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Sediment granulometric parameters of the Brazilian Barreta beach in Rio Grande do Norte

EMERSON O. DE LUNA[1], MOACYR ARAUJO[1,2,3] & HUMBERTO L. VARONA[1,2,*]

[1] *Department of Oceanography (DOCEAN). Federal University of Pernambuco. Recife-PE. Brazil.*
[2] *Center for Risk Analysis, Reliability Engineering and Environmental Modeling (CEERMA). Federal University of Pernambuco. Recife-PE. Brazil.*
[3] *Brazilian Research Network on Global Climate Change (Rede CLIMA), São José dos Campos, SP, Brazil.*

* *Corresponding author: humberto.varona@ufpe.br*

Abstract: The objective of this research was to characterize the granulometric parameters of the sediments of Barreta beach, geographically located on the east coast of the Brazilian state of Rio Grande do Norte, this beach stands out for the presence of beach sandstones, which play an important role in the morphology of the region. These granulometric parameters were studied through morphoscopy, and the determination of the calcium carbonate content and the content of total organic matter in 10 samples collected in the dune and in the intertidal zone. This beach is dominated by medium-sized, well-selected, and moderately selected sediments, with approximately symmetrical and mesokurtic sand-grain size distributions. Morphoscopic analysis showed a predominance of angular to subangular sand-grains (64%) in the samples, also a high degree of sphericity (59 - 78%).

Key words: Granulometric, Roundness, Morphoscopy, Barreta beach.

Parâmetros granulométricos de sedimentos da praia brasileira Barreta no Rio Grande do Norte. Resumo: O objetivo desta pesquisa foi caracterizar os parâmetros granulométricos dos sedimentos da praia de Barreta, localizada geograficamente na costa leste do estado brasileiro do Rio Grande do Norte. Essa praia se destaca pela presença de arenitos de praia, que desempenham um papel importante na morfologia dessa região. Esses parâmetros granulométricos foram estudados por meio de morfoscopia e da determinação do teor de carbonato de cálcio e do teor de matéria orgânica total em 10 amostras coletadas na duna e no estirâncio. Essa praia é dominada por sedimentos de tamanho médio, bem selecionados e moderadamente selecionados, com distribuição de tamanho de grão de areia aproximadamente simétrica e mesocúrtica. A análise morfoscópica mostrou uma predominância de grãos de areia angulares a subangulares (64%) nas amostras, além de um alto grau de esfericidade (59 - 78%).

Palavras-chave: Granulometria, Arredondamento, Morfoscopia, Praia Barreta.

Introduction

Beaches are deposits of unconsolidated, non-vegetated sediments, usually sandy in grain size, which extends from the low-water mark to some geomorphological feature, such as a dune, cliff, rocky shore or any structure developed by man (Millero, 1996). Waves, currents, and winds act on beach sediments, eroding, transporting, and depositing them (Hansell et al., 2009). Coastal agents act on the sand-grains, selecting them by size, density, and shape (Chaves, 2000). In addition to the mean, median and mode, the granulometric parameters include other statistical parameters such as selection, skewness, and kurtosis (Hansell et al., 2009). The dissipation of wave energy occurs mainly on the outer face of the sandstones, which causes the thinner or less cemented layers to fracture and subsequently break the continuity of the sandstone. This break in the sandstones is popularly called a notch, which allows water to enter and leave the sea, and it is this characteristic that gives the beach its name. The granulometric characterization of the sediments helps to understand coastal dynamics, supporting beach recovery projects through artificial sediment feeding, and providing subsidies for environmental planning of the area under erosive processes (Nordstrom, 2010).

The mean diameter is the mean size of the particles (Folk and Ward, 1957). The grain size of beach sediments generally ranges from very fine to medium sand, while the sand-grain size of river sediments ranges from medium to coarse sand (Martins, 2003). However, when the supply of sediment is very large, the beach can be composed of both sand and gravel (pebbles, granules) and silt (Friedman, 1967). Fine sediments (mud) tend to accumulate in low wave energy environments, while sand-sized sediments tend to accumulate in high wave energy environments (Davis and FitzGerald, 2009). The action of storm events, however, can temporarily alter the energy of the environment, favoring the momentary deposition of coarser sediments (Komar, 1977). The proportion of coarser sediments is higher on beaches adjacent to river mouths, due to their proximity to the source area (Bird, 2008).

Selection or degree of selection is a measure of sample dispersion, i.e. the standard deviation of the size distribution (Bird, 2008). Well-selected sediments imply sand-grains with little dispersion of their granulometric values, or of the values of the measures of central tendency. With increased transport or agitation of the medium, particles of different sizes tend to be separated by size (Nichols, 2008). On a beach, the degree of selecting reflects the characteristics of the sediments that are transported to the coastal zone and their subsequent reworking by the action of waves, tides, swash, currents, and winds (Neal et al., 2007). Beach sediments derived from the same source will be well-selected than river sediments due to the action of coastal agents (Folk, 1980). Beach sediments are generally moderately to well selected, while fluvial sediments are poorly to moderately selected and eolian sediments are well to very well selected (Martins, 2003).

The statistical parameters reflect the processes of sediment transport and deposition, such as: selective deposition, abrasion, selective removal, and sediment mixing (Gao and Collins, 1994). Skewness and kurtosis are the parameters that best define depositional environments (Mason and Folk, 1958), however, skewness best defines the depositional environment (Friedman, 1967). Sand-grain size is useful in distinguishing sedimentary environments (Martins, 2003). In addition, textural parameters reflect the mode and intensity of the transport agent (Friedman, 1967). Therefore, understanding the meaning of the statistical parameters of sediments is fundamental when studying sedimentary environments. However, the best distinction between fluvial, eolian and beach environments is the use of silt content, heavy minerals and degree of sand-grain roundness, in parallel with the use of sedimentary structures (Shepard and Young, 1961).

The aim of this investigation is to characterize the granulometric parameters of the sediments of Barreta beach, which is located on the east coast of the state of Rio Grande do Norte and is characterized by its occurrences of beach sandstones, which play an important role in the recent morphology of the site, Knowledge of sandstone formations helps to assess coastal dynamics, since the presence of these bodies significantly modifies the energy of the waves incident on the coast, influencing the distribution of sediments with consequent changes in coastal morphology, or as an energy dissipating structure.

Study region: The study region is located on the east coast of the State of Rio Grande do Norte and extends over the municipality of Nísia Floresta, with physical-geographical limits to the east, the Atlantic Ocean; to the south, the Guaraíras lagoon; to the west, parabolic dune fields and the cliffs of the barrier formation; and to the north, the Camurupim beach. The climate on the east coast of the state of Rio Grande do Norte, according to (http://bancodedados.cptec.inpe.br/) varied between a minimum of 24.3°C and a maximum of 27.6°C between the years 1980 to 2018 with an annual average of 26.6°C. In the 38 years of analysis, the lowest monthly averages were found during June to September (24.7 - 25.7°C) and the highest during December to March (27.2° to 27.3°C). Rainfall on the east coast of Rio Grande do Norte from 1980 to 2018 averaged 1478mm, with the highest rainfall of 2658 mm in 2000 and the lowest of 783 mm in 1981 (INPE database, available at http://bancodedados.cptec.inpe.br/).

In coastal areas, the interaction between the forces of water masses and sediments leads to continuous changes in beach morphology. A crucial aspect of this dynamic is the suspension of sediments by wave action. Once suspended, the sediments are transported by coastal currents, which causes erosion of the beaches, leaving only the coarser sediments. In contrast to open beaches, those protected by barriers of rock formations, reefs or artificial structures exhibit different sediment dynamics. These barriers reduce the energy of incoming waves, thus decreasing suspension and thus sediment transport. Beaches with protective barriers tend to maintain finer-grained sediments and exhibit less morphological change over time.

The study region is very active in terms of coastal dynamics. Figure 1a shows the annual mean significant wave height (SWH) obtained from the WAVERYS model (GLOBAL_MULTIYEAR_WAV_001_032 product; EUCMS, 2019), this ranges from 0.28 to 1.94 m. Also shown is the NOAA northward drifter transport, this drifter data has been obtained from the AOML dataset (Laurindo et al., 2017) obtained through the driftViewer v1.0 software (Noriega et al., 2023). The Barreta beach is well protected by a rock formation barrier, so it is not influenced by the predominant coastal dynamics of the region (Figure 1c).

Material and Methods

This research was carried out in two stages: field work and laboratory work. The field work was carried out from September 30 to October 1 and consisted of collecting 10 sediment samples from Barreta beach in 2 profiles, one transversal and the other longitudinal, distributed over 5 points during the periods of high-tide and low-tide (Fig. 1c, Table 1). During the collections, the ST3 point was always submerged in seawater.

The intertidal zone or tidal zone is the area that experiences periodic fluctuations in seawater level due to tides and its coverage varies throughout the day (Davis, 2015). During low tide, much of this area is uncovered, while at high tide it is inundated under seawater (Fig. 2a). Foreshore is the area of the beach that is exposed to the air and seawater when the tides are rising and falling. In other words, the intertidal zone is a type of foreshore, but the foreshore is not always an intertidal zone. For example, if the beach is protected from waves, the foreshore may be covered with sand or rocks, and not inundated by tides, in which case the foreshore would not be an intertidal zone.

In the Geological Oceanography Laboratory of the Oceanography Department of the Federal University of Pernambuco, the sediments were analyzed for calcium carbonate concentration and total organic matter, using the weight difference method, before and after attack with hydrochloric acid (HCl) and hydrogen peroxide (H_2O_2), after which the sediments were filtered dry stack, following the standard procedure. The distribution of the sediment samples into granulometric classes was computed statistically using the software SYSGRAN

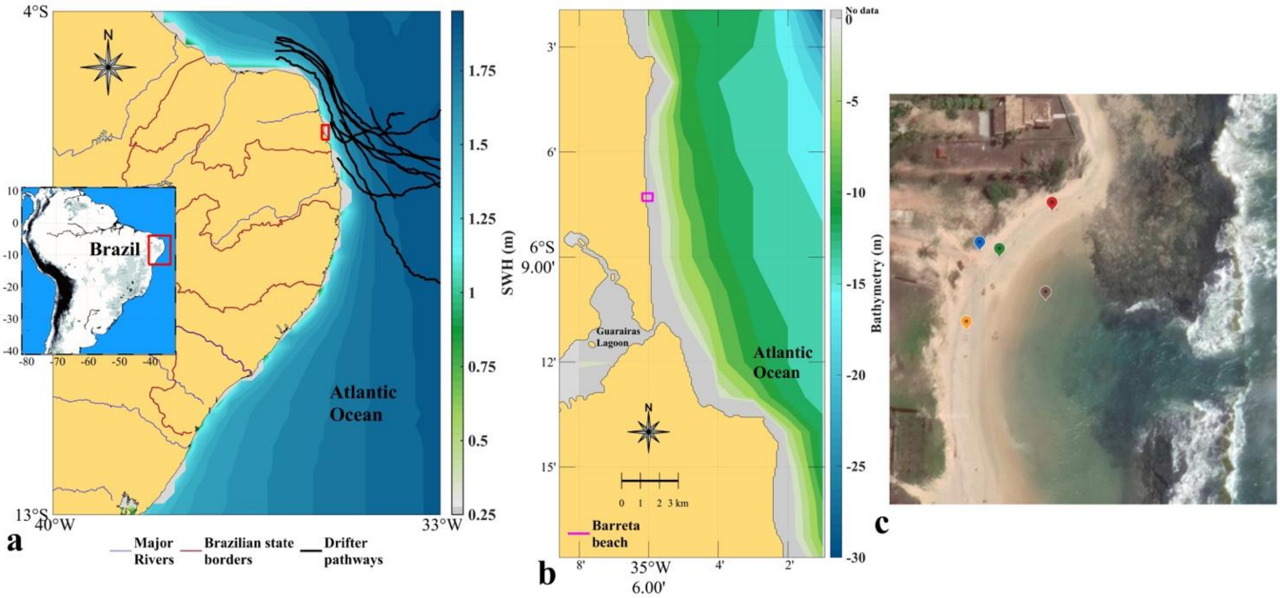

Figure 1. Geographic location: a) study region: annual mean significant wave height (SWH) and NOAA drifter pathways; b) Barreta beach at Rio Grande do Norte; and c) sampling points at Barreta beach (adapted from Google Earth): ST1 (blue point), ST2 (green point), ST3 (brown point), ST4 (red point), and ST5 (orange point).

Table 1. Sediment collection points on the Barreta beach.

Point		Longitude	Latitude
ST1	Dune	35°05'58.2"W	6°07'19.3"S
ST2	Intertidal zone	35°05'57.9"W	6°07'19.4"S
ST3	Limit between foreshore and nearshore	35°05'57"W	6°07'18"S
ST4	Intertidal zone (North)	35°05'57.1"W	6°07'18.7"S
ST5	Intertidal zone (South)	35°05'58.4"W	6°07'20.5"S

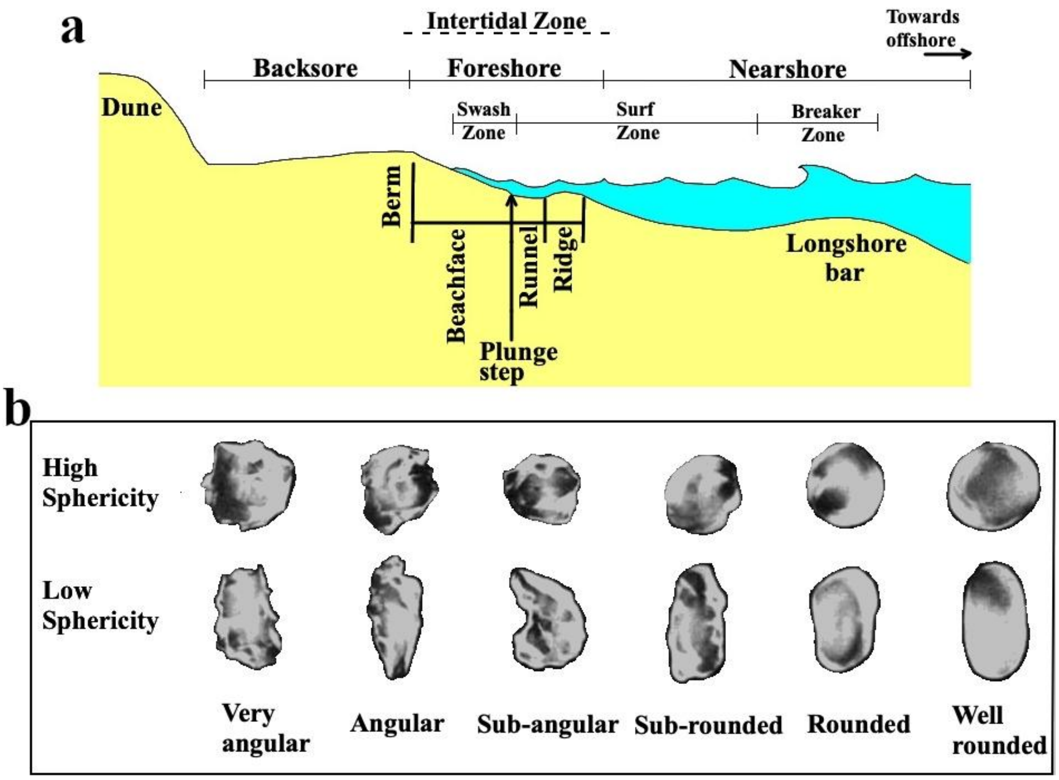

Figure 2. **a)** Diagram of a beach with a typical profile, adapted from Davis (2015) and Brand et al. (2020). **b)** Roundness scale, adapted from Powers (1953).

(Camargo, 2006) available at http://200.17.232.45/sysgran19. In parallel, the mStatGraph v1.7 software (Varona et al., 2023a,b) was used to perform other calculations, figures, and statistical analyses.

In nature, calcium carbonate ($CaCO_3$) occurs in the form of vast sedimentary deposits resulting from the fossilization of the remains of prehistoric marine life. In these deposits, $CaCO_3$ occurs mainly as calcite, the most common form, and as aragonite, more frequent in temperate seas. These two forms of $CaCO_3$ differ in their crystalline arrangements. Vast beds of aragonite form the Bahamas and the bed of the Red Sea. Calcite most commonly occurs as limestone, dolomite (a mixed carbonate of calcium and magnesium $CaMg(CO_3)_2$ and marble. The weight difference method was used to determine the calcium carbonate content and the total organic matter content in the samples (equation 1).

$$CCC = TOMC = 100\left(\frac{W_i - W_f}{W_i}\right) \qquad \text{Equation 1}$$

Where *CCC* is the calcium carbonate content in samples (%), *TOMC* is the total organic-matter content in samples (%), W_i is initial weight (g), and W_f is the final weight (g).

Organic matter is the set of chemical compounds formed by organic molecules found in natural environments, whether terrestrial or aquatic. Organic matter is generally heterogeneous and made up of animal and plant remains and their waste thrown into the environment. It plays an essential role in nature, serving as a source of food for living organisms and as a link between various biogeochemical cycles. This matter can be transported between terrestrial and aquatic environments and normally undergoes recycling and/or degradation processes (Millero, 1996).

Microorganisms play a fundamental role in the recycling of organic matter, whether in soil, sediment, or in the water column of aquatic bodies. The entry of organic matter of anthropogenic origin into the aquatic environment significantly increases the amount of nutrients available, causing an imbalance in photosynthetic and respiratory processes. This can trigger environmental problems such as eutrophication, hypoxia, and pollution (Hansell et al., 2009). Equation 1 was also used to compute the total organic matter content.

Morphoscopic analysis of sediments is a procedure used to study the properties (shape: sphericity and roundness) and surface texture (gloss and matting) of sedimentary particles. By studying these properties, it is possible to gain an understanding of the processes involved in the transportation and deposition of the grains under study. These analyses were carried out using a binocular magnifying glass on the samples in the 1 phi and 2 phi fractions, to show the physical and morphological characteristics of the sediments.

Results

The calcium carbonate content in Table 2 is low, probably because it is a beach protected by low-energy beach sandstones. There is also a slight increase from the dune to the foreshore, which is probably due to the greater contribution of biogenic sediments deposited at the high tide line; the southern stretch has a slightly higher value, probably because the sample was collected close to the beach guild area.

We observed that the total organic-matter content also showed low values (Table 3), and a slight increase from the dune to the foreshore, which is probably due to the greater contribution of biogenic sediments deposited at the high tide line, as the sample was collected at high tide. We also observed that the southern foreshore showed a slightly higher value of total organic matter, probably because the sample was collected close to the spit beach area.

Sediment classification: The sediments were predominantly classified as medium sand (100%) with an average ranging from 1.213 to 1.766 phi (Table 4). On beaches close to river mouths, the presence of coarser sediments (medium to coarse

Table 2. Calcium carbonate content.

Point	Initial weight (g)	Final weight (g)	MOT(%)
ST1	9.98	9.929	0.51
ST2	10.0	9.884	1.16
ST3	10.05	9.834	2.15
ST4	9.99	9.927	0.63
ST5	10.0	9.91	0.90

Table 3. Total organic-matter content.

Point	Initial weight (g)	Final weight (g)	MOT(%)
ST1	30.09	29.845	0.81
ST2	30.02	29.682	1.13
ST3	30.0	29.52	1.60
ST4	29.989	29.766	0.74
ST5	30.0	29.8	0.67

sand) brought in by the rivers is common, corroborating the suggestion by Martins (2003) that these deposits are distributed all along the Potiguar coast, so the Níssia Floresta lagoon system probably contributes as a source of sediment for Barreta beach.

The sand-grains distribution in all cases was approximately symmetric (Fig. 3), with skewness ranging from -0.06499 to 0.03763; and mesokurtic, with kurtosis ranging from 0.9425 to 1.022 (Table 4). The sediment particle size distribution curves were characterized as approximately symmetrical, positive asymmetrical (20%), and negative asymmetrical (80%). The higher percentages of negative asymmetry are typical of beach environments. The percentage of positive asymmetry refers to the dune sample, corroborating the literature that states that when the curve has a longer tail towards the extreme end, the asymmetry is said to be positive. All the sediment samples showed mesokurtic curves. The high percentage of mesokurtic curves presented by the sediments from Barreta beach reflect a tendency towards equilibrium in the distribution of the different sediment populations, characteristic of aeolian transport (Monteiro, 2015).

We can see in Figure 4f that the cumulative frequency curves of the samples from Barreta beach show several straight-line segments. These segments are generally limited by four points of intersection, whose positions define the types of transport. In the coarsest fraction, there is an intersection point on the 0.1 to 6% frequency line. It can be assumed that it limits the line segments that represent subpopulations of sediment transported by rolling, where 6% corresponds to ST3. In the central part of the curves, there are two line segments.

Table 4. Sediment classification from SYSGRAN software.

Point	Mean	Median	Selection	Classification	Skewness	Kurtosis
ST1	1.427	1.4	0.4339	Well selected	0.03763	0.9756
ST2	1.512	1.522	0.4381	Well selected	-0.055847	1.022
ST3	1.213	1.216	0.5194	Moderately selected	-0.03379	0.9665
ST4	1.513	1.524	0.4227	Well selected	-0.03917	0.9721
ST5	1.766	1.78	0.4564	Well selected	-0.06499	0.9425

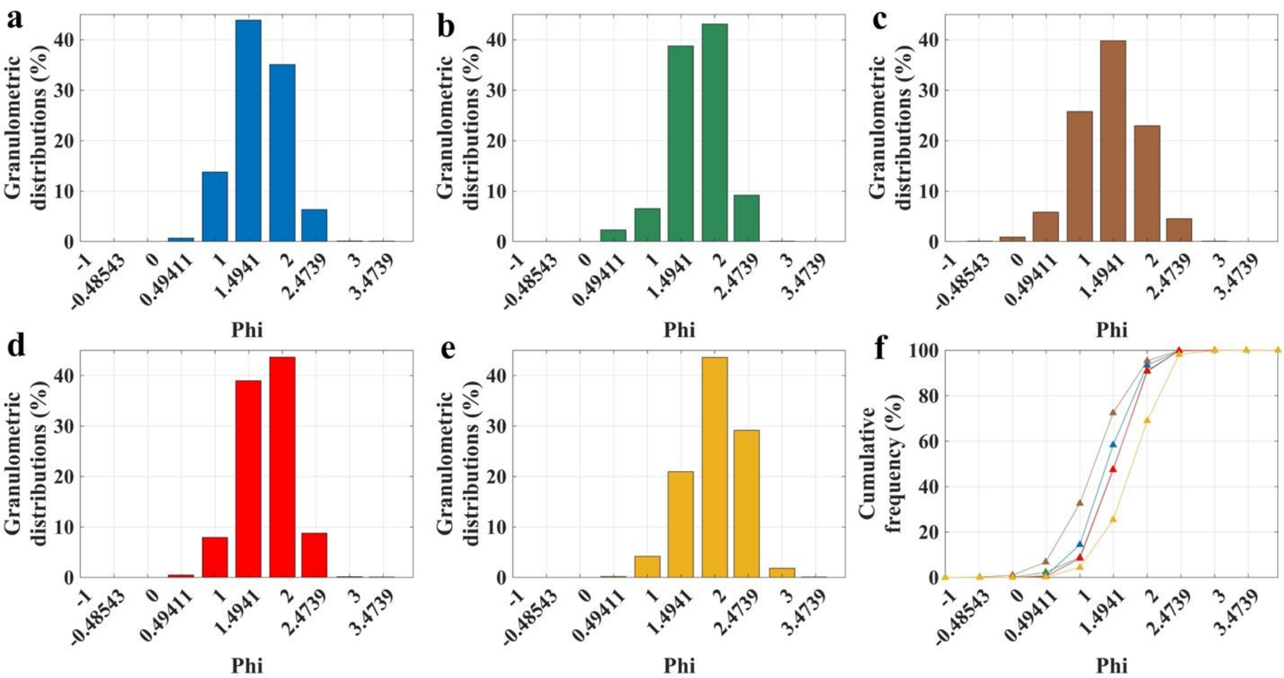

Figure 3. Granulometry distribution histogram: a) ST1, b) ST2, c) ST3, d) ST4, and e) ST5; f) Cumulative sediment frequency: ST1 (blue triangles), ST2 (green triangles), ST3 (brown triangles), ST4 (red triangles), and ST5 (orange triangles).

The segment from 0.5 to 1 phi size class accounts for less than 10% of the particle weight, while the segment from 1 to 2.5 phi accounts for 85% of the weight. In ST5, this division of the central part has two straight segments, representing the difference in energy present in the flow of washing and backwashing in the ST2 zone, as this is where the beach rocks open, or the action of two transport agents, such as wind and water. In the 5% of the finest fraction of the samples, two segments may represent subpopulations transported by suspension. The angle of inclination of the line segments represents the degree of selection of the sediment subpopulations. The more vertical it is, the greater the selection, as the smaller the number of size classes covered. Thus, the line segments between 1 and 2 phi have the steepest slope, and therefore the best selection, since they include around 90% of the sediment.

The sediments were predominantly characterized as well-selected, except sample ST3, which was classified as moderately selected according to Table 4. The presence of moderately to well-selected sediments on the beach investigated corroborates what has been proposed by Martins (2003) for sediments on beaches. According to Briggs (1977), sediments tend to be less well selected close to the source area in the depositional environment and have not yet been effective in selecting the particles, as suggested by Folk (1980). Thus, according to Emery (1978), a "mixture" of subpopulations can be inferred.

Morphoscopic analysis: It was not possible to determine significant differences in (roundness, sphericity, and surface texture) between the sediments of the 1 phi and 2 phi fractions, however, it was possible to characterize the sediments between ST1, ST2, and ST3 (Fig. 4). At point ST1 (Fig. 4a) the sediments varied from angular to subangular in the degree of roundness, with almost similar results for these sediments between 29% and 31%, where we can also see the degree of high

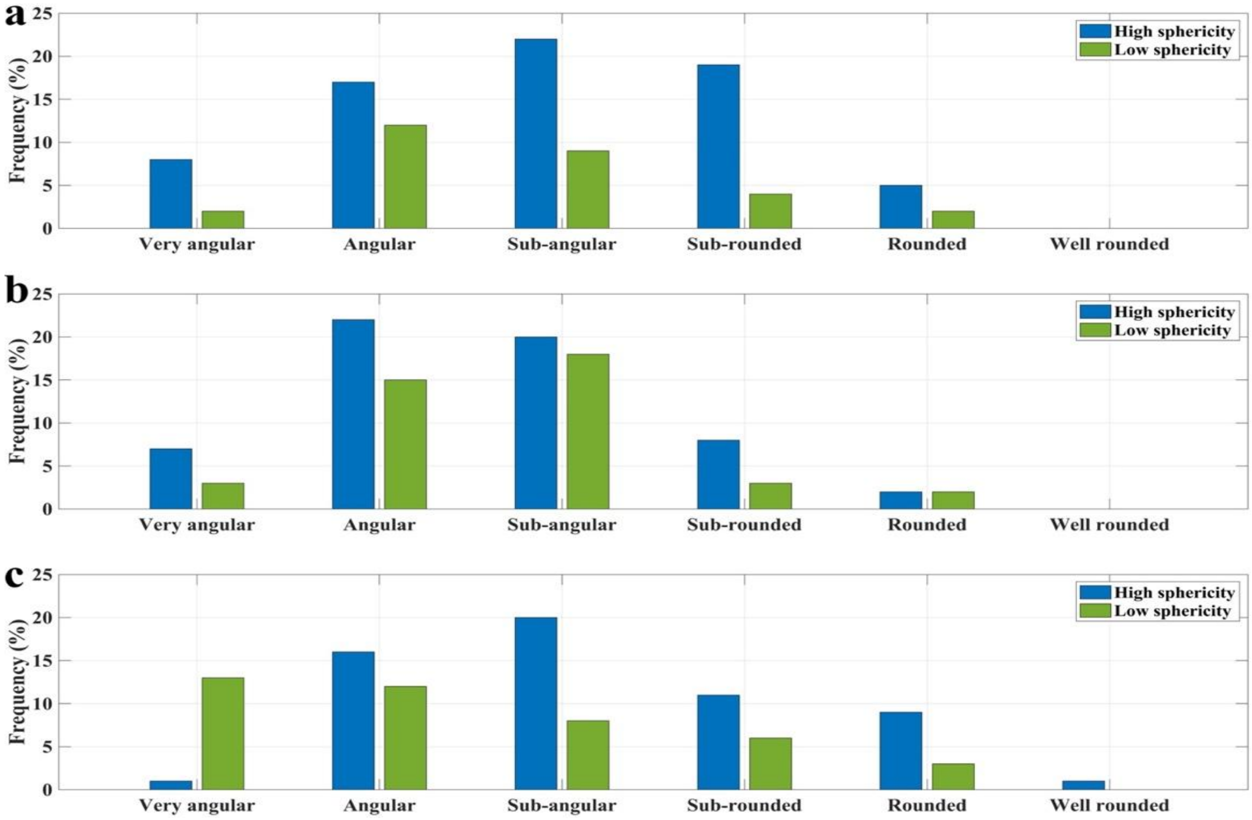

Figure 4. Sediment morphoscopy: a) ST1, b) ST2, and c) ST3.

sphericity (70%), these sediments have characteristics of underwater transport. At point ST2, the sediments varied from angular to sub-angular in their degree of roundness, with similar results of 37% and 38%. They are also brightly colored, slightly rounded, and with fractures, indicating that they are sediments of recent origin, as characterized in the sample in Fig. 2b, where we can also see the degree of High sphericity (59%), thus highlighting their angularity. Point ST3 is the only underwater zone analyzed. The degree of roundness of the sediments varied from angular to sub-angular, equally at 28%. There was a greater presence of shiny sediments in this sector, whose degree of sphericity remained high (78%), showing that these sediments are mostly from an aqueous environment (Fig. 4c).

Conclusions

The sedimentological study on Barreta beach is a contribution to our knowledge of the sedimentological characteristics of the area. A low calcium carbonate content was observed, and a slight increase was also observed from the dune to the shore, with the southern section showing a slightly higher value. The total organic matter content was also low. Morphoscopic analysis showed a predominance of angular to sub-angular sand-grains (64%) in the samples. The sediments are quartz with small concentrations of heavy minerals. In addition, the sediments that makeup Barreta beach are predominantly of medium sand size, well selected, with approximately symmetrical, and mesokurtic sand-grain size distributions. A high degree of sphericity was determined, ranging from 59 to 78%.

Ethical statement

The dataset used in this article does not have any restrictions on use.

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