	0.50	0.21	25.87	0.80
	28	1.54	91.51	6.96	3.40	0.51	0.07	19.32	0.80
	29	0.00	90.32	9.68	3.43	0.49	0.22	31.35	0.80
	30	0.14	90.78	9.08	3.42	0.52	0.14	29.45	0.80
	31	0.14	91.14	8.72	3.39	0.54	0.12	31.15	0.20
	32	1.16	91.88	6.96	3.34	0.69	-0.13	28.64	0.80
	33	2.40	92.31	5.30	2.03	1.32	0.11	67.34	0.80
	34	0.12	76.96	22.92	3.63	0.57	0.40	27.24	1.10
	35	1.31	93.96	4.73	3.18	0.70	-0.35	55.73	1.00
	36	0.00	92.58	7.42	3.39	0.44	0.22	34.16	0.60
	37	0.88	92.41	6.72	3.29	0.73	-0.21	40.40	0.00
	38	0.00	95.54	4.46	3.32	0.36	0.08	34.50	0.00
	39	0.71	93.34	5.96	2.81	1.79	0.19	43.96	1.20
	40	0.05	88.06	11.89	3.42	1.71	0.57	28.99	1.30
	41	0.13	90.87	9.00	3.35	1.64	0.51	24.41	0.70
	42	0.41	85.05	14.55	3.47	1.71	0.62	27.44	1.10
	43	1.91	98.11	0.00	2.40	1.14	-0.31	79.29	0.00

Table 1 Grain-size data and calcium carbonate and organic matter content.

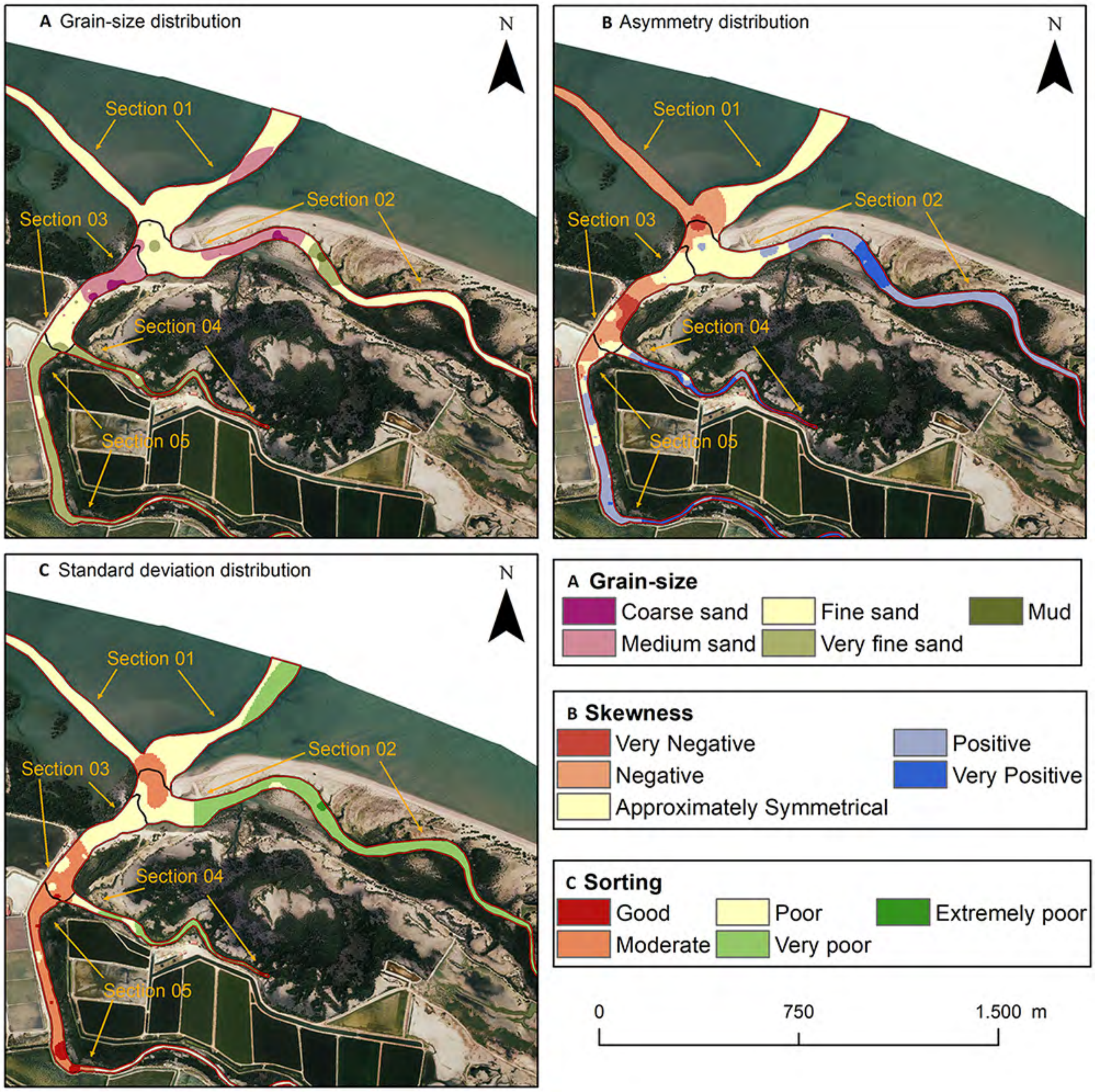

Figure 2 Map compilation of tidal channel of Barra Grand Port showing the distribution of diverse statistical parameters; A. Grain-size; B. Skewness; C. Standard deviation.

of lag sediments in the channel. However, by analyzing the clustering of sector samples it is possible to identify behavioral trends (Figure 4).

The samples of section 02 show a tendency to increase the values of standard deviation which are directly proportional to the grain-sinze mean (Figure 4A). The skewness is frequentely positive and is also directly proportional to the other statistical parameters, such as grain size mean and standard deviation (Figures 4B and 4C). This shows a tendency of the section system to accumulate fine grains and poorly sorted.

In section 03 the samples present grouped values showing low correlation between grain-size mean and standard deviaton (Figure 4A) and skewness (Figure 4B) where the graphics show an increase of grain-size mean values and a stabilization of standard deviation and

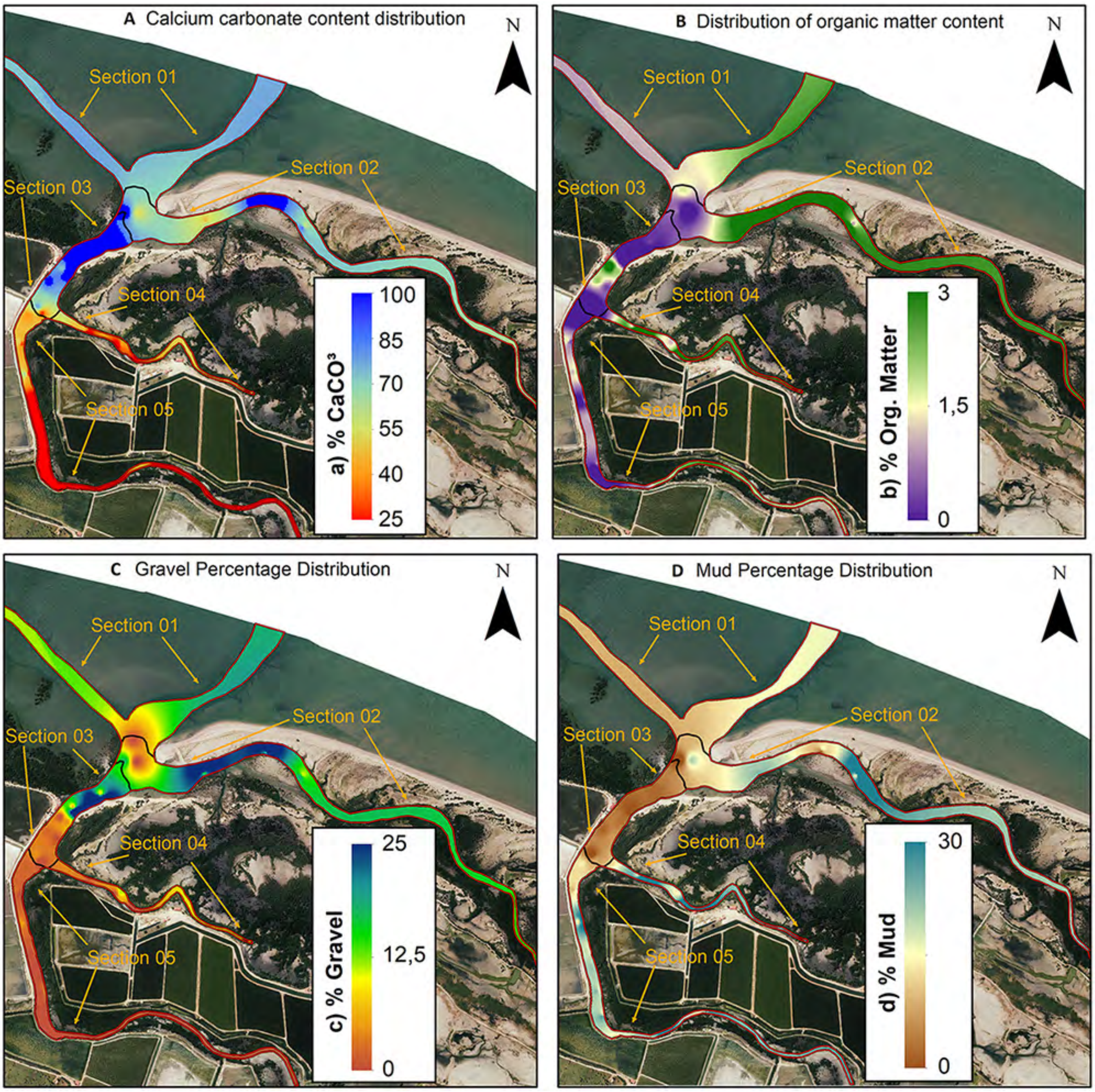

Figure 3 Map compilation of tidal channel of Barra Grande Port showing the distribution of the content of several components; A. Carbonate; B. Organic matter; C. Gravel; D. Mud.

skewness values. However, when these last two parameters are compared, the graphic shows a directly proportional correlation (Figure 4C). This occurs due to the tendency to accumulate coarse grains in this section of the channel.

Analyzing the samples of section 04 a dispersive pattern is observed. The graphics show positive values of skewness, high values of grain-size mean and standard deviation (Figure 4), similar to section 02.

In section 05 the samples present grouped and stable values of grain-size mean and standard deviation when correlated to skewness (Figures 4B and 4C). Differently, grain-size mean and standard deviation correlate inversely proportional, showing an indirect correlation (Figure 4A). In general, in depositional system is expected an indirect correlation between grain-size mean and skewness with an increase of sorting towards the sediment transport course

(McLaren & Bowless, 1985). However, in section 5, the innermost portion of the channel, mud and very fine sands with good to moderate sorting were deposited, showing that this environment has a peculiar dynamic. In addition, the results show a slightly tendency to accumulate coarse grains in this section, due to the positive values of skewness, in an environment dominated by fine grains.

In general, the sections 02 and 04 presented dispersed behavior, while the sector 03 behaved in a concentrated manner (Figure 4). This indicates that the branches of sectors 02 and 04 present a low transport effectiveness, while the main channel presents an effective transport (sectors 03). In the sections 02 and 04 there is a tendendy to accumulate coarse grains, while in the section 03, fine grains, highlighted by the skewness positive and negative, respectively. However, in the section 03 the standard deviation presents lower values than section 02 and 04 indicating a better sorting in that area.

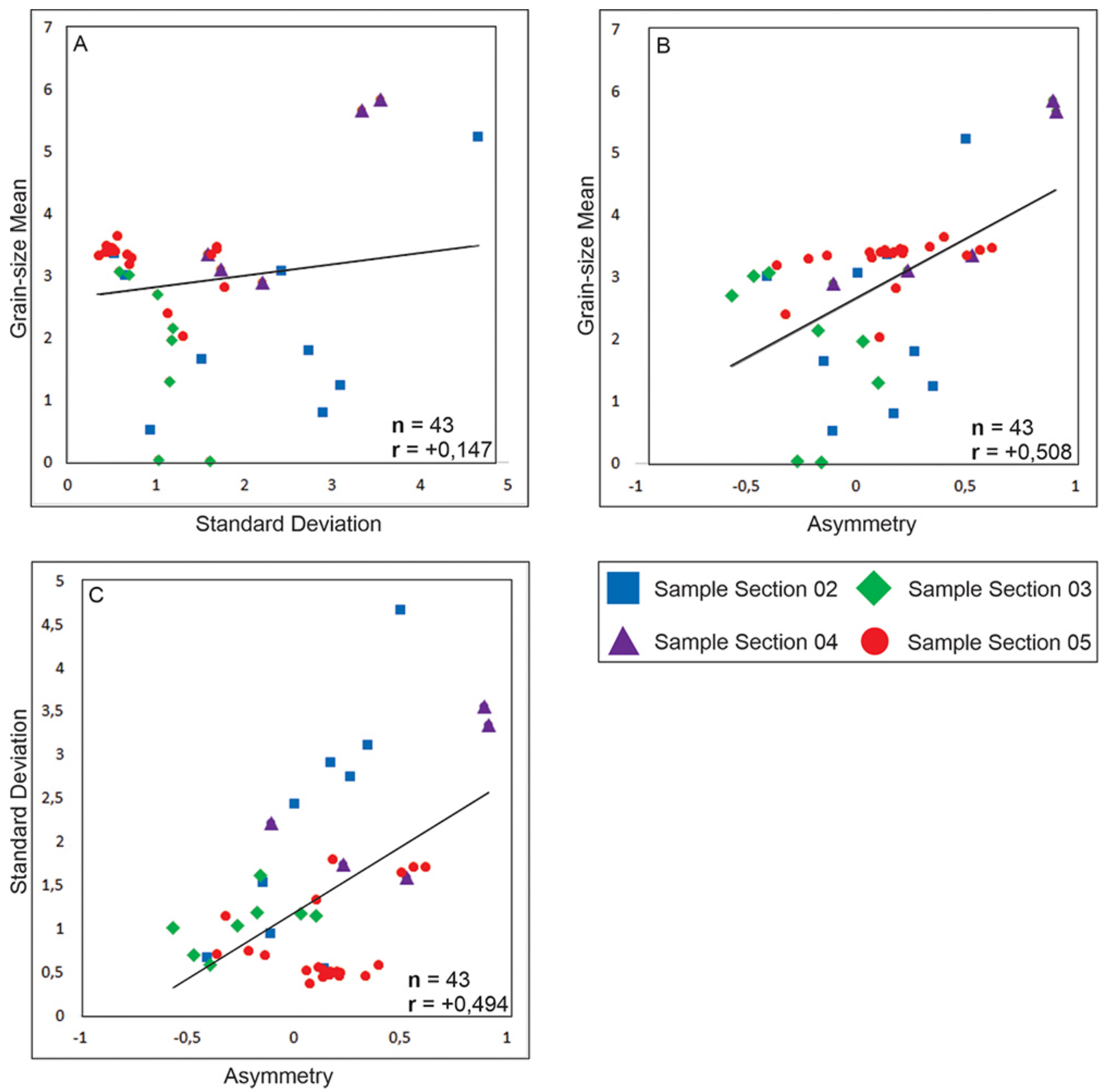

Figure 4 Correlation degree between the main particle size parameters ("n" represents the number of samples and "r" the correlation coefficient) showing the relationship between diverses statistical parameters; A. Grain-size mean and standard deviation; B. Grain-size mean and skewness; C. Standard deviation and skewness.

5 Discussion

The tide and channel network are important factors influencing of its morphodynamics and the distribution of the sedimentary facies. However, other factors also influenced in the sedimentation of Barra Grande tidal channel, such as, the morphology, the climate, the natural biological diversity, the anthropogenic activities, among others, as it is discussed as follow.

The high levels of organic matter in section 02 can be related to algae proliferation and consequently the attraction of bivalve organisms composed of carbonate carapaces (Figures 5B and 5C) (Nogueira, 2012; Marinho *et al.*, 2018; Silva, 2020). Thus, the levels of carbonates are equally high in this sector. The region closest to the point of entrande of the tide is susceptible to the highest transport energy and consequently to the deposits of coarser grained sediments. However, at the end of the branch the energy decreases depositing finer particles but the skewness of these sediments is positive. According to McLaren & Bowles (1985), positive skewness values indicate that the sediments tend to become coarser. Thus, it is suggested that there will be contributions of out-of-system sedimentary sediments (*e.g.* marine and eolic sediments) and indigenous biogenic sediments.

The sedimentary variability of the third sector was interpreted as a consequence of the cross-sectional morphology of the channel, which presents a northern zone closest to the shoreline, with greater distance between the banks, lower slope and depth. While in the southern zone there is anthropic interventions in the upstream margins. These activities resulted in narrowing of the margins, steep slope and greater depth. This region has great relevance to the other sectors of the channel due to the morphological growth of a sand bar (Figure 5A), which acts as a natural hydraulic dam, hindering the access of the tide and consequently reducing the effectiveness of sedimentary transport. Typically, tidal channels sizes and shapes are controlled by hydrodynamic flow that passes through channel inlet during the ebb and flood periods (Hughes, 2012). Thus, the sandbar development close to the tidal inlet (Figure 5F), in section 03, potentially influenced the sedimentation in the rest of the channel (sections 03,04 and 05). In the study area, this sandbar promoved the sorting increase, the grain-size mean and carbonate content decrease, and a slightly increase of skewness.

Despite the marjoritary influence of tidal variations, the channel presents a great influence of its morphology, where the banks and sand bar make a contribution to the flow within the channel. In the sector 03 there is also a hydraulic dam system (Figure 5A), being the point of greater sedimentary accumulation, mainly of coarser particles (Figures 1, 2A and 3C), while sector 05 accumulates finer particles in a low energy environment, due to the influence of this dam system in sector 03. While the branches 02 and 04 are directly correlated due to their geographical positioning, perpendicular to the main channel, the section 02 presents greater heterogeneity and coarser particles than the sector 04 which shows slight variation with predominance of fine particles. This occurs due to the different distance of the transport agent. Therefore, the progressive siltation that the channel has undergone may have been caused by the exaggerated growth of sector 03. During the flood tide the coarse sediments are trapped in the section in question and during the ebb tide the tide cannot effectively flow due to the hydraulic dam caused by the growth of the sand bar and thus the fine sediment that enters cannot be remobilized causing a sedimentary deficit. The speed difference within the channel also causes accumulation and erosion points such as in the northern part of section 03.

Modifications on the surrounding tidal system lead to a reduction in cross-section area and infilling of the channel with fine-grained sediments (*e.g.* Rieu *et al.*, 2005). Thus, the construction of salt pans, shrimp farming tanks and port structures influenced on growth of sand bar on section 03. These human activities exist in the region due to several favorable conditions, one of which is the tropical semi-arid climate. For example, the salt pans exist due to the geological and environmental settings of the area and, in compliance, according to Shinn (1983), some evaporitic minerals, such as halite, anhydrite and gypsum, are present on all modern arid tidal flats. In addition, according to Krögel & Flemming (1998), particles in warm waters settle more rapidly and entrained less readily than in cold waters. Thus, it is expected that tidal channel systems in tropical semi-arid climate need more effective hydraulic transport than in temperate climate.

Furthermore, the tropical semi-arid climate plays a role in the concentration of carbonate content in sediments of Barra Grande Port Tidal Channel due to its high temperature and low influx rates, allowing the development of a rich carbonate sedimentation. Similarly, other researches have identified high carbonate contents in several semi-arid environments (*e.g.* Gomes *et al.*, 2007; Abreu Neto, 2012; Moraes *et al.*, 2015).

Organic matters contents presented low vallues opposite to the expected due the presence of vegetation and mangrove around of the channel. This can be explained by the influence of shrimp farming and salt pans. According to Morrissey *et al.* (2014) the salinity contributes to the decomposition of organic matters. In the case of Barra Grande Port tidal channel, the shrimp farming and salts pans may have contributed for anomalous increase of salinity through the discharge of effluents (Figure 5D). Futhermore, the channel only has rainfall as source of freswater and the tropical semi-arid climate is characterized by low precipitation rates.

Figure 5 Compilation of pictures showing distribution of the elements in the channel; A. Sand bar developed closer to channel inlet; B. Algae proliferation on the section 02; C. Shelves accumulation on a lateral sandbar accretion; D. Effluent discharge point; E. Intense vegetation closer to the edge of the channel; F. Sandy bar on channel central portion.

6 Conclusion

The tidal channel was compartmentalized on five sections that presented important variation. The section 1 is located in supratidal zone while the sections 02, 03, 04 and 05 are in intertidal. The grain-size mean has a tendency to decrease toward the end of the channel as well as the gravel percentage, and the carbonate and organic matter contents. Conversely, the mud content and the sorting increase toward the end of the channel and the skewness becomes more positive.

This was attributed to the presence of sandy bars which act as natural hydraulic dam system, hindering the access of the tide to the innermost parts of the channel and consequently reducing the effectiveness of sedimentary transport, resulting in the deposition of fine sediments in the most sheltered areas (sections 04 and 05) and causing the progressive siltation in the area.

In a general way, the carbonate content is high almost throughout the tidal channel ranging from 20 to 98% while the organic matter content is low ranging from 0 to 3%. The high temperatures and low rainfall of the tropical semi-arid climate allowed the development of carbonate sedimentation as well as the development of anthropic activities such as salt extraction in artificial salt pans which may have influenced the low levels of organic matter.

This study characterized the superficial sedimentary deposit of Barra Grande Port tidal channel, correlating the results with the local hydrodynamics, channel morphology and climate. Therefore, this work shows data and offer possibilities that can help future environmental studies that may be developed in the area.

7 Acknowledgements

The authors thank the Laboratory of Marine and Applied Geology (LGMA) and the Department of Geology (DEGEO) of the Federal University of Ceará (UFC) for the funding and infrastructure granted for the development of this work. In addition, they are grateful to the entire team that assisted in the fieldwork.

8 References

Abreu Neto, J.C. 2012. *Análise textural e geoquímica dos argilominerais do talude continental do oeste do Ceará.* Programa de Pós-graduação em Geologia, Universidade Federal do Ceará, Dissertação de Mestrado, 77p.

Adams, P. 1997. Absence of creeks and pans in temperate Australian salt marshes. *Mangroves Salt Marshes, 1*: 239-241.

Allen, J.R.L. 2000. Morphodynamics of Holocene salt marshes: a review sketch from the Atlantic and Southern North Sea coasts of Europe. *Quaternary Science Reviews, 19*: 1155-1231.

Allen, J.R.L. & Duffy, M.J. 1998. Temporal and spatial depositional patterns in the Severn Estuary, Southwestern Britain: intertidal studies at spring-neap and seasonal scales, 1991–1993. *Marine Geology*, *146*: 147-171.

Ashley, G. 1980. Channel morphology and sediment movement in a tidal river Pitt River British Columbia*. Earth Surface Process and Ladforms*, *5*: 347-368.

Barros, E.L. 2018. *Erosão Costeira no Litoral do Município de Icapuí-CE na última década: Causas, consequências e perspectivas futuras*. Programa de Pós-graduação em Ciências Marinhas Tropicais, Universidade Federal do Ceará, Tese de Doutorado, 254p.

Barletta, M. & Costa, M.F. 2009. Living and Non-living Resources Exploitation in a Tropical Semi-arid Estuary. *Journal of Coast Research*, *56*: 371-375.

Braga, H. & Medeiros W.D.A. 2015. Percepção do avanço do mar na Praia da Barrinha, Icapuí/CE. *Geotemas*, *5*: 49-62.

Burger, J.; Mizrahi D.; Jeitner, C.; Tsipoura, N.; Mobley, J. & Gochfeld, M. 2019. Metal and metalloid levels in blood of semipalmated sandpipers (Calidris pusilla) from Brazil, Suriname, and Delaware Bay: Sentinels of exposure to themselves, their prey, and predators that eat them. *Enviromental Research*, *173*: 77-86.

Carlos, C.J.; Fedrizzi, C.E., Campos, A.A.; Matthews-Cascon, H.; Barroso, C.X.; Rabay, S.G.; Bezerra, L.E.A.; Meirelles, C.A.O.; Meireles, J. & Thiers, P.R.L. 2010. Migratory Shorebird Conservation and Shrimp Farming in NE Brazil. Final Report.

Casemiro, M.B. 2017. *Análise do plano de intervenção na orla marítima de Icapuí-CE à luz dos sistemas ambientais e sociais: a área da Barra Grande e Barreiras de Sereia.* Programa de Pós-graduação em Geografia, Universidade Estadual do Ceará, Dissertação de Mestrado, 173p.

Ciarlini, C. 2014. *Aproveitamento Econômico de Explotação dos Recursos Minerais na Plataforma Continental no Município de Icapuí Ceará*. Programa de Pós-graduação em Geografia, Universidade Estadual do Ceará, 114p.

Cleveringa, J. & Oost, A.P. 1999. The fractal geometry of tidalchanneltidal channel systems in the Dutch Wadden sea. *Geologie en Mijnbouw*, *78*: 21–30.

Dalrymple R.W.; Makino, Y. & Zaitlin, B.A. 1991. Temporal and spatial patterns of rhythmite deposition on mud fl ats in the macrotidal, Cobequid Bay Salmon River estuary, Bay of Fundy, Canada. *Clastic Tidal Sedimentology*, *16*: 137-160.

Fenies, H. & Faugères, J.C. 1998. Facies and geometry of tidal channel-fill deposits (Arcachon lagoon, SW France). *Marine Geology*, *150*: 131-148.

French, J.R. & Stoddart, D.R. 1992. Hydrodynamics of salt marsh creek systems: implications for marsh morphological development and material exchange. *Earth Surface Processes and Landforms*, *17*: 23-252.

FUNCEME. 2018. Fundação Cearense de Meteorologia e Recursos Hídricos – Mapas Temáticos. Disponível em: <http://www2.ipece.ce.gov.br/atlas/capitulo1/12/pdf/1.2.6_Tipos_Climaticos.pdf>. Acesso em: 12 jan. 2020.

Gabet, E.J. 1998. Lateral migration and bank erosion in a salt marsh tidal channel in San Francisco Bay, California. *Estuaries*, *4*: 745-753.

Ginsberg, S.S. & Perillo, G.M.E. 2004. Characteristics of tidal channels in a mesotidal estuary of Argentina. *Journal of Coastal Research*, *20*: 489-497.

Gomes, A.A.S.; Freire, G.S.S.; Aderaldo, J.F.; Rodrigues, A.S. & Santos, D.M. 2007. Análise química e textural dos sedimentos quaternários de Barra Grande e Gamboa, Icapuí – CE. *In:* XI Congresso da Associação Brasileira de Estudos do Quaternário, Belém, 2007, p. 1-13.

Hood, W.G. 2006. A conceptual model of depositional rather than erosional tidal channel development in the rapidly prograding Skagit River Delta (Washington USA). *Earth Surface Processes and Landforms*, *90*: 94-118.

Hood, W.G. 2010. Tidal channel meander formation by depositional rather than erosional processes: examples from the prograding Skagit River Delta (Washington, USA). *Earth Surface Processes and Landforms, 35*:319–330.

Hughes, Z.J. 2012. Tidal channels and tidal flats and marshes. *In:* DAVIS Jr, R.A. & DALRYMPLE, R.W. (ed.). *Principles of Tidal Sedimentology*. Springer, New York, p. 270-300.

Krögel, F. & Flemming, B.W. 1998. Evidence for temperature-adjusted sediment distributions in the backbarrier tidal flats of the East Frisian Wadden Sea (Southern North Sea). *Tidalites*, *61*: 31-41.

Lamas, F.; Irigaray, C.; Oteo, C. & Chacón, J. 2005. Selection of the most appropriate method to determine the carbonate content for engineering purposes with particular regard to marls. *Engineering Geology, 81*: 32-41.

Maia, A.O. 2017. *Reconstrução ambiental e evolução sedimentar da região costeira de Icapuí-CE por meio de processamento digital de imagens e análise de fácies.* Programa de Pós-graduação em Geologia, Universidade Federal do Ceará, Dissertação de Mestrado, 103p.

Maia, G.A.M.; Souza, I.C.O.; Abreu Neto, J.G.; Freire, G.S.S. & Medeiros, M.E. 2019. Estudo da Influência da Maré sob a remobilização do material em suspensão no período de enchente no canal do porto da barra grande, Icapuí-CE. *Estudos Geológicos*, *29*: 211-220.

Marinho, R.A.; Maia, L.C.; Conceição, R.N.L. & Cascon, H.M. 2018. Determinação do indicador de estabilização da forma da concha (IEF) de Anomalocardia brasiliana em Icapuí (Ceará, Brasil). *Revista Brasileira de Higiene e Sanidade Animal*, *12*(4): 510-519.

McLaren, P. & Bowles, D. 1985. The effects of sediment transport on grain-size distributions. *Journal of Sedimentary Petrology*, *55*: 457-470.

Meireles, A.J.A. 1991. *Mapeamento geológico/geomorfológico da planície costeira de Icapuí, extremo leste do Estado do Ceará*. Programa de Pós-graduação em Geologia, Universidade Federal de Pernambuco, 178p.

Meireles, A.J.A.; Gorayeb, A.; Silva, D.F.R. & Lima, G.S. 2013. Socio-environmental impacts of wind farms on the traditional communities of the western coast of Ceará, in the Brazilian Northeast. *Journal of Coastal Research*, *65*: 81-86.

Meireles, A.J.A.; Silva, J.A. & Souza, W.F.A. 2017. Área de proteção ambiental (APA) da Barra Grande em Icapuí - CE: caminhos para a sustentabilidade. *Revista Conexão Científica e Tecnológica*, *11*: 90-100.

Monteiro Neto, C.; Andrade, C.F.E.; Carvalho, N.M.; Araújo, M.E.; Lucena, R.I. & Leite, B.G.M. 2003. Analysis of the marine ornamental fish trade at Ceará State, Northeast Brazil. *Biodiversity and Conservation*, *12*: 1287-1295.

Moraes, M.V.A.R.; Freire, G.S.S. & Manso, V.A.V. 2015. Morfologia e sedimentologia da plataforma continental interna do município de Acaraú – Ceará – Brasil. *Revista de Geociências do Nordeste*, *1*: 1-15.

Morrissey, E.M.; Gillespie, J.L.; Morina, J.C. & Franklin, R.B. 2014. Salinity affects microbial activity and soil organic matter contente in tidal wetlands. *Global Change Biology*, *20*: 1351-1362.

Mudd S.M.; D'alpaos, A. & Morris, J.T. 2010. How does vegetation affect sedimentation on tidal marshes? Investigating particle capture and hydrodynamic controls on biologically mediated sedimentation. *Journal of Geophysical Research*, *115*: 1-14.

Nogueira, L.M.M. 2012. *Catadoras de molusco em Icapuí: saberes e práticas de pesca*. Programa de Pós-graduação em Ciências Marinhas Tropicais, Universidade Federal do Ceará, 129p.

Portela, J.P.; Freire, G.S.S.; Moraes, M.V.A.R. & Silva, C.A. 2014. Evolução da morfologia costeira do litoral oeste de Icapuí – CE. *Revista Geonorte*, *5*: 89-93.

Rieu, R.; Van Heteren, S. Van der Spek, A.J.F. & De Boer, P.L. 2005. Development and preservation of a mid-Holocene tidal channel network offshore the western Netherlands. *Journal of Sedimentary Research*, *75*: 409-419.

Rinaldo, A.; Fagherazzi, S.; Lanzoni, S.; Marani, M. & Dietrich, W.E. 1999. Tidal networks: 3 Landscape-forming discharges and studies in empirical geomorphic relationships. *Water Resources Research*, *35*: 3919-3929.

Settlemyre, J.L. & Gardner, R.L. 1977. Suspended sediment flux though a salt marsh drainage basin. *Estuarine Coastal Marine Science*, *5*: 653–663.

Shinn, E.A. 1983. Tidal Flat. *In*: PETER, A.S.; DON, G.B. & CLYDE, H.M. (ed.). *Carbonate Depositional Environments.* Oklahoma, AAPG Memoir, 33. p. 171-210.

Shi, Z.; Lamb, H.F. & Collins, R.L. 1995. Geomorphic change of salt marsh tidal creek network in the Dyfi Estuary Wales. *Marine Geology*, *128*: 73-83.

Silva, J.A. 2012. *Manguezal do estuário Barra Grande em Icapuí-CE: da degradação ao processo de recuperação e mudança de atitude*. Programa de Pós-graduação em Geografia, Universidade Federal do Ceará, 149p.

Silva, J.A. 2020. Alguns aspectos da diversidade biológica (fauna e flora) do manguezal da barra grande em icapuí-ce. Memória Viva dos Povos do Mar de Icapuí. Disponível em: <http://www.brasilcidadao.org.br/museu/artigos_02.php> Acesso em: 26 de março de 2020.

Souza, I.C.O.; Maia, G.A.M; Almeida, N.M.; Abreu Neto, J.C.; Freire, G.S.S.; Albuquerque, L.N. & Silveira, A.D.S. 2020. Fácies e estratigrafia do canal de maré do porto da barra grande, Icapuí – CE. *Revista de Geociências do Nordeste*, *6*(1): 49-55.

Tomczak, M. 1998. Spatial Interpolation and its Uncertainty Using Automated Anisotropic Inverse Distance Weighting (IDW) – Cross-Validation/Jacknife Approach. *Journal of Geography Information and Decision Analysis*, *2*: 18-30

Vital, H.; Neto, F.S. & Plácido Junior, J.S. 2008. Morfodinâmica de um canal de maré tropical: Estudo de caso na costa norte rio grandense, nordeste do Brasil. *Revista de Gestão Costeira Integrada*, *8*: 113-126.

Walkley, A. & Black, J.A. 1934. An examination of the Degtjareff method for determining soil organic matter, and proposed modification of the chromic acid titration method. *Soil Science, 37*: 29-38.

Wentworth, C.A. 1922. A scale of grade and class terms for clastic sediments. *Journal of Geology*, *30*: 377-392.