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Sedimentology of sandy beaches of Santa Catarina Island, SC, Brazil
Sedimentologia das praias arenosas da ilha de Santa Catarina, SC, Brasil

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Abstract

The sedimentological aspects of the beaches of *Santa Catarina* island: *Cacupé Grande*, *José Mendes, Lagoinha*, *Mole*, *Matadeiro* and *Solidão* were seasonally monitored. The used methods consisted on the sampling of surface sediments from the backshore, beach face and foreshore morphologic zones, in order to analyze parameters such as mean size, standard deviation, skewness, kurtosis and roundness. The beaches from Northwest and Southwest coasts, *Cacupé Grande* and *José Mendes*, respectively, adjacent to the North and South bays, protected from waves hydrodynamic action, are composed by coarse to very coarse sand, poorly selected, angular, typical of immature depositional environments. The *Lagoinha* and *Matadeiro* beaches, from the North and Southeast coasts, respectively, represents semi-exposed beaches, composed with fine sand, well sorted, rounded, which is typical of supermature depositional environments. The *Mole* beach, on the Northeast coast, represents an exposed beach from a supermature depositional environment, with medium sandy grains, moderately sorted and well-rounded. The *Solidão* beach, on the South coast, also considered exposed and supermature, has fine sandy grain, well sorted and rounded. There were no significantly seasonal variations in any of the parameters.

Keywords: sediment; texture; roundness; hydrodynamic; seasonal variations.

Resumo

Os aspectos sedimentológicos das praias da ilha de Santa Catarina: Cacupé Grande, José Mendes, Lagoinha, Mole, Matadeiro e Solidão foram monitorados sazonalmente. Os métodos utilizados consistiram na amostragem de sedimentos superficiais nas zonas morfológicas do pós-praia, face praial e antepraia, para analisar parâmetros como tamanho médio, desvio padrão, assimetria, curtose e arredondamento. As praias situadas nas costas Noroeste e Sudoeste, Cacupé Grande e José Mendes, respectivamente, adjacentes às baías Norte e Sul, protegidas da ação hidrodinâmica das ondas, são compostas por areia grossa à muito grossa, pobremente selecionadas, angulares, típicas de ambientes deposicionais imaturos. As praias Lagoinha e Matadeiro, nas costas Norte e Sudeste, respectivamente, representam praias semi-expostas, compostas por areia fina, bem selecionadas, arredondadas, típicas de ambientes deposicionais supermaduros. A praia Mole, na costa Nordeste, representa uma praia exposta de ambiente deposicional supermaduro, com grãos de areia média, moderadamente selecionadas e bem arrendondadas. A praia da Solidão, na costa Sul, também considerada exposta e supermadura, tem areias finas, bem selecionadas e arredondadas. Não houve variação sazonal significativa em nenhum dos parâmetros.

Palavras-chave: sedimento; textura; arredondamento; hidrodinâmica; variações sazonais.

1. Introduction

The oceanic sandy beaches result from the interaction of wave action with accommodated sediments on the coastline, and the extent and characteristics of these depend on the tidal ranges, wave regime, grain size and shape of the beach in plant (Short 1999). These beaches are among the most dynamic environments on Earth's surface, occurring at all latitudes, climates, tidal ranges and types of coasts, being, however, susceptible to modifications by processes such as winds, tides and parameters such as the type of constituent material, among others. Hoefel (1998) defined the sandy beaches as extremely active environments, dominated by hydrodynamic agents and consisting of coastal sedimentary deposits of varying compositions and particle size, limited between the maximum levels of storm wave action and closure depth.

This highly dynamic environment, morphology and sedimentology, together with the socio-economic importance presented by beaches, especially as recreational areas, have encouraged research seeking a better understanding for rational use, management and conservation of these environments (Horn Filho 2006).

In this context, the study presented in this article aimed to characterize, from the sedimentological point of view, six beaches located in different sectors of the coast of the Brazilian island of Santa Catarina, through seasonal sampling of sediments, in order to compare the textural and morphoscopic parameters of every beach and along four campaigns. The beaches studied were Cacupé Grande, José Mendes, Lagoinha, Matadeiro, Mole and Solidão.

2. Study area

The Santa Catarina island, where is located the city of Florianópolis, capital of the state of Santa Catarina, in southern Brazil, features an elongated shape oriented toward NE-SW, with 399km² of total area. Along the entire perimeter of 174.3km, the island exhibits a diversity of coastal ecosystems, being highlighted the 117 sandy beaches (Horn Filho 2006). Six of these 117 beaches were selected for carrying out this study.

According to Caruso Jr. (1993), the Santa Catarina island consists of two main geological provinces: the more ancient crystalline basement, represented by the lithostratigraphic units of Escudo Catarinense and Planalto da Serra Geral, and the coastal plain deposits of Quaternary age, represented by sediments of continental and transitional origin. The crystalline basement is composed predominantly by granitic rock masses, intruded by diabase dikes, all these lithologies joined by flat areas of coastal sedimentation of the coastal plain. Deposits are related to the depositional systems of alluvial fan and lagoon-barrier, and this is characterized by sediments genetically associated with coastal processes and relative changes of the sea level that occurred during the Pleistocene and Holocene. They are represented by Beach Deposit, Eolic Deposit, Lagoon Deposit and Paludial Deposit.

On the coast of the Santa Catarina island, the tide is a micro tidal regime (<2m) with semi-diurnal regime and maximum amplitudes of 1.4m to the harbor of Florianópolis, according to data from Diretoria de Hidrografia e Navegação (DHN). Araújo et al. (2003) reported that, throughout the year, there is a predominance of south waves (swell) with a period around 12s and east high waves (sea) with a period of 8s. During fall and winter months, the southern ripples prevail over the east high waves; in summer, there is a balance between them and the east high waves prevail in the spring.

Martins et al. (1970) concluded in their study that the beaches located on the East sector, Northwest and Northeast coasts of the Santa Catarina island have a more mature texture and mineralogy than the beaches of the Southeast and Southwest coasts. According to the authors this is due to greater beach momentum in the first ones. They also emphasized that the main sediment source to these beaches is an igneous complex, acid to intermediate, and metamorphic rocks. The geographical and geological settings enabled the development of beaches with all levels of hydrodynamic energy (exposed, semi-exposed and protected from wave action) and of all kinds (dissipative, reflective and intermediate) (Horn Filho 2006).

In order to compare them from a sedimentological point of view, the six sandy beaches studied are situated one on each coast of the Santa Catarina island, denominated: Cacupé Grande beach, in the Northwest coast; Lagoinha beach, in the North coast; Mole beach, in the Northeast coast; Solidão beach, in the South coast; Matadeiro beach, in the Southeast coast and José Mendes beach, in the Southwest coast (table 1 and figure 1).

Table 1: Geographical location of the beaches monitored.

Beach	Lat. (27°S.)	Long. (48°W.)
Cacupé Grande	32'28.5"	31'31.1"
Lagoinha	23'20.6"	25'24.7"
Mole	36'07.1"	25'57.5"
Solidão	47'38.6"	32'01.1"
Matadeiro	45'15.2"	29'05.3"
José Mendes	36'44.4"	32'50.1"

Lagoinha beach is the northernmost beach on the Santa Catarina island, bordered by two rocky granitic promontories, with E-W orientation and extends over 920m long and 35m wide, having an average slope of 4º. Sand fraction ranges from fine to medium and are well compacted. By locating in the north end of the island, waves energy can increase when associated with winds from the north and northeast. The longitudinal currents at times reach the ends of the beaches with greater intensity (Horn Filho et al. 2012).

Mole beach is in the district of Lagoa da Conceição in the Northeast coast of the Santa Catarina island. Oriented towards NE-SW, with a length of 1.187m, width of 47m and a slope of 9º. Its name derives from the dominant medium to coarse sand grain sizes. Gré et al. (1994) reported that the changes in the profile of the Mole beach are related to the passages of cold fronts that act through the winds and hydrodynamic agents, these erosive processes being more common in winter months, while in the summer months deposition processes prevail. These agents create a circulation cell, causing the retention of the grains passing in a semi-closed system, not allowing exchanges with the adjacent beaches and the inner continental shelf.

Cacupé Grande beach, located in the district of Santo Antônio de Lisboa, in the Northwest coast of the Santa Catarina islands, is characterized by being a coarse sandy beach, of low wave energy, oriented toward NW-SE. It extends over 910m long and 10m wide and its average slope is 8º.

Solidão beach is a fine sandy pocket beach of the South coast of the Santa Catarina island, located between the headlands of Pacas in the south and Régua in the north, in the district of Pântano do Sul. It is oriented towards NE-SW and has 850m length, average width of 30m and slope of 4º. Güttler (2006) pointed out that the southern and northern boundaries of the beach consist of outcrops of the Granito Ilha.

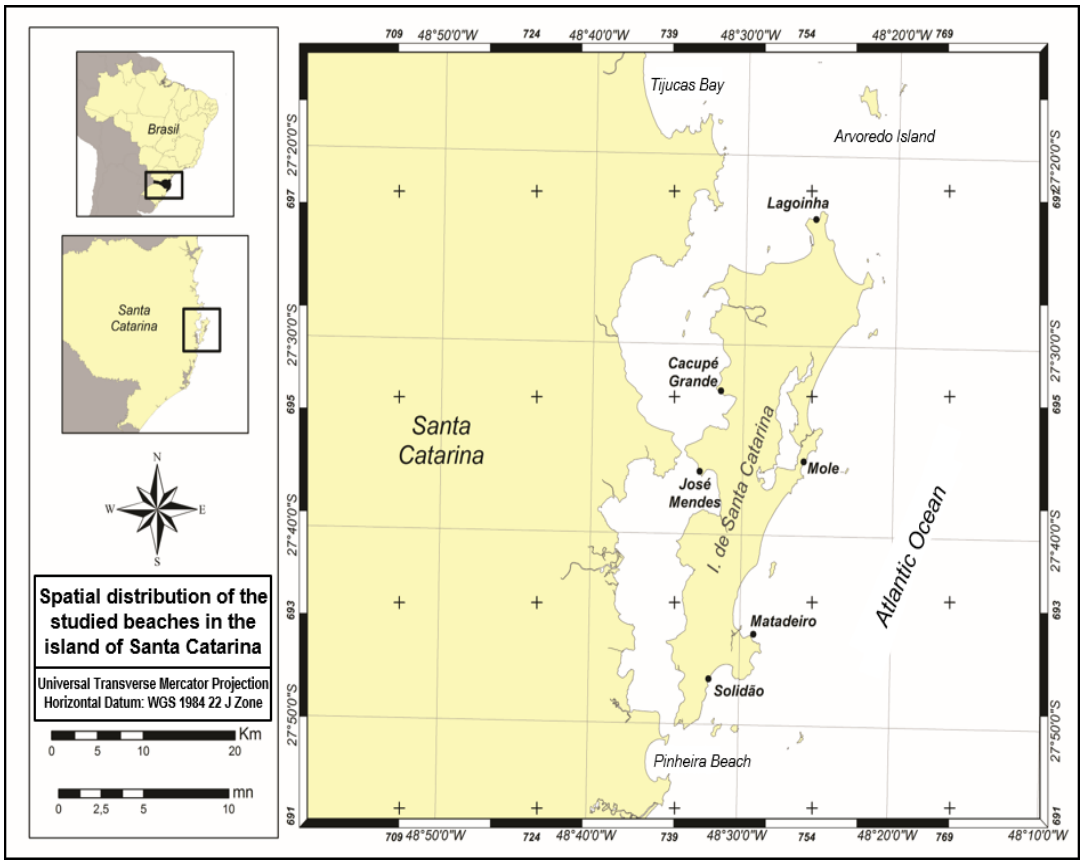

Figure 1: Geographical location of the island of Santa Catarina and the six beaches studied.

Matadeiro beach, located in the district of Pântano do Sul, in the Southeast coast, is a semi-shaded beach between two rhyolitic rocky headlands, protected from the waves coming from the south, but being more exposed to the ripples from the east and to the high waves of the northeast (Mazzer et al. 2008). The beach is composed of fine sands and has an extension of 1.200m, width and average slope of 25m and 8º, respectively.

José Mendes beach is in the Central-western sector of the Santa Catarina island, in the Southwest coast. Located in the district of the same name, José Mendes the beach is oriented towards NW-SE, which makes it protected from the action of waves, as its location is turned to the North bay. According to Horn Filho et al. (2012), José Mendes beach is 267m long, with a width of 8m in average and a sope of 8o.

3. Materials and methods

In addition to an extensive literature review, the study included the collection of beach sediment samples during the fieldwork and laboratory analysis.

During the months of July and October 2009 and January and April 2010, corresponding to a seasonal interval of four months, 12 surface sediment samples were collected at each beach, totaling 72 units in three different morphological zones of the beach profile: backshore, beach face and upper foreshore.

In the laboratory, samples were washed and dried to obtain a minimum weight necessary for sieving, as well as obtaining data relating to soil organic matter and biodetritic carbonate, whose analyzes were performed at the Laboratório de Sedimentologia of the Departamento de Geosciências, both of Universidade Federal de Santa Catarina. The preparation of sediment samples followed the methods cited in Suguio (1973). For the mechanical sieving the grain grading scale used was Wentworth (1922), in mm, and Krumbein (1934), in phi (∅), in intervals of ½ ∅. The statistical analysis of the sediments after sieving was performed using the software SysGran 3.0 (Integrated System for Granulometric Analysis), where the statistical parameters determined by Folk and Ward (1957) were calculated, as a grain average diameter (Mz), standard deviation (Dp), asymmetry (Ski) and kurtosis (Kg).

The degree of roundness was defined by counting at least 100 grains of the modal fraction of each sample, visual comparison tables were developed from five different classes of degrees of roundness with intervals defined by numeric values and names for the angular, sub-angular, sub-rounded, rounded and well-rounded classes.

4. Results

Regarding the color of the sediments, no significant differences were observed between a campaign and another, both for the colors of the samples in situ and after drying. According to the scale of Munsell (Goddard et al. 1975), the sediments in situ collected in the backshore of the Lagoinha, Mole, Solidão and Matadeiro beaches showed the color pale yellow (2.5Y7/3, 2.5Y 7/4 and 2.5Y 8/2) in the scale. As for

sediments collected in the backshore of Cacupé Grande and José Mendes, and in the humid portions of all the profiles (beach face and upper foreshore) presented sand with colors light yellowish brown, (2.5Y6/3 and 2.5Y 6/4) and in smaller occasions light olive brown (2.5Y5/3, 2.5Y 5/4 and 2.5Y 5/6). After being washed and dried, the sediments, in 100% of the samples, presented the color pale yellow (2.5Y7/3, 2.5Y 8/2 and 2.5Y 8/3).

4.1. Cacupé Grande beach

Cacupé Grande beach presented an average granulometric composition of 73.5% of sand, 26.4% of gravel and 0.1% of mud. From the sand fraction, the predominant fraction in the samples was coarse sand (66.7%) and very coarse sand (33.3%). The observed average diameter of the grain was -0.03∅, with samples poorly sorted (91.7%) to moderately sorted (8.3%, whose average was 1,23∅. Regarding asymmetry, 75% of the samples were ranked with positive asymmetry (nine samples), 16.7% with very positive (two samples) and 8.3% with approximately symmetric, whose asymmetry values (Ski) ranged from 0.05 to 0.57. As for the kurtosis (Kg), 66.7% of the samples were ranked as platykurtic, 25% as mesokurtic and 8.3% as very platykurtic, whose average was 0.81.

At the backshore zone prevailed coarse sand (75%), with grain average diameter of -0.08∅. The average standard deviation found was of 1.09∅, prevailed poorly sorted sediments (75%). All the samples exhibited positive asymmetry, with values between 0.17 and 0.25. Regarding kurtosis, the samples were ranked as platykurtic (50%, two samples) and mesokurtic (50%, two samples), with average value of 0.89.

In the beach face zone, coarse sand prevailed (75%, with a grain average diameter of 0.08∅. All the samples were ranked as poorly sorted and the average standard deviation was 1.31∅. Regarding asymmetry, 50% of the samples presented a positive asymmetry, 25% very positive asymmetry and 25% approximately symmetric, with values between 0.05 and 0.34. Regarding kurtosis, the average value obtained was 0.79, with all the samples ranked as platykurtic. The histograms of simple frequency (figure 2) indicate bimodal samples, with the modal diameter between -1 and -0.5∅ (very coarse sand) and a crescent between diameters 1.5 and 2∅ (average to fine sand).

The upper foreshore zone presented a mixed domain, with 50% of coarse sand and 50% of very coarse sand, the grain average diameter being equal to -0.10∅. The average standard deviation obtained was of 1.30∅, with all the samples poorly sorted. Among them, 75% presented positive asymmetry and 25% very positive, with values between 0.13 and 0.57. Kurtosis showed an average value of 0.26, with predominance of platykurtic samples), and 25% of very platykurtic and mesokurtic samples. Granulometric distribution still indicates the presence of bimodal samples, with modal diameter between -1 and 0∅, and an increase of sediment between fractions 1 and 2∅.

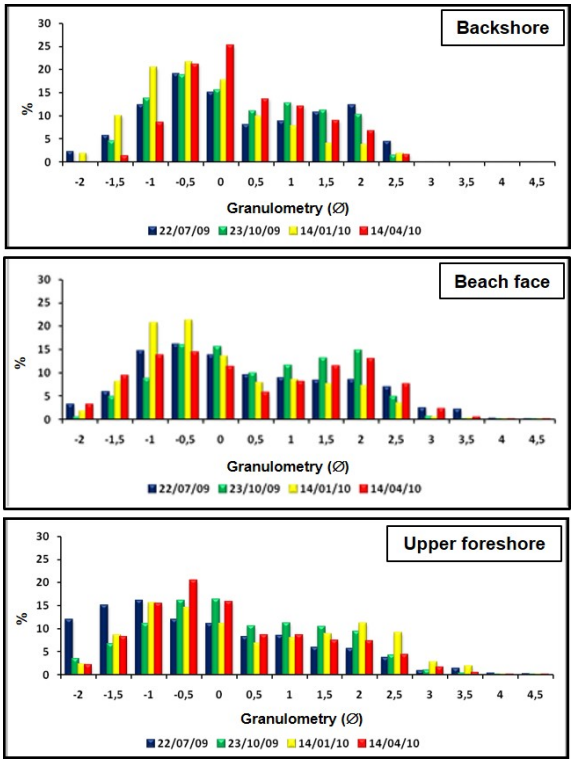

Figure 2: Histograms of simple frequency in the backshore, beach face and upper foreshore zone of the Cacupé Grande beach, regarding the four campaigns performed.

Cacupé Grande beach presented prevalence of sub-rounded and sub-angular grains. At backshore zone, sub-rounded grains prevailed in all campaigns. The beach face zone presented predominance of sub-rounded grains (spring, summer and fall campaigns) and in the upper foreshore was observed sub-angular sediments in winter and spring and sub-rounded in the summer and fall campaigns. It is possible to note that the degree of roundness tends to migrate from the more rounded classes to the more angular of the backshore zone to the upper foreshore zone.

4.2. Lagoinha beach

The samples presented a granulometric composition of fine sand (100%), with an average size of grain (Mz) equal to 2.42∅. The average standard deviation (Dp) found was of 0.44∅, with well sorted samples in 75% of the cases, moderately sorted in 16.7% and very well sorted in 8.3%. The samples presented values of asymmetry (Ski) between -0.15 and 0.18, being 41.7% of them with positive asymmetry, 33.3% approximately symmetric, and 25% with negative asymmetry. Regarding the kurtosis (Kg), 50% of the samples were ranked as mesokurtic, 41.7% as leptokurtic and 8.3% as platykurtic; with an average value equal to 1.09.

The backshore zone presented fine sand with average diameter of 2.35∅. The average standard deviation found was equal to 0.37∅, with well sorted samples in

75% and very well sorted 25%. The asymmetry values are found between -0.13 and 0.12, with samples ranked as positive asymmetry in 50%, 25% with negative asymmetry and 25% approximately symmetric. The average value of the kurtosis found was equal to 1.09 and the samples were ranked as leptokurtic in 50% of the cases, mesokurtic in 25% and platykurtic in the other 25%. The histograms of simple frequency, where predominantly unimodal samples can be observed, with the mode found in diameter 2.5∅ (fine sand) in all the campaigns (figure 3).

In the beach face zone, fine sand prevailed, with a grain average diameter equals to 2.47∅. All the samples were ranked as well sorted and the average value of the standard deviation was 0.42∅. Regarding asymmetry, 50% of the samples have a positive asymmetry and other 50% are approximately symmetric, with values between -0.06 and 0.18. Regarding kurtosis, the average value obtained was of 1.06, with 75% of the samples ranked as leptokurtic and 25% ranked as mesokurtic. The histograms of simple frequency indicate a unimodal distribution in the four campaigns, and in winter and summer they have the grain diameter peaks in 2.5∅, and during spring and fall they have the grain diameter peaks in 3∅ (fine sand) (figure 3).

The upper foreshore zone also presented fine sand in 100% of the samples, with grain average diameter equal to 2.42∅. The average standard deviation found was of 0.53∅, with 50% of the samples well sorted and 50% moderately sorted. These samples showed negative asymmetry in 50% of the cases, with positive asymmetry in 25% and approximately symmetric in the other 25%, whose values are found between -0.15 and 0.10. Regarding kurtosis, the average value found was of 1.12, with leptokurtic samples in 50% of the cases and mesokurtic also with 50%. The simple frequency histograms indicate unimodal samples, with modal diameter between 2.5 and 3∅ (figure 3).

Lagoinha beach presented a prevalence of rounded and well-rounded sediments. The backshore zone has well-rounded grains in all campaigns and in the beach face and upper foreshore zones prevail rounded grains. Angle grains were not found in the samples.

4.3 Mole beach

Mole beach presented granulometry consisting mainly in medium sand (83.3%) and coarse sand (16.7%), with grain average diameter (Mz) equal to 1.35∅. The average standard deviation (Dp) found was of 0.63∅, with a prevalence of moderately sorted samples (83.3%) and well sorted (16.7%). Asymmetry (Ski) has values between -0.23 and 0.11 and the samples were ranked as approximately symmetric in 75% of the cases, negative asymmetry in 16.7% and positive asymmetry in 8.3%. Kurtosis (Kg) showed an average value equal to 0.96, with 75% of mesokurtic and 25% of platykurtic samples.

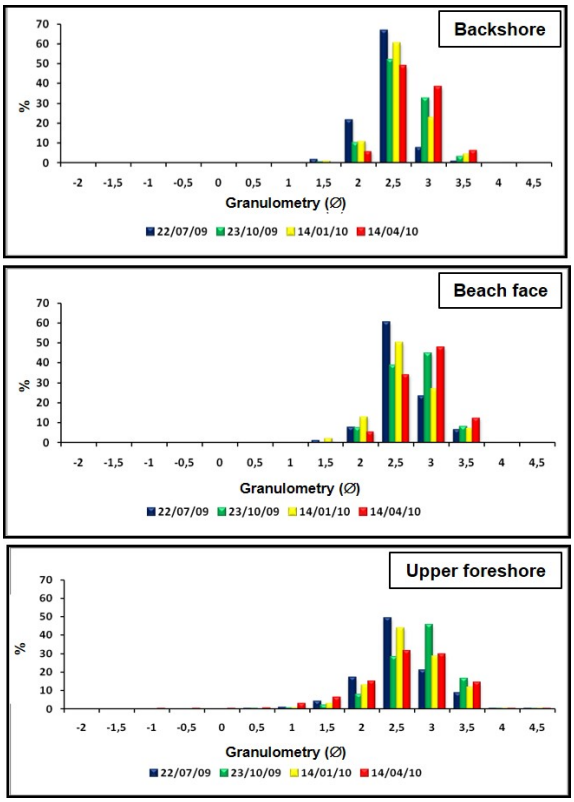

Figure 3: Histograms of simple frequency in the backshore, beach face and upper foreshore zone of the Lagoinha beach, regarding the four campaigns performed.

The backshore zone has a granulometric composition of medium sand (100%) with average diameter of 1.54∅. The average standard deviation found was equal to 0.52∅, with 75% of the moderately sorted samples and 25% well sorted. The values of asymmetry observed ranged from -0.04 to 0.05, with all the samples approximately symmetric. Regarding kurtosis, all the samples are mesokurtic, with average value equal to 0.99. The simple frequency histogram of the grain diameter (figure 4) indicates that the samples are predominantly unimodal, with the modal diameter between 1.5 and 2 ∅ (average sand).

The beach face zone presented a granulometric composition of medium sand (100%), with a grain average diameter equal to 1.32∅. The average standard deviation observed was equal to 0.61∅ with 75% of the moderately sorted and 25% well sorted. The asymmetry values ranged between -0.04 and 0.09, the samples being ranked as approximately symmetric. Average kurtosis was equal to 0.94, the samples ranked as mesokurtic in 75% and platykurtic in the other 25%.

The simple frequency histograms (figure 4) of the beach face zone show samples still predominantly unimodal, with modal diameter between 1 and 1.5∅ (average sand), but it is observed that the winter and fall samples showed a larger distribution of the sediments by the intervals, i.e., they have a larger standard deviation than the other samples.

The upper foreshore zone has a prevailing granulometric composition, mixed with medium sand (50%) and coarse sand (50%), with a grain average

diameter equal to 1.19∅. Regarding the standard deviation, all samples were ranked as moderately sorted and the average value found was equal to 0.75∅. The asymmetry values ranged from -0.23 to 0.11, with negative asymmetry in 50%, positive asymmetry in 25% and 25% of samples approximately symmetric. Kurtosis presented an average value of 0.94 and the samples ranked as platykurtic and mesokurtic in 50% of each case.

The grain diameter simple frequency data show the similarity among the spring and summer campaigns, including how they differ from the winter and fall samples (figure 4). The first two are presented unimodal, with modal diameter in 1∅ (average sand); the one from the winter have greater standard deviation, with modal distribution between 2 and 2.5∅ (fine sand); and the one from the fall shows bimodality with greater standard deviation, main modal diameter in the interval of 3∅ (fine sand), besides another peak in 1∅, which takes to a value of Mz regarding the average sand.

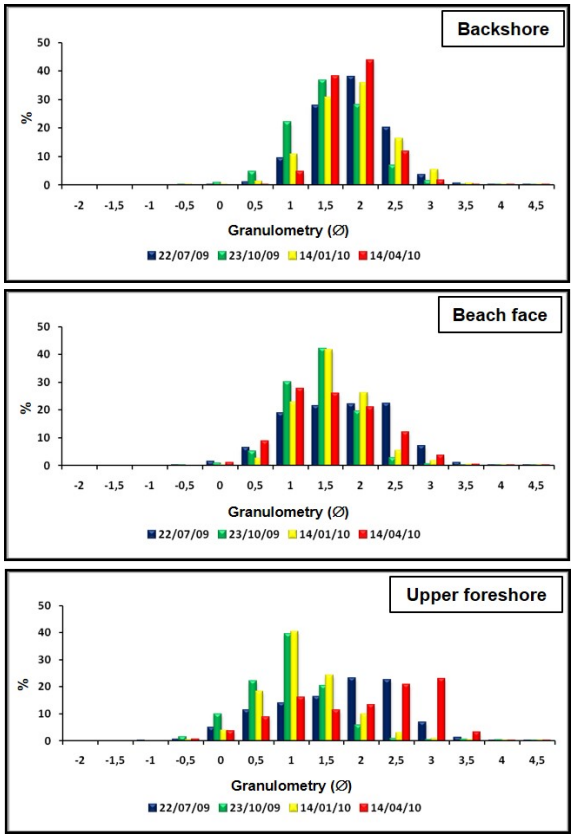

Figure 4: Histograms of simple frequency in the backshore, beach face and upper foreshore zone of the Mole beach, regarding the four campaigns performed.

At Mole beach predominated well-rounded and rounded grains. The backshore zone presented a predominance of well-rounded grains, followed by rounded grains, in all campaigns, in a practically uniform mode. At the beach face zone also prevailed well-rounded grains in all campaigns, but with a more balanced distribution of the values between this class and the rounded class. In the upper foreshore zone there was a prevalence of well-rounded sediments in winter and summer and rounded in fall and spring, the dominance of the class being more evident in spring (60%). There was no occurrence of sub-angular nor angular grains.

4.4 Solidão beach

The Solidão beach profile presented a prevailing granulometric composition of fine sand, with 91.7%, and medium sand, with 8.3%, with average grain diameter (Mz) equal to 2.27∅. The average standard deviation (Dp) observed was equal to 0.51∅, prevailing well sorted samples (66.7%) and moderately sorted (33.3%). Among the samples, 75% are approximately symmetric and 25% have a positive asymmetry, whose values ranged between -0.10 and 0.18. As for kurtosis (Kg), there were mesokurtic (66.7%), leptokurtic (25%) and platykurtic (8.3%), which kurtosis average value being equal to 1.03.

At the backshore zone the dominant granulometric composition was fine sand (100%), with an average diameter of 2.34∅. The average standard deviation found was equal to 0.42∅, with all the samples ranked as well sorted. The asymmetry values ranged between 0.04 and 0.11, being 50% of the samples with positive asymmetry and 50% approximately symmetric. The kurtosis average value found was equal to 1.05, mesokurtic (75%) and leptokurtic (25%) prevailing. The histograms of simple frequency show predominantly unimodal samples, with the mode found in diameter 2.5∅ in all campaigns (fine sand) (figure 5).

The beach face zone showed prevalence of fine sand (100%), with grain average diameter equal to 2.32∅. The average standard deviation obtained was of 0.46∅, with a prevalence of well sorted (75%) and moderately sorted (25%). From these samples, 75% are approximately symmetric and 25% have a positive asymmetry, whose values ranged between -0.10 and 0.18. Regarding kurtosis, there is a distribution of 50% of leptokurtic and 50% of mesokurtic, with an average value of kurtosis equal to 1.06. The simple frequency histograms (figure 5) represent unimodal samples, with the modal diameter in the interval of 2.5∅.

The upper foreshore zone showed a composition of fine sand (75%) and medium sand (25%), with a grain average diameter equal to 2.14∅. The average standard deviation obtained was of 0.51∅, with a prevalence of moderately sorted (75%) and well sorted (25%). The samples were all ranked as approximately symmetric, the average values being between -0.02 and 0.04. Regarding kurtosis, 75% are mesokurtic and 25% are platykurtic, with kurtosis average value being equal to 0.99. The simple frequency histograms (figure 5) represent unimodal samples, with the modal diameter between the intervals of 2 to 2.5∅.

Solidão beach presented a prevalence of rounded, well-rounded and sub-rounded sediments. All the zones presented a prevalence of rounded grains. A somehow uniform behavior of the values is observed during the

campaigns, except at the backshore zone during winter. Angular grains were not found.

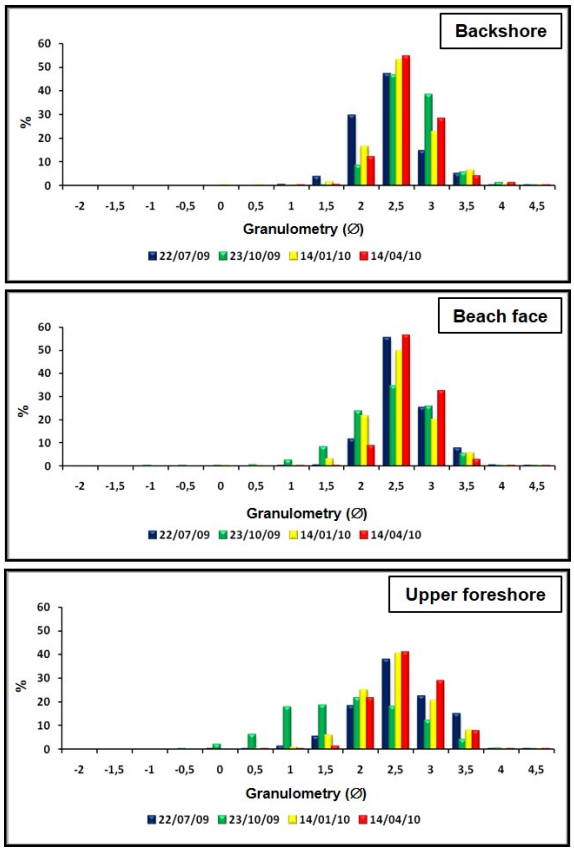

Figure 5: Histograms of simple frequency in the backshore, beach face and upper foreshore zone of the Solidão beach, regarding the four campaigns performed.

4.5 Matadeiro beach

Granulometric data of the Matadeiro beach showed a predominance of the fine sand composition in 100% of the samples, with an average grain size (Mz) equal to 2.65∅. The standard deviation average value (Dp) was of 0.40∅, with a prevalence of well sorted (83.3%) to very well sorted (16.7%. In this profile, 83.3% of the samples are approximately symmetric and 16.7% have negative asymmetry, whose values ranged from -0.13 to 0.00. Regarding kurtosis (Kg), 66.7% are mesokurtic and 33.3% are leptokurtic, and the kurtosis average value is equal to 1.07.

At the backshore zone fine sand (100%) prevailed, with an average diameter of 2.65∅. The average standard deviation was equal to 0.37∅, with well sorted (75%) and very well sorted (25%). The asymmetry value ranged from -0.08 to 0.00, with 100% of the samples approximately symmetric. The kurtosis average value found was equal to 1.07, and mesokurtic (75%) and leptokurtic (25%) prevailed. The simple frequency histograms (figure 6) indicate unimodal samples, with a modal diameter found in interval 3∅ (fine sand) in all campaigns.

At the beach face zone fine sand (100%) prevailed, with a grain average diameter equal to 2.65∅. The average standard deviation obtained was of 0.38∅, with a prevalence of well sorted (75%) to very well sorted (25%). All the samples were ranked as approximately symmetric, ranging from -0.08 to 0.00. The kurtosis average value obtained was equal to 1.07, where 75% are mesokurtic and 25% are leptokurtic. The simple frequency histograms (figure 6) represent unimodal samples, with the modal diameter in the interval of 3∅.

The upper foreshore zone showed prevalence of fine sand (100%), with grain average diameter equal to 2.64∅. The average standard deviation obtained was of 0.44∅, prevailing well sorted (100%) samples. The samples were shown approximately symmetric (50%) and with negative asymmetry (50%), with values ranging between -0.13 and 0.00. Regarding kurtosis, 50% are mesokurtic and 50% leptokurtic, with kurtosis average value being equal to 1.07. The simple frequency histograms of the grain diameter show that in this sector, as well as at the backshore and face beach, the samples are unimodal, with a modal diameter in 3∅ (figure 6).

Regarding the roundness degree, the beach presented a dominance of rounded, sub-rounded and well-rounded grains. In the three zones of the profile there was a predominance of rounded sediments in all samples, generally with over 50% of dominance. The backshore zone has in average the largest amount of well-rounded grains and the upper foreshore zone the largest amount of sub-rounded grains. Angular grains were not observed.

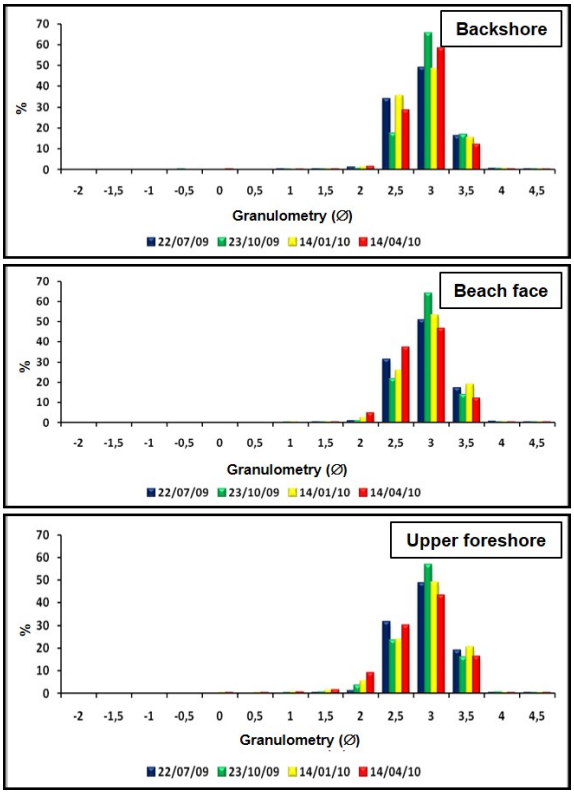

Figure 6: Histograms of simple frequency in the backshore, beach face and upper foreshore zone of the Matadeiro beach, regarding the four campaigns performed.

4.6 José Mendes beach

José Mendes beach has in its granulometric composition gravel (15.35%), sand (84.61%) and mud (0.04%). From the sand fraction, the prevailing composition is of coarse sand (58.4%), medium sand (33.3%) and very coarse sand (8.3%). The grain average diameter (Mz) obtained was equal to 0.60∅. The average standard deviation (Dp) found was of 1.27∅, with poorly sorted (91.7%) to moderately sorted (8.3%). The samples were ranked in approximately symmetric (50%), negative asymmetry (25%), very positive asymmetry (16.7%), and positive asymmetry (8.3%), whose values ranged from -0.27 to 0.70. Regarding kurtosis (Kg), the samples are platykurtic (58.4%) and mesokurtic (41.6%), with average value of 0.8.

At the backshore zone prevailed medium sand (75%) and coarse sand (25%), with grain average diameter of 1.07∅. The average standard deviation found was of 1.05∅, and the samples were classified as poorly sorted (75%) and moderately sorted (25%). Half of the samples showed negative asymmetry and the other half was approximately symmetric, with values between -0.27 and -0.03. Regarding kurtosis, mesokurtic samples prevailed (75%) and platykurtic (25%), with an average value equal to 0.95. The histograms of simple frequency of the grain diameter indicate that the spring and fall campaigns have a unimodal distribution of the grain diameter, and in spring the modal diameter occurred in 1∅ (average sand) and in fall in 2.5∅ (average sand) (figure 7).

At the beach face zone prevailed medium sand (75%) with a grain average diameter being 0.53∅. All the samples are poorly sorted, and the average standard deviation was 1.26∅. Regarding the asymmetry, 50% of the samples are approximately symmetric, 25% have positive asymmetry and 25% have negative asymmetry, with values between -0.20 and 0.29. As for kurtosis, the average value obtained was of 0.89, with platykurtic (50%) and mesokurtic samples (50%). The simple frequency histograms (figure 7) indicate campaigns with unimodal, bimodal and polimodal distribution. The winter and summer campaigns presented polimodal distribution and the spring campaign was distributed in a bimodal mode, with "peaks" in the intervals 0.0∅ (modal diameter) and 1∅. Finally, the fall campaign was distributed in a unimodal mode, with a modal diameter in the interval of 0.0∅.

The upper foreshore zone has a composition of coarse sand (75%) and very coarse sand (25%), being the grain average diameter equal to 0.20∅. The average standard deviation found was equal to 1.50∅, and all the samples were ranked as poorly sorted. Among the samples, 50% are approximately symmetric and 50% presented a very positive asymmetry, with values between -0.06 and 0.70. Kurtosis showed an average value of 0.76, and all the samples were classified as platykurtic. The simple frequency histograms again indicate the presence of bimodal and polimodal samples (figure 7). The spring sample showed a bimodal distribution in the intervals of -0.5 and 2∅ being the modal diameter observed in the interval of -0.5∅. The summer campaign also has a bimodal distribution, with most of the sediment content in the coarser grains and the modal diameter in the interval of -1∅, besides the occurrence of a "peak" in the interval of 2∅. In winter there three "peaks" of the grain diameter distribution in the intervals of -0.5, 1 and 2.5∅, being the modal diameter found in the interval of 2.5∅. The fall campaign also showed to be polimodal, with "peaks" of the distribution in the intervals of -1, 1 and 3∅, with a modal diameter in the interval of -1∅.

At this beach prevailed sub-rounded and sub-angular grains. At the backshore and beach face zone prevailed sub-rounded grains in all campaigns. At the upper foreshore zone there was a prevalence of sub-rounded sediments in winter, spring and fall, and sub-angular grains in summer. Only José Mendes beach showed grains in all rounded degree categories.

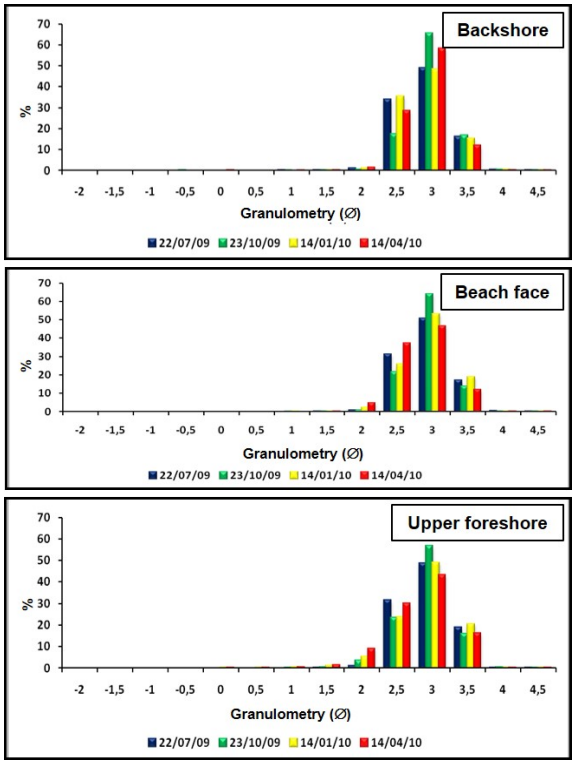

Figure 7: Histograms of simple frequency in the backshore, beach face and upper foreshore zone of the José Mendes beach, regarding the four campaigns performed.

4.7 Comparison among beaches

Regarding the texture, the grain average diameter (Mz) presented variations among the beaches and among the beach profiles sectors. It was observed that Lagoinha, Solidão and Matadeiro beaches have finer sand than the others. At Mole beach prevailed medium sand, at Cacupé Grande beach coarse to very coarse sand, and at José Mendes beach there was a variation from medium to very coarse sand.

It was noted that in most of the profiles along the campaigns the value of Mz decreases from the backshore zone towards the upper foreshore zone, indicating an increase in the granulometry among these zones. The Lagoinha and Matadeiro beaches did not show a significant variation of Mz among the zones of their profiles during the campaigns, keeping the ranking of fine sand in all the points. At the Solidão and Mole beaches there was an increase of Mz of the emerged portions for the upper foreshore zone during the spring (Solidão beach) and summer (Mole and Solidão beaches) campaigns. In turn the Cacupé Grande and José Mendes beaches demonstrated larger variation of Mz among the points and the campaigns. However, they did not present a definite pattern or like the other beaches, nor seasonal changes among the points shown.

It is observed that the Lagoinha, Solidão and Matadeiro beaches have values of Dp and Mz that are similar among fine sand and very well sorted, well sorted to moderately sorted samples. At Mole beach there was a prevalence of medium, well sorted to moderately sorted sand. At the Cacupé Grande beach there was a prevalence of poorly sorted samples because of the coarser granulometry at this beach. The José Mendes beach also showed a prevalence of poorly sorted samples, but with greater variation in the grain average size. The Dp values of the samples of the backshore zone were smaller than the beach face zone values and at the upper foreshore zone in most of the profiles, and the larger values of Dp indicate lower sorting degrees. At the backshore zone the sediments presented finer granulometry and more selection at the upper foreshore zone coarser granulometry and a lesser degree of sorting and at the beach face zone intermediate characteristics among the other sectors.

The relationship between average diameter values and kurtosis (Kg) showed that Lagoinha, Mole, Solidão and Matadeiro beaches present a prevalence of mesokurtic samples, where the granulometric distribution is dispersed among the intervals of Mz, but there is evidence of a prevalence of a single modal fraction. At Lagoinha, Solidão and Matadeiro beaches also occurred leptokurtic samples, where the granulometric distribution curve is sharper, i.e., it concentrates the larges values in a single modal interval. Platykurtic samples, where the distribution curve is flat, with the occurrence of more than one modal interval, were observed with greater frequency at the bay beaches (Cacupé Grande and José Mendes beaches), where also occurred samples with larger values of standard deviation and asymmetry. Besides, at these beaches it was noted that the kurtosis values, in average, decrease from the backshore zone to the upper foreshore zone, indicating in this last sector a larger presence of more than one significant interval in the granulometric distribution. At the other beaches, the average values of Kg were shown without significant changes between a sector and another of the profile.

The degree of roundness was shown to be diversified among the beaches. The Mole beach obtained a predominance of well-rounded grains in the three sectors of the profile, and this fact is associated to a greater dynamic that the beach presents in the remobilization of sediments of the submerged area to the emerged zone and to the greater action of the acting waves, which transform the environment in a smaller space of time, if compared to the other beaches. The Lagoinha, Solidão and Matadeiro beaches had a predominance of rounded sediments in their profiles. The Cacupé Grande and José Mendes beaches showed a prevalence of sub-rounded grains in their profiles in the campaigns analyzed because these beaches have low energy of wave, as already described in their morphodynamics characteristics.

5. Discussion

At most of the ocean beaches the upper foreshore zone samples presented the smallest values of asymmetry and largest grain average diameters. This relationship is given by the fact that the submerged zone has a larger competency of transport, making possible the inclusion of coarser sediments in the granulometric distribution, which allows for the curve to tend for the negative asymmetry. In the emerged portion, especially at the backshore zone, the type of transport prevailing is the wind, that has greater capacity of selection, remobilizing and transporting the finer grains, resulting in a trend of distribution approximately symmetric or with small values of positive or negative asymmetry (Felix 2010).

Nonetheless, at the bay beaches this fact was not noticed in most of the profiles, and the largest values occurred precisely at the upper foreshore zone, in a reverse pattern to the ocean beaches. This may be explained by the fact that practically there is no transport between the emerged and submerged zones at this type of beach. Therefore, the sediments in the emerged zone do not go through transport with the same intensity of the ocean beaches and present more homogeneous asymmetry values (Nordstrom 1992).

It was observed in all the beaches that the grains are more rounded in the backshore zone and greater angularity at the upper foreshore zone. This difference is also related to the type sediment transport, being the aqueous at the upper foreshore zone and the one with wind at the emerged portion. Water transports coarser sediments and does not deposit them in the bottom nor reworks them, while the wind transport reworks the sediments, which ends up making them smaller in size, with more roundness. These patterns were observed during the four seasonal campaigns, and there were no significant variations between one campaign and another.

In an overview of the six beaches (table 2), a larger similarity of values and parameters is noticed between the bay beaches (Cacupé Grande and José Mendes beaches) (table 2). Both are located at the western domain of the island of Santa Catarina, their sand is

immature, coarse to very coarse, poorly sorted, platykurtic, sub-rounded, positive to approximately symmetric. The beaches ranked as semi-exposed (Lagoinha and Matadeiro beaches) presented in common a fine sandy texture, well sorted, approximately symmetric, mesokurtic, rounded and supermature. The ocean beaches, exposed (Mole and Solidão beaches), have the stage of maturity supermature, mesokurtic sediments and approximately symmetric.

From the three groups of beaches, the ones exposed present more contrasting characteristics, possibly by the larger exposition of the Mole beach when compared to the Solidão beach. Therefore, the Mole beach presents average, moderately sorted and well-rounded sand. As for Solidão beach, it shows the presence of fine sand, well sorted and rounded grains.

Table 2: Overall results regarding the sedimentology and mineralogical maturity.

Data	Cacupé Grande	Lagoinha	Mole	Solidão	Matadeiro	José Mendes
Coast	Northwest	North	Northeast	South	Southeast	Southwest
Exposure	Protected	Semi-exposed	Exposed	Exposed	Semi-exposed	Protected
Texture	VCS	FS	MS	FS	FS	CS
Sorting	Ps	Bs	Ms	Bs	Bs	Ps
Asymmetry	P	AS	AS	AS	AS	AS
Kurtosis	Platykurtic	Mesokurtic	Mesokurtic	Mesokurtic	Mesokurtic	Platykurtic
Roundness	Sr	R	Wr	R	R	Sr
Maturity	Immature	Supermature	Supermature	Supermature	Supermature	Immature

Legend: Texture: VCS = very coarse sand, CS = coarse sand, MS = medium sand, FS = fine sand; Sorting: Ps = poorly sorted, Ms = moderately sorted, Bs = well sorted. Asymmetry: P = positive, AS = approximately symmetric. Roundness: Sr = sub-rounded, R = rounded, Wr = well-rounded.

From this summary and the study by Horn Filho (2006), characterizing the texture aspects of the beaches of the Santa Catarina islands, there was an attempt to establish a correlation between the results of each coast, according to the sectors suggested by Horn Filho et al. (1999), regarding the sediment parameters and the exposition of the beach environment to waves and currents.

In general, it is noticed that the data presented by the beaches and by the coasts are similar in most of the occasions, specially at the North, Southeast and South coasts. The Lagoinha, José Mendes and Solidão beaches obtained greater similarity with the prevailing characteristics at their coasts, such as sediment texture, degree of sorting, asymmetry and kurtosis, besides the degree of exposition of the beach to the coastal hydrodynamics. In this research, the kurtosis values obtained were shown slightly higher than in the general study from Horn Filho (2006).

The Cacupé Grande beach, in turn, characterizes the Northwest coast regarding the profile dimensions, the grain average size and the exposed beach environment, but it demonstrated lower values of sorting, asymmetry and kurtosis, regarding the prevailing rankings at this coast. The Mole and Matadeiro beaches are located on the coasts marked by the presence of several beaches with different characteristics, in terms of sediments and of morphodynamics, varying the composition of fine to coarse sand, exposed to semi-exposed beaches. Thus, these beaches end up not representing their respective coasts in a precise way, but only in some aspects.

6. Conclusion

The grain diameter average values, standard deviation, asymmetry and kurtosis were like the ones obtained by Horn Filho (2006), besides agreeing with the proposals from Martins et al. (1970), Suguio (1973, 2003), Nordstrom (1992), among others. Nonetheless, seasonal variations among the parameters were not observed, most of these with relatively stable values during the campaigns and the variations that occurred were not significant to define a seasonality. The bay beaches, Cacupé Grande and José Mendes showed coarse sandy, immature sediments, which is evidence of little transport of material. As for the ocean beaches (exposed and semi-exposed), Lagoinha, Mole, Solidão and Matadeiro beaches, they presented more mature, average to fine sandy grains, showing evidence of larger rework and transport. At the backshore, the sediments are constituted of finer, better sorted sand, while at the upper foreshore the sand is coarser and less sorted.

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