

Chapter 6

WASHOVER TEXTURAL SIGNATURE AND ASSOCIATED SEDIMENTARY DYNAMICS

6.1. INTRODUCTION

Coastal sedimentary studies have been undertaken in the Ria Formosa barrier island system since 1980. Some of the objectives from those studies were: (1) obtain a general characterisation of the textural parameters of the barrier environments (foreshore, dune, inlet, tidal channel, salt marsh; Granja, 1984; Bettencourt, 1988; Andrade, 1990); (2) identification of sedimentary sources to the system (updrift cliffs, littoral drift, continental shelf) by analysing texture, composition and shape (Granja, 1984; Bettencourt, 1988; Dias, 1986; Andrade, 1990); and (3) determinate the foreshore grain-size variations in response to the seasonal wave regime (Bettencourt, 1988; Teixeira *et al.*, 1989; Mendes *et al.*, 1999). Washover sediments have never been analysed in depth, although the importance of overwash processes has been recognised for this barrier system (Dias, 1988; Pilkey *et al.*, 1989; Andrade, 1990). The only existing study on washover sediments was made by Andrade (1990). However, this author analysed sediment samples that were collected from pre-existing washovers that were not recently formed, some even corresponding to vertically accreted features not yet completely vegetated.

This chapter has two main objectives: (1) definition of the washover textural signature; and (2) identification of sediment dynamics of washovers in the barrier islands. The definition of the textural signatures aims to distinguish sediment textures in both barrier islands and tidal inlet environments. The main goal is to provide an explanation of the defined textural groups for barrier environments in terms of their associated sediment dynamics. Washover sediment dynamics are defined as the spatial and temporal variability of sediments deposited by overwash flows, as well as post-overwash sedimentary evolution.

6.2. METHODS

6.2.1. SAMPLE COLLECTION

The study area for the sediment textural analysis is the eastern end of the Barreta Island and the Ancão Inlet, in the Ria Formosa barrier island system (Figures 3.1 and 3.2). Geomorphologic units, and the sedimentary environments hierarchy and relationships are represented in Figure 6.1. The direct spatial relationships were represented (by arrows), but indirect sediment exchanges can also occur with non sampled environments. For instance, the lagoon channels (not sampled) may transport sediments to and from the flood delta and the washover terminus.

Periodic topographic surveys were conducted on the western part of Barreta Island (Figure 6.2) from June 2001 to June 2004 (details of surveys can be found in section 5.2.2). Seventy five percent of the samples collected for this study correspond to sedimentary environments located on the barrier island. Sediment sample collection was made for five of the campaigns on five profiles (Profiles 1, 4, 8, 12 and 16, Figure 6.2). Superficial sediment samples were collected during post-storm conditions (January and November 2003), fair-weather conditions (July 2002 and 2003), and mixed conditions (April 2002). A total of 111 samples were collected (Table 6.1), 30 from the beach and 72 from the washover plain. In addition, in January 2004 dune samples were collected westward of the washover (5 samples, area inside the rectangle *D* in Figure 6.2) and from an embryonic aeolian ridge near the landward part of the terrace (3 samples, triangle *de* in Figure 6.2). The samples were then classified according to the barrier morphology into the following categories: beach face, berm, dune, embryonic dune, washover crest, active washover, inactive washover, and washover terminus (Figure 6.3). The criteria for defining the difference between active and

inactive washover was the existence (active) or absence (inactive) of significant morphological changes on the surface due to overwash, between consecutive surveys.

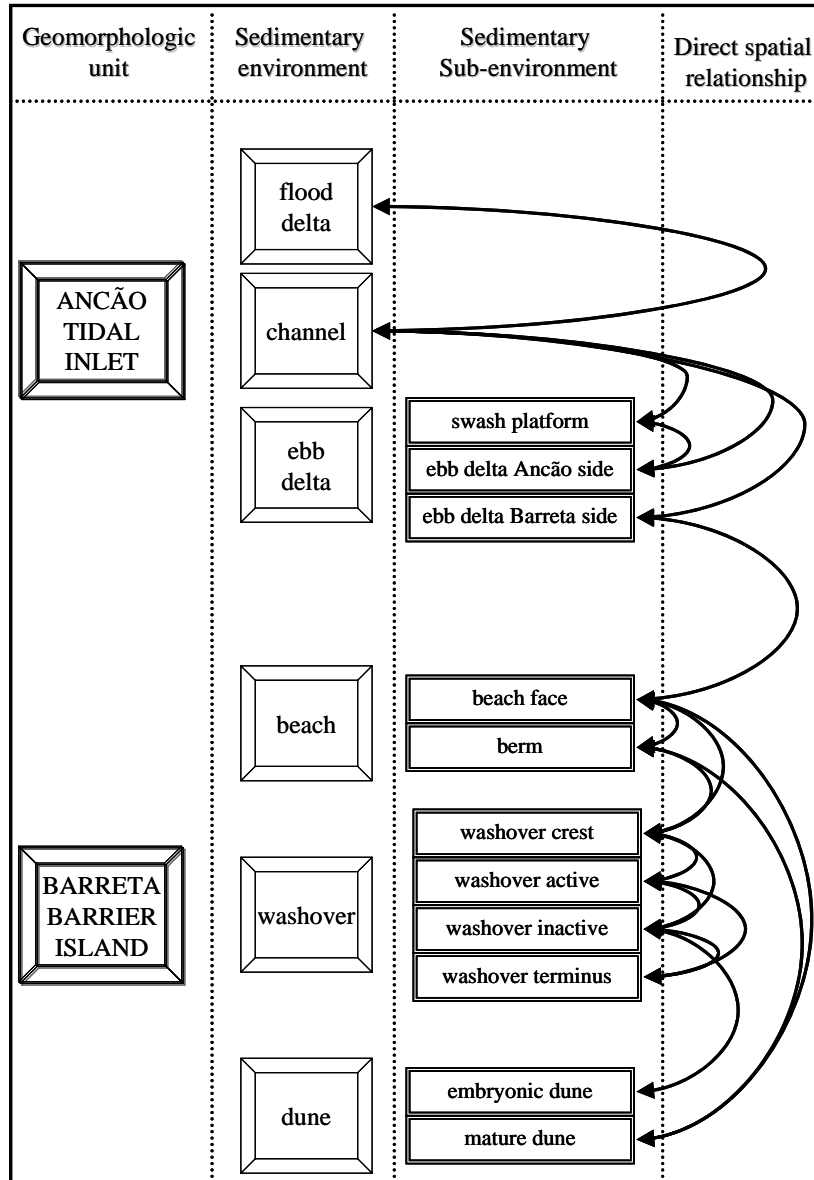


Figure 6.1. Diagram representing direct spatial relationships (represented by arrows) between the geomorphologic units (tidal inlet and barrier island), the sedimentary environments for each of the geomorphologic units, and the sedimentary sub-environments.

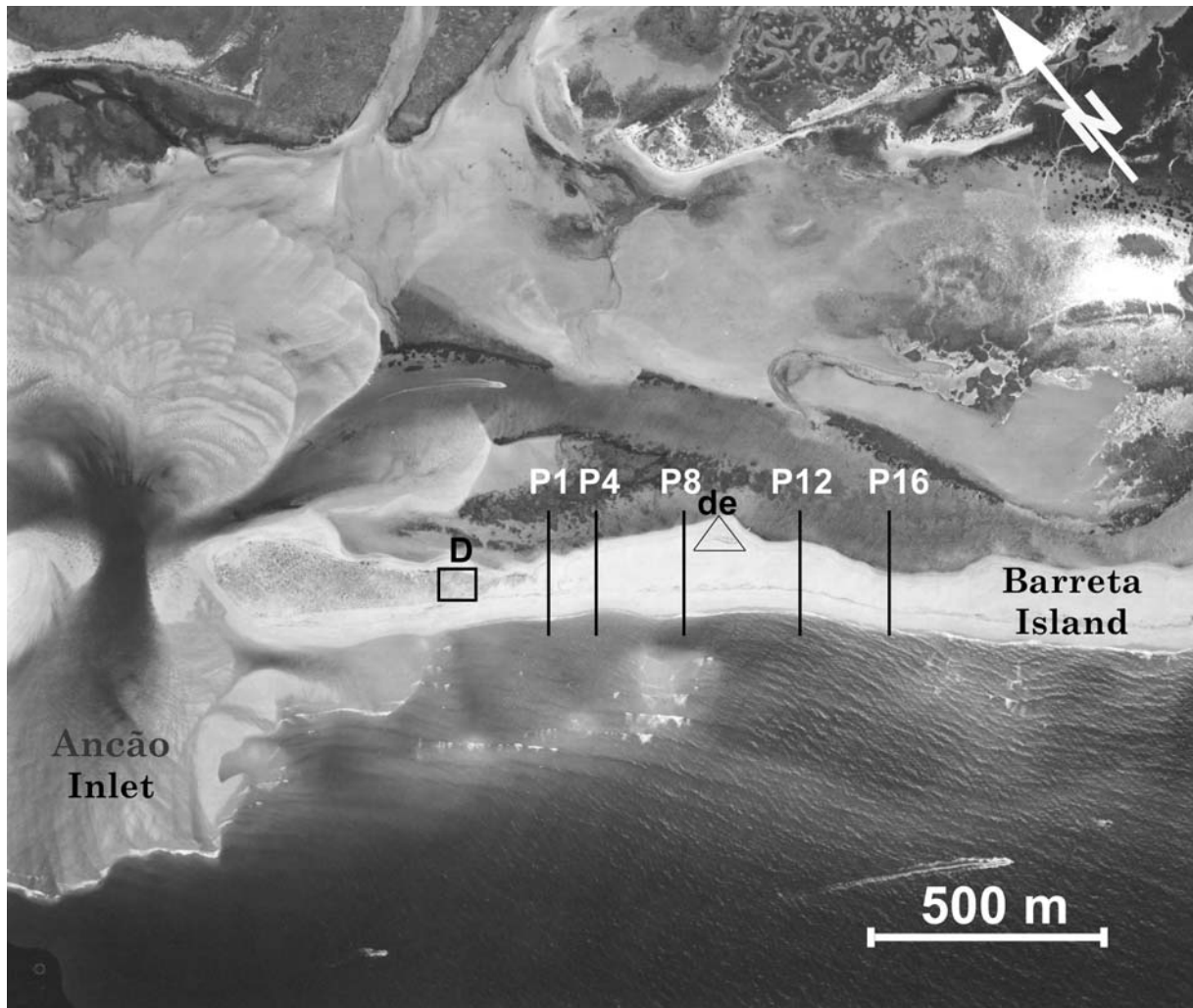


Figure 6.2. Location of profiles on the Barreta Island washover plain. The square (D) encloses the mature dune samples location, and the triangle (de) encloses the embryonic dune samples location.

Table 6.1. Number of collected samples, outliers and analysed samples, for the barrier island sedimentary environments.

Sedimentary environment	# Collected samples	# Outliers	# Analysed samples
Dune	9	1	8
Beach face	25	2	23
Beach berm	5	1	4
Washover crest	20	1	19
Active washover	13	1	12
Inactive washover	15	2	13
Washover terminus	24	0	24
TOTAL	111	8	103

Samples were also taken during two overwash events. Two intensive campaigns were made, in February 2001 (GO.1) and February 2003 (GO.3), that were described and analysed in Chapter 4. Fieldwork was performed between Profiles 1 and 4 (for GO.1), and westwards of Profile 1 (GO.3; Figure 6.2). During these two campaigns, samples were collected on

cross-shore profiles, including beach face, washover crest, active washover and washover terminus. During GO.1, three profiles were sampled, with 20 m to 30 m between them, resulting in a total of 38 samples. While during GO.3, two profiles were sampled, about 30 m apart, and 28 samples were obtained.

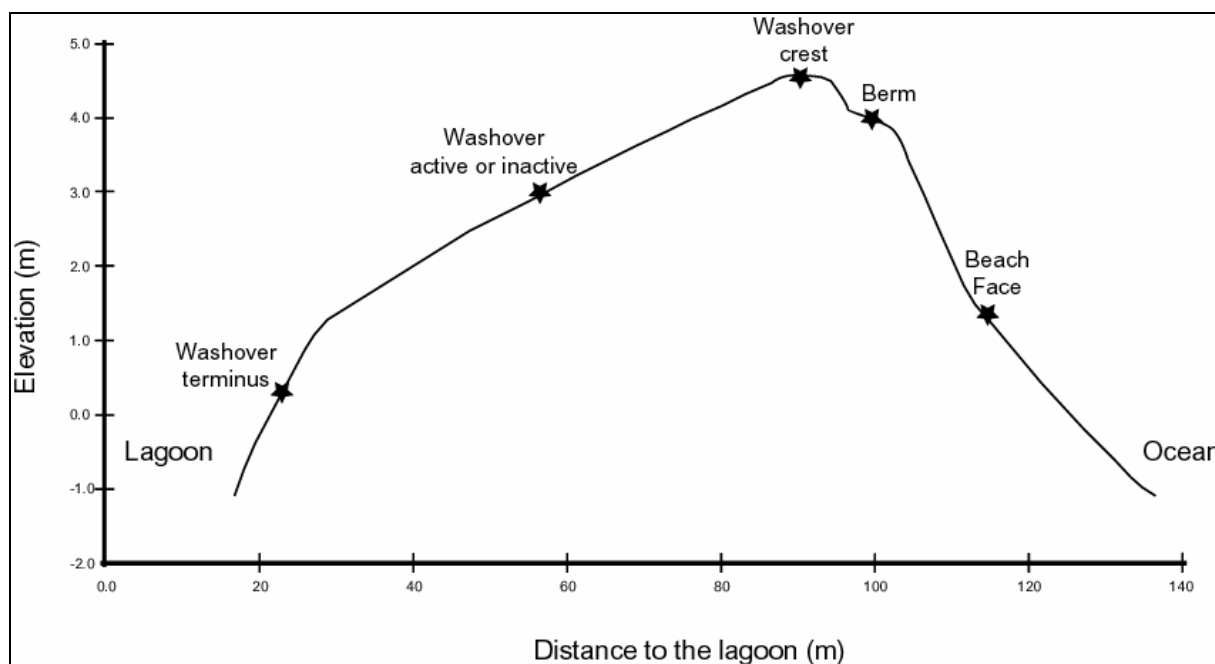


Figure 6.3. Sample collection scheme for the washover area of Barreta Island. Elevation is relative to MSL.

During the GO.1 intensive fieldwork a band of green-painted shells was placed on the crest of the washover as described in Chapter 4, section 4.2.1. The shells sizes varied from fine gravel to cobble (larger shells with 70 mm), and both entire shells and fragments were used.

Samples of the tidal inlet environments were collected in April 1999. A grid with about 250 nodes was defined covering the flood and ebb deltas, and inlet channel. The samples were taken by boat, using a “petit-ponar” grab, which is a quantitative bottom scoop-sampler. The positioning was obtained through a DGPS and the depth was measured with a dual frequency echo sounder. For the purposes of this study only 38 samples were selected (Figure 6.4).

Since the objective is to compare the depositional environments, and because the inlet morphologies (deltas and channel) do not have rigid boundaries, only the samples clearly located within the analysed sedimentary environments were considered. The set of selected samples comprises of 10 samples of the channel, 5 samples of the flood delta, and 22 samples of the swash platform and ebb deltas on both sides of the inlet (Table 6.2).

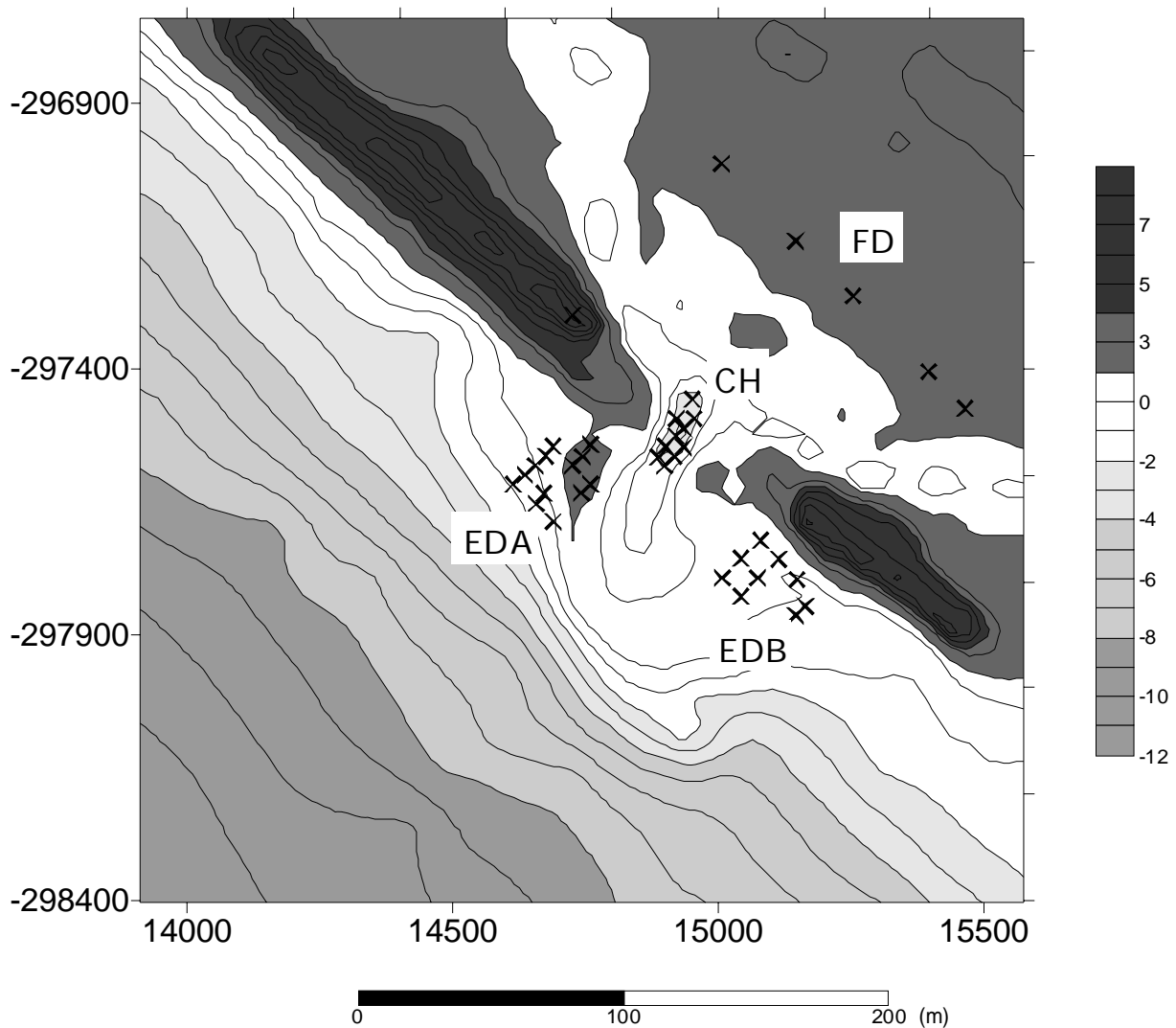


Figure 6.4. Sample locations at the Ancão Inlet. Elevation in meters, referred to Portuguese Hydrographic zero (2m below MSL), with bathymetry represented by negative values. FD – Flood delta; EDA – Ebb delta on Ancão Peninsula, EDB – Ebb delta on Barreta Island, CH – Inlet Channel. Note: the swash platform samples correspond to the crosses on the ebb delta on Ancão Peninsula, above the level +1m. Map dated May 1999 (adapted from Vila-Concejo *et al.*, 2003).

Table 6.2. Number of collected samples, outliers and analysed samples, for the tidal inlet sedimentary environments.

Sedimentary environment	# Collected samples	# Outliers	# Analysed samples
Flood delta	5	1	4
Ebb delta Ancão	8	1	7
Swash platform	5	0	5
Ebb delta Barreta	9	1	8
Channel	10	1	9
TOTAL	37	4	33

6.2.2. GRAIN-SIZE ANALYSIS

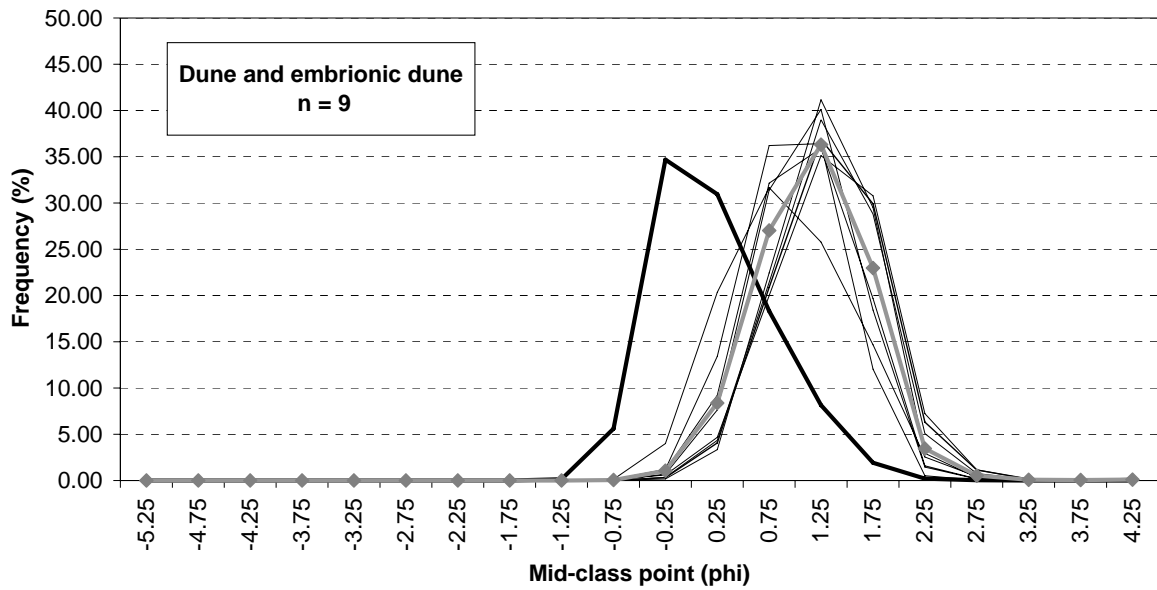
Traditional laboratory dry sieving procedures for unconsolidated clastic sediments were used for all samples. Sieving was done between -5.0ϕ and 4.0ϕ , with 0.5ϕ discrimination interval, thus using 20 sieves.

The classical grain-size parameters were determined (mean, sorting, skewness, and kurtosis) as well as the mode, percentiles 10 (d10), 50 (median) and 90 (d90), using the GRADISTAT program (Blott and Pye, 2001).

Frequency curves were constructed for all samples, and plots of all samples that belong to the same sedimentary environment were then made (for example see Figure 6.5). These plots allowed the comparison between the grain-size distributions of all samples belonging to the same environment. The samples collected during the intensive campaigns GO.1 and GO.3 were not used for environment characterisation, since the sample spacing and timing was not adequate for a global characterisation of each environment. These samples were used for the washover sediment dynamics and cross-shore textural grading analysis.

Inspection of the curves permitted the identification of some samples that had a completely different behaviour with respect to the others (outliers). There are outlier curves that have similar shapes to the more frequent normal curves, but displaced by a certain grain-size interval (Figure 6.5a). In other cases, curves have different shapes and modes, for instance an abnormally high frequency of a certain number of classes (Figure 6.5b).

(a)



(b)

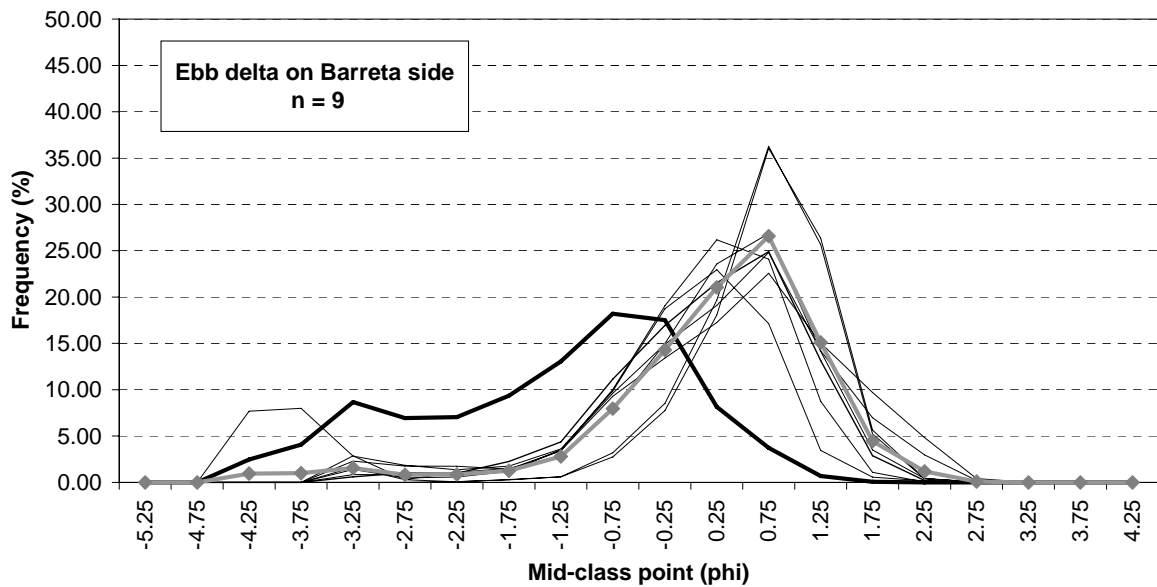


Figure 6.5. Examples of frequency curves of sedimentary sub-environments (thinner black line), outlier curves (thicker black line) and composite curve excluding outliers (thicker grey line). (a) Dune sub-environments (outlier curve displaced towards the coarser grain sizes), and (b) Ebb delta on Barreta side sub-environment (outlier curve displaced towards the coarser grain sizes and addition of coarser-grained population).

The existence of outlier curves that combine both different shapes and frequencies were also observed. An outlier sample can result from fieldwork and/or analytical errors or from intra-environmental variability in dominant physical processes. For example, shells, litter, floating wooden fragments, are generally coarser than the surrounding mineral sediment

components. Samples taken in runnels (e.g. Parker, 1976) or rill marks, on the beach, or in wind shadows on dunes (e.g. Bagnold, 1941) may have distinct grain-size characteristics, representing natural variability. Some other situations can induce intra-environment grain-size variations, such as large-scale bedforms (e.g., Ashley, 1990), proximity to rocky cliffs (e.g., Sunamura, 1983), or existence of placers (e.g. Clifton, 1969). Thus, samples collected at these sites might not represent the global depositional environment. Careful choice of the sampling sites will prevent these situations because an attempt is made to collect sediments that are representative of the global depositional environment. However, superficial samples can include a few centimetres depth of sediment, which may result in the collection of different deposition conditions.

In the case of submerged sampling it is very difficult to avoid certain misleading situations. Because the objective of this work is the identification of the textural characteristics of washover and neighbouring environments the samples should be representative of such sedimentary conditions. The outliers would alter significantly the interpretation and definition of these textural characteristics, and should therefore be carefully identified and removed. In intra-environmental studies, safety standards computations, or non-periodical forcing mechanisms studies, outliers should not be taken from the data series (Fenster *et al.*, 2001).

To define outliers, some basic statistical values [mean, standard deviation, 1st quartile (Q_1), 3rd quartile (Q_3), inter-quartile range (IQR)] were calculated for each of the grain-size frequency classes (0.5ϕ), for each of the environments. The grain-size frequency of a class was considered as an outlier if not included on the interval [$Q_1 - (1.5 \times \text{IQR})$, $Q_3 + (1.5 \times \text{IQR})$]. Because the frequencies cannot have negative values, the limiting factor for outlier grain class definition is being greater than $Q_3 + (1.5 \times \text{IQR})$. However, a sample having only one of the previously defined outlier grain-size classes should not be immediately excluded from the

data set. Each environment has an inherent variability, related to the different wave energy, wind velocity, and overwash flow competency, that are responsible for the deposition of the sediments. During the surveyed period both fair-weather and storm conditions occurred and therefore some variability is expected. Therefore, to define an outlier sample a certain number of grain-size classes of the frequency curve must be classified as outliers. For this study, the minimum value considered for the definition of an outlier sample was 4 outlier grain-size classes ($2.0 \phi = 4 \times 0.5 \phi$) that is, 20 % of the grain-size range used (-5.0ϕ to 4.0ϕ). Based on this criterion, only a few contrasting cases were identified as outliers (Tables 6.1 and 6.2). The definition of the number of classes that would define an outlier was made so that only the more contrasting curves would be considered. If less than 4 outlier classes were considered, then too many curves would be outliers, and intra-sample natural variability would not be incorporated in the data set. If more than 4 outlier classes were accepted then very different curves would be considered, which results in a misrepresentative composite. The defined criteria therefore confirm what visually could be considered as outlier grain-size distributions.

After excluding the outlier curves, a mean curve was calculated for each of the barrier and inlet environments. The grain-size parameters for each of the environments were then calculated using both suite and composite statistics, as defined by Balsillie and Tanner (1999). The suite statistic first assesses descriptive moment measures for each sample, and then moment measures are computed for each environment based on the individual sample statistics. The composite statistics result from a mixture of all samples belonging to the same environments (see thicker grey line on Figures 6.5a and 6.5b, for example), in which multiple sample frequencies for each screen interval, when averaged, provide the input data for moment measure calculation. An analysis was also made of each sample content of gravel (GC), coarse and very coarse sand (CVCC), medium sand (MC), and fine and very fine sand

(FVFC). Average, standard deviation, median, Q_1 and Q_3 were computed for the selected contents.

6.3. RESULTS

A brief description for all environments belonging to the two main geomorphologic units is made in this section based on the suite statistics of classical grain-size parameters, and on the samples content of defined grain-sizes. Some statistic quantities were determined to identify the relative heterogeneity inside each sub-environment (average, standard deviation, amplitude, and inter-quartile interval).

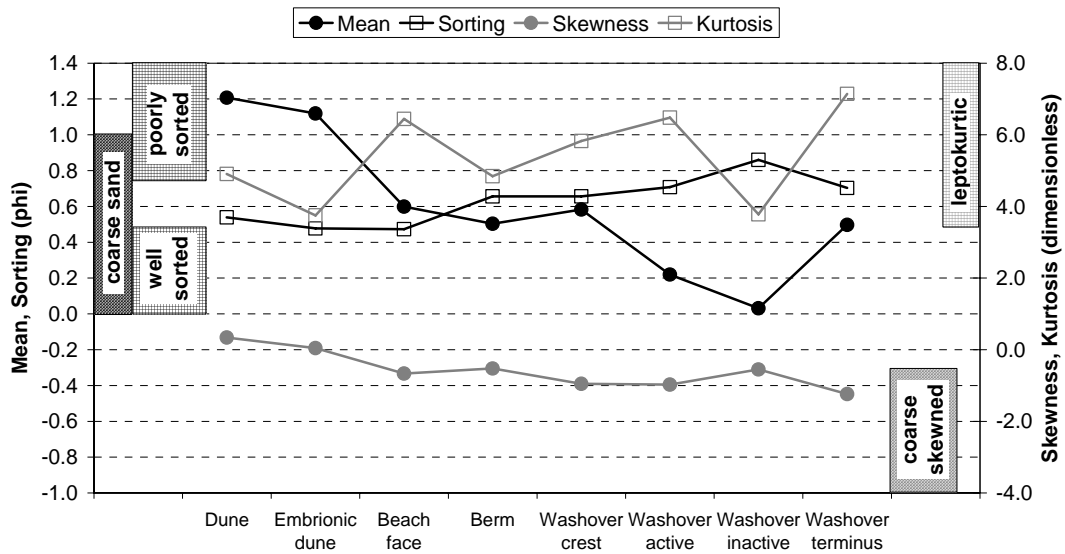
6.3.1. BARRIER ISLAND ENVIRONMENTS

The dune sediments are globally medium sands (1.21ϕ), moderately well sorted (0.54ϕ), symmetrical (0.34), and leptokurtic (4.91 ; Figure 6.6a). Embryonic dunes are medium sands, well sorted, symmetrical and mesokurtic. Generally, mature and embryonic dunes have similar curves (Figure 6.7a). Both mature and embryonic dunes are characterised by a lack of gravel size grains (Figure 6.8a) and relatively high contents ($5.4 \pm 2.9\%$ for mature dunes and $1.9 \pm 1.4\%$ for embryonic dunes) of FVFC (Figure 6.8b). The embryonic dunes include small amounts of mud (0.03% in average), but the older dunes may have up to 0.2% . Intra-sample variability is relatively small, even between mature and embryonic dunes (d_{50} is $1.20 \pm 0.18 \phi$ for mature dunes and $1.13 \pm 0.15 \phi$ for embryonic dunes). All dune samples are unimodal, 80% of the mature dunes and 100% of the embryonic dunes have medium sand as the principal mode.

The beach face sediments are globally coarse sands (0.60ϕ), well sorted (0.47ϕ), coarse skewed (-0.67), and leptokurtic (6.44 , Figure 6.6a). Beach berm sediments are coarse sands (0.50ϕ), moderately well sorted (0.66ϕ), coarse skewed (-0.52) and leptokurtic (4.85 , Figure 6.6a). Beach face sediments have generally small GC (average 0.7% , Figure 6.8a) and also

small amounts of FVFC (average 0.2%, Figure 6.8b). Berm sediments can have slightly higher GC (average 1.7%), and FVFC (average 0.55%). No mud content was found in these marine deposits. Intra-sample variability is moderate (d_{50} is $0.62 \pm 0.22 \phi$), however all samples are unimodal and 96% have coarse sand mode.

(a)



(b)

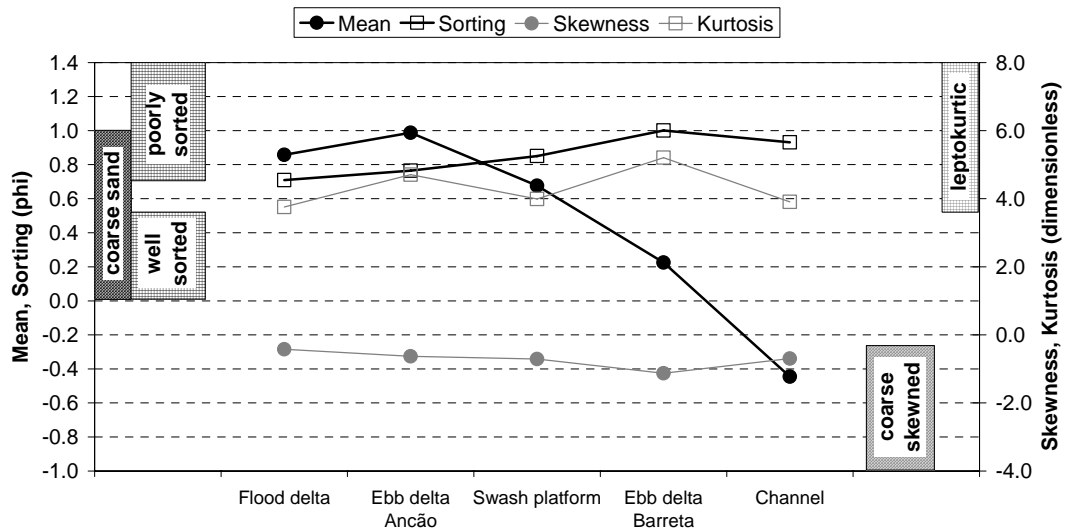


Figure 6.6. Moment measures (mean, sorting, skewness, kurtosis) for (a) barrier sedimentary sub-environments, and (b) inlet sedimentary sub-environments. Note that some classification limits are represented in the left and right margins of the graphs.

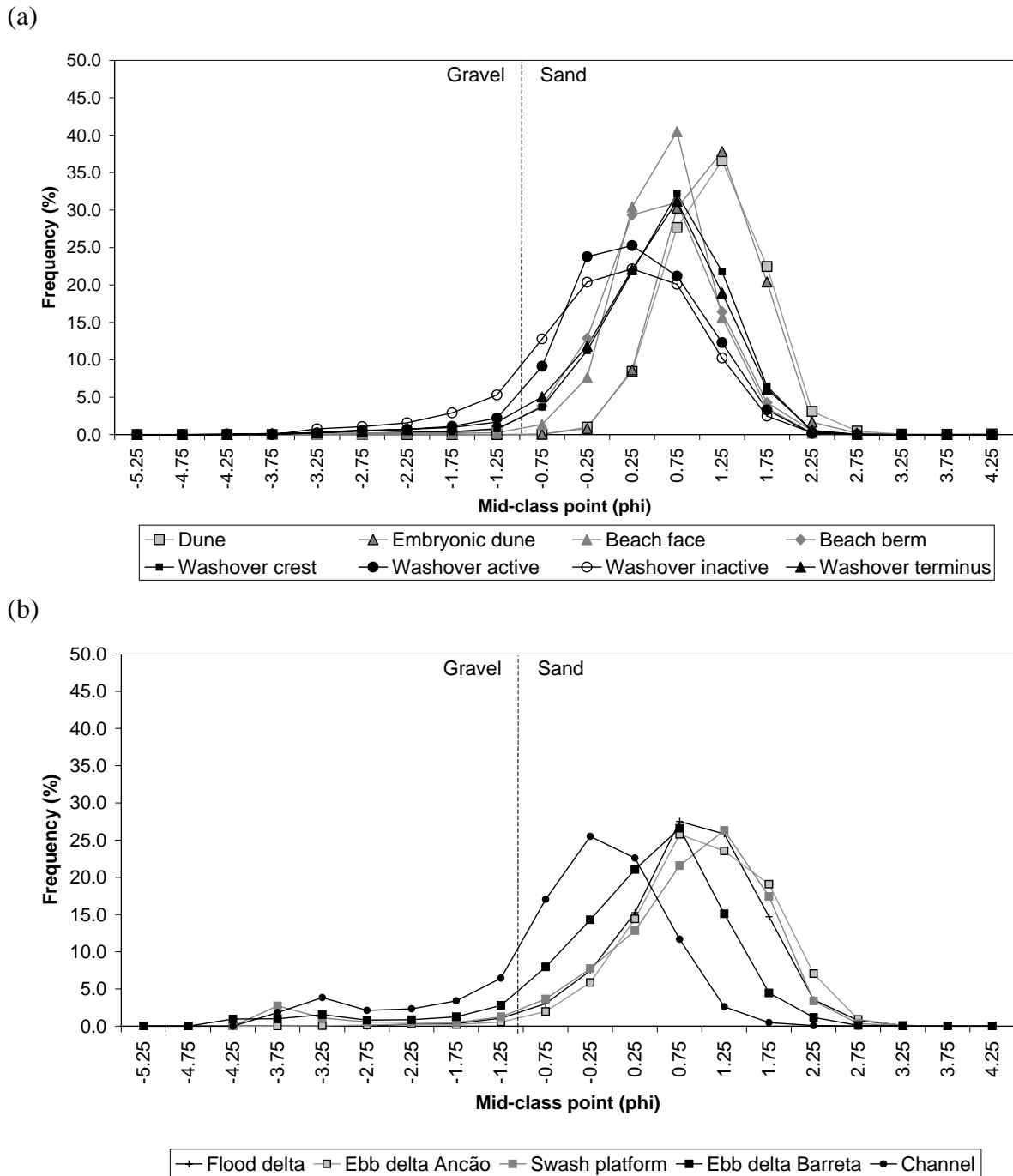


Figure 6.7. Composite grain size curves for: (a) barrier sub-environments, and (b) inlet sub-environments.

All washover sub-environments deposits are generally composed of coarse sands (average mean of 0.58ϕ for the crest, 0.22ϕ for the active washover, 0.03ϕ for the inactive washover and 0.49ϕ for the terminus, Figure 6.6a). The washover crest is moderately well sorted, but all other sub-environments are moderately sorted.

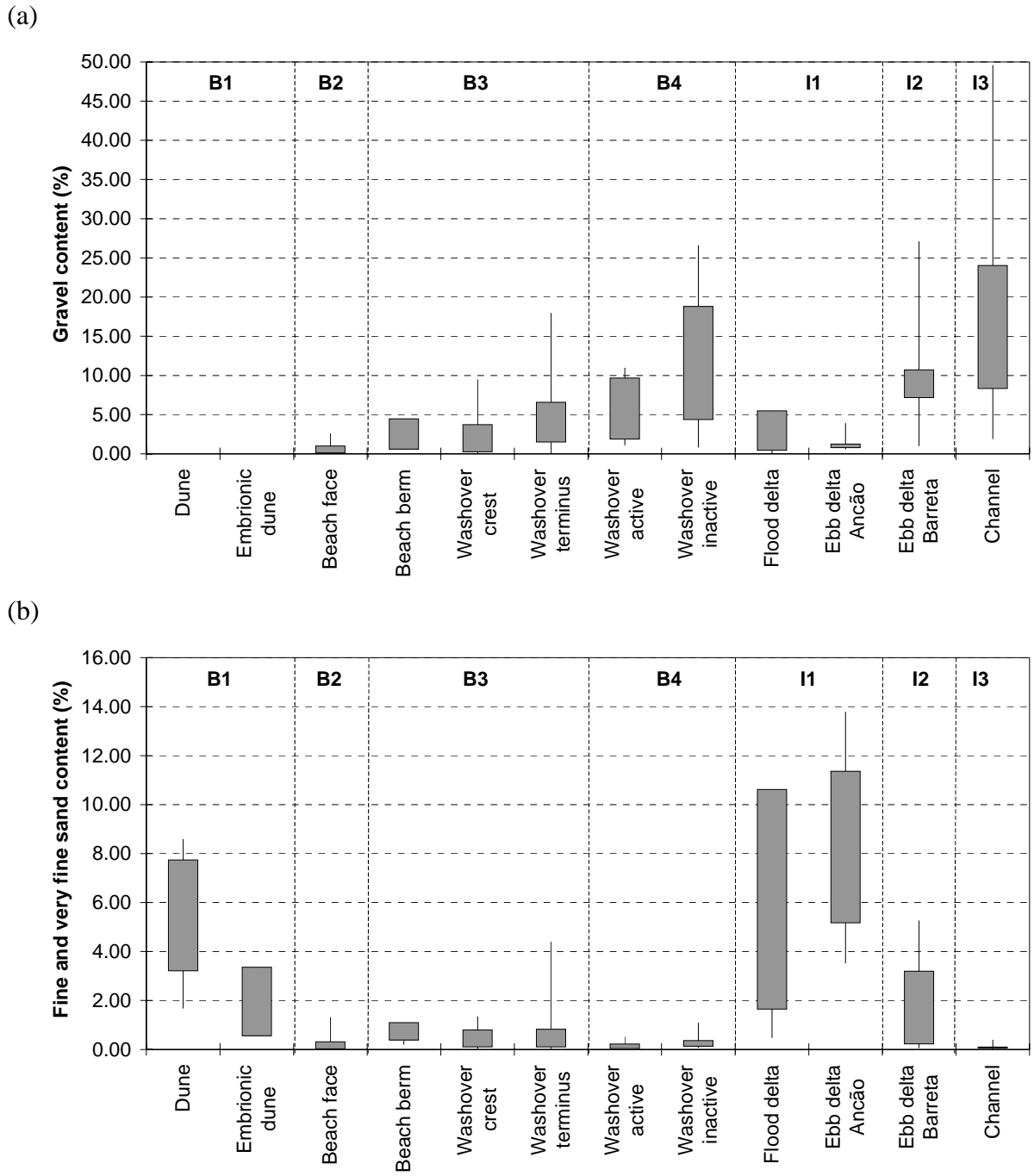


Figure 6.8. Specific grain-size contents for all analysed sedimentary sub-environments represented as box-plots: (a) gravel content (GC) maximum, minimum, and quartiles Q_1 and Q_3 ; (b) fine and very fine sand content (FVFC) maximum, minimum, and quartiles Q_1 and Q_3 . Note that the swash platform was not included.

On average these deposits are coarse skewed and leptokurtic. Although washover sub-environments have sediments with the same classification in terms of grain-size parameters, intra-sample variability is high. Considering all sub-environments d_{50} amplitude vary from

1.00 ϕ on the washover crest to 1.43 ϕ on the washover terminus. One of the main characteristics of washover sediments is the relatively high GC (between 2.5% in average for the crest and 11.6% in average for the inactive washover, Figure 6.8a). No significant amount of mud is generally present in these environments. All samples of the washover crest and active washover are unimodal; 23% of the inactive washover and 8% of the washover terminus are bimodal.

6.3.2. TIDAL INLET ENVIRONMENTS

The flood delta sediments are generally composed of coarse sand (0.86 ϕ), moderately sorted (0.71 ϕ), symmetrical (0.42) and leptokurtic (3.76, Figure 6.6b). The average GC is 1.8% and the FVFC is about 4.4% (Figures 6.8a and 6.8b). All samples are unimodal, and intra-sample variability is moderate (d_{50} is $0.90 \pm 0.31\phi$).

The ebb delta on the Ancão side of the inlet and the adjacent swash platform are generally composed of coarse sand, moderately sorted, coarse skewed and leptokurtic (Figure 6.6b). The ebb delta on the Barreta side is composed of coarse sand, poorly sorted, coarse skewed and leptokurtic. The GC on the Ancão and Barreta sides of the ebb delta is very different: on the Ancão side it is between 0.6% and 3.9% while on the Barreta side it is between 1.0% and 27.1% (Figure 6.8a). Also the FVFC differs from an average of about 8.0% at the Ancão side to 1.3% at the Barreta side. The ebb deltas have variable percentages of bimodal samples (30% for Ancão side, 13% for Barreta side, and 20% for the swash platform). The ebb delta on the Barreta side has moderate intra-sample variability (d_{50} is $0.41 \pm 0.30\phi$). The swash platform exhibits a very high intra-sample variability (d_{50} is $0.82 \pm 0.63\phi$) while the adjacent submerge ebb delta on the Ancão side is relatively homogeneous (d_{50} is $1.02 \pm 0.19\phi$).

The channel sediments are generally very coarse sands (-0.45ϕ), poorly sorted (0.93ϕ), coarse skewed (-0.70) and leptokurtic (3.91 , Figure 6.6b). The GC is very high, with an average of 20.0% and a maximum of 49.6%, and the FVFC is low (average of 0.12%, Figures 6.8a and 6.8b). The intra-sample variability is high (d_{50} is $-0.29 \pm 0.40 \phi$).

6.4. DISCUSSION

6.4.1. BARRIER ISLAND TEXTURAL SIGNATURE

6.4.1.1. Definition of textural groups

The analysis of the grain-size distribution curves, moment measures, and the contents of specific grain-sizes, permits the definition of similarities and discrepancies between the different sedimentary sub-environments. The sedimentary environments defined through morphologic criteria (Figure 6.1) may not constitute textural homogeneous groups because textural signatures are more related with the depositional conditions rather than to the geographic positions. The several sub-environments considered must therefore be separately analysed and regrouped in terms of their textural resemblances.

The grain-size quantities first discussed for the definition of textural signatures are the classical parameters: mean, sorting, skewness and kurtosis. Mean grain-size shows a clear distinction between the dunes and other barrier island environments, because they have finer mean grain-size (Figure 6.6a). Beach environments and the washover crest sub-environment have similar average mean grain-size. Active and inactive washover sub-environments have the coarsest average mean grain-size of the barrier environments, and the washover terminus is similar to the washover crest. The general trend is towards an increase in mean grain-size from the beach face to the washover surface, with a subsequent decrease toward the terminus (Figure 6.6a). For the inlet sub-environments, the channel has a clearly distinct mean grain-size, with the coarsest values of all the sedimentary sub-environments (Figure 6.6b). The average mean grain-size of the ebb delta on the Ancão side is more similar to the flood delta than to the Barreta side. The Barreta ebb delta has intermediate but distinct mean grain-size values.

The analysis of the mean for both geomorphologic units (barrier and inlet) shows that the dunes and the inlet channel are the most distinctive sub-environments. The flood delta and part of the ebb delta also have distinctive means (intermediate between dunes and all other barrier environments). However, washover, beach and ebb delta on the Barreta side have mean grain-sizes inside the same range of values, and the mean can not therefore be used exclusively to define textural signatures in these sub-environments.

Sorting also distinguishes dunes from the other barrier sub-environments, except from the beach face that also has better sorting (Figure 6.6a). Most of the other barrier sub-environments have similar sorting values, although some slight increase in sorting values is noted towards the washover sub-environments. For the inlet sub-environments, sorting also allows a distinction between flood delta and ebb delta on the Ancão side from the Barreta side. Thus, except for dunes, barrier and inlet sub-environments cannot be distinguished by sorting (Figures 6.6a and 6.6b).

Skewness shows one symmetrical group (dunes) whilst all other barrier sub-environments are generally negatively skewed (Figures 6.6a and 6.6b). The washover terminus has the greatest values of negative skewness. For the inlet environments, skewness is similar for all delta sub-environments, however the flood delta has the slightly more symmetrical grain-size curves. Skewness does not allow clear distinction between barrier and inlet environments (Figures 6.6a and 6.6b).

Kurtosis is similar for most barrier environments and for most inlet environments (Figure 6.6a and 6.6b), thus not allowing any clear distinction between sub-environments. The joint analysis of the moment measures (e.g. mean *versus* sorting, skewness *versus* kurtosis, etc.) did not provide any further information in terms of sub-environments distinction or definition of textural groups.

The second type of grain-size characteristics analysed for the sedimentary sub-environments are the contents of specific fractions: gravel content (GC), very coarse sand content (VCC), medium sand content (MC), and fine and very fine sand content (FVFC).

The GC is almost absent on dunes which allows a separation of this environment from other barrier sub-environments (Figure 6.8a). For the beach two distinctive characteristics were noticed, beach face sediments usually have relatively low GC (usually inferior to 2%) and berm GC is more similar to the washover crest. The washover environments have higher GC than the other barrier sub-environments (generally higher than 2%). The washover terminus has GC similar to the washover crest, consistent with the trend that was already noticed for the mean grain-size. For the inlet environments, the channel is characterised by high percentages of GC (values usually greater than 8%; Figure 6.8b). The flood delta and the Ancão ebb delta usually had GC inferior to 5%. The Barreta side of the ebb delta shows intermediate values that can be similar to part of the channel samples. Globally, although GC permits some distinction inside barrier or inlet environments, it is not sufficiently discriminative when all sub-environments from both geomorphologic units are considered.

The fine and very fine sand content (FVFC) can also contribute for the distinction of the environments. Dunes, both mature and embryonic, have FVFC higher than all other barrier sub-environments (Figure 6.8b). However, beach and washover environments have similar FVFC. For inlet sub-environments, the flood and Ancão ebb deltas have higher FVFC. The channel has very small FVFC (usually smaller than 0.2%), which allows a clear distinction of this environment. The ebb delta on the Barreta side has intermediate FVFC in relation to the other sub-environments.

The MC distinguishes the dunes from other environments because the percentages are generally higher (dunes have $MC=60 \pm 12\%$). The beach and the washover environments have smaller and similar amounts of MC. The MC distinguishes the several inlet sub-

environments, with the flood delta having the higher values, and the channel the lower ones. Once again, the ebb delta on the Ancão side is more similar to the flood delta than to the Barreta side of the ebb delta.

To enhance the differences between environments, an average representative sample was computed for each environment, using the composite statistic (Balsillie and Tanner, 1999). Based on this composite representative sample, a comparison between the specific grain-size contents was made (Figures 6.9a and 6.9b).

The analysis of the fraction frequencies for the composite distributions shows that a good distinction between barrier and inlet environments is obtained by comparing the GC and FVFC (Figure 6.9a). The barrier sub-environments tend to have lower values of FVFC, and variable amounts of GC. The integrated analysis of FVFC and GC is adequate for distinguish dunes (low GC, high FVFC), beach and washovers (low FVFC), inlet deltas (intermediate GC and FVFC) and inlet channel (low FVFC, high GC).

The comparison between the medium sand content (MC) and the very coarse sand content (VCC) permits a good distinction between the sub-environments (Figure 6.9b). A decrease in MC and an increase in VCC defines a trend by which the sub-environments appear in the following order: dunes; ebb delta on the Ancão side + flood delta; berm + washover crest + washover terminus; ebb delta on the Barreta side; washover active and inactive; and channel. Dunes and inlet channel are at opposite ends of the trend. The beach face is not on the defined trend because it has MC similar to the berm but with lower VCC. However, it should be noticed that between the barrier sub-environments the variations in MC are small, with the distinction made clearer by the VCC.

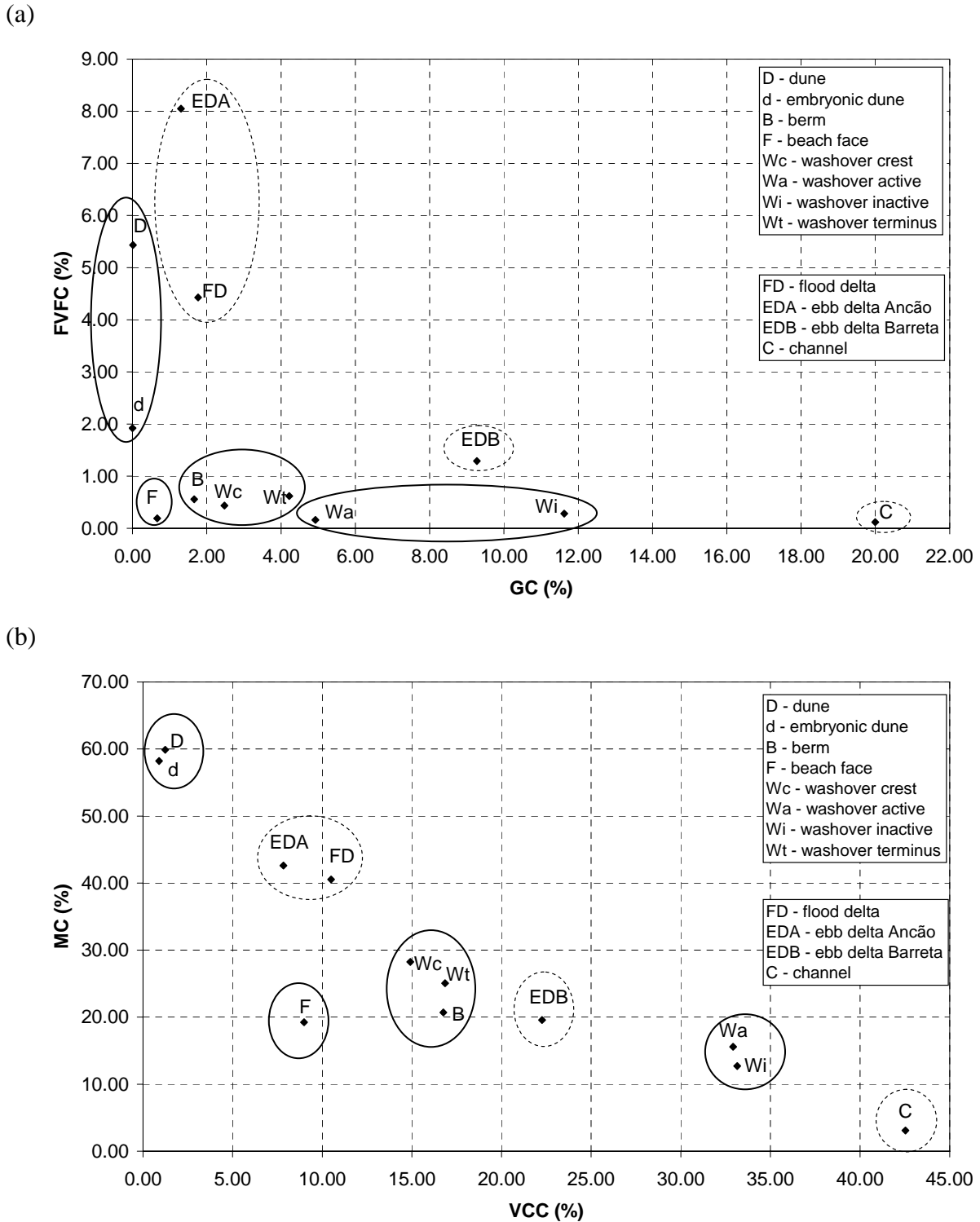


Figure 6.9. Distinctive average grain size contents for all analysed sedimentary sub-environments: (a) FVFC versus GC, and (b) MC versus VCC. The ellipses enclose the defined textural sedimentary groups. Ellipses with solid lines represent barrier textural groups and ellipses with dashed lines represent inlet textural groups.

Based on the previously described characteristics, a general division between sedimentary sub-environments was made. The goal of this division is to define texturally

homogeneous groups of sub-environments that probably have some similarities in terms of hydrodynamic deposition conditions. A textural signature for each sub-environment would probably be somewhat artificial since in some cases the variability noticed inside a sub-environment was similar to the variability between different sub-environments. The grouping of the samples followed a criteria mainly focused on the information given by the grain-size fractions contents. This results from the existence of more distinctive values at the ends of the population curve (GC and FVFC) for most of the cases. Doeglas (1946) observed that the tails of the distribution provide much of the important information that is available. This conclusion has been used as an argument for the importance of skewness and kurtosis in differentiation of environments (e.g., Mason and Folk, 1958). In the present work skewness and kurtosis were not suitable for the grouping because the values are too similar for many of the considered environments.

For the barrier environments four textural groups were considered (Table 6.3): B1 (mature dunes and embryonic dunes), B2 (beach face), B3 (berm, washover crest, washover terminus), and B4 (washover active and inactive). The most intuitive morphogenetic division between beach and washover does not represent the most similar sediment textures. On the other hand, the washover crest and terminus are in the same textural group, in spite of their somewhat different depositional conditions. However, the purpose is to define the textural signatures, and it seems that different sub-environments can produce similar textures. Group B1 is dominated by medium sand, low VCC, no GC and relatively high FVFC. Group B2 is dominated by coarse sand with relatively small amounts of GC and FVFC. Group B3 have intermediate amounts of GC and FVFC, with values between groups B2 and B4. Group B4 has higher GC and smaller FVFC, relative to the other groups.

For the inlet environments three groups were considered (Table 6.3): I1 (flood delta and ebb delta on Ancão side), I2 (ebb delta on Barreta side), and I3 (channel). Again two

separated sub-environments with apparently different deposition conditions were grouped in I1. However, the analysed grain-size characteristics does not allow any differentiation between the samples belonging to these two sub-environments. The swash platform was not included in any of the groups since it has a high intra-sample variability, with samples similar to the Ancão ebb delta but also to the Barreta ebb delta. This lack of sedimentological homogeneity does not allow the methods used to define any textural signature since they imply a certain background uniformity of the samples. This high variability is probably related to different deposition conditions that occur and also to the presence of bedforms. Vila-Concejo *et al.* (2004) noticed that this is an area of divergence of sedimentary patterns. Sediments arriving at the swash platform are either transported to the ebb delta on the Ancão side or to the channel margin. Group I1 have the smaller GC, low VCC, high MC, and relatively high FVFC. Group I2 have intermediate contents of GC, VCC, MC and FVFC. Group I3 has high GC, very high VCC, low MC and is almost absent of FVFC.

One of the principal benefits of defining textural groups for modern deposits is the possible application for interpreting ancient deposits. Both geomorphologic units analysed belong to the Ria Formosa barrier island system. The primary source of sediments to the barrier system has been considered to be the erosion of the cliffs located updrift (Granja, 1984; Bettencourt, 1985; Andrade, 1990), with fluvial contribution being very small (Dias, 1986, Andrade, 1990) and the inner continental shelf either considered as a source (Dias, 1988) or a sink (Andrade, 1990). All of these possible sources bring sediments into the coastal area, but the short- to medium-term main transport agent into the study area is the longshore transport (Granja, 1984; Bettencourt, 1985; Dias, 1988; Andrade, 1990). Therefore, sediments arriving to both Ancão Inlet and Barreta Island are fairly similar. Furthermore, except for the shells, lithic grains are almost monomineralic (Bettencourt, 1988). Thus, no compositional

differentiation is expected to occur due to coastal processes. Hence, the sediments arrive to both geomorphologic units via longshore drift and no mineralic signature is easily detected.

Table 6.3. Synthesis of geomorphologic units, sedimentary environments and sub-environments, corresponding textural groups, and barrier textural groups named after main driving mechanism.

Geomorphologic unit	Sedimentary environments	Sedimentary Sub-environments	Groups	Textural groups name/driving mechanism
Tidal inlet	Channel		I3	
	Flood delta		I1	
	Ebb delta	Ebb delta Ancão side		
		Ebb delta Barreta side	I2	
Barrier island	Dune	Mature dune	B1	AEOLIAN
		Embryonic dune		<ul style="list-style-type: none"> • MC dominated • No GC
	Beach	Beach face	B2	BEACH BAFS
		Berm		<ul style="list-style-type: none"> • No GC • No FVFC
Washover		Washover crest	B3	FLOW DECAY
		Washover terminus		<ul style="list-style-type: none"> • Intermediate GC • Intermediate FVFC
		Washover active	B4	OVERWASH
	Washover inactive	<ul style="list-style-type: none"> • High GC • High VCC • No FVFC 		

The driving forces that generate the studied sedimentary sub-environments deposits result from a particular combination of waves and tides, except for the wind-generated deposits. Therefore, any grouping is difficult, other than aeolian deposition. It must be stressed that the divisions between the defined groups are somewhat diffuse and subtle. It is expectable that textural differences are pronounced considering that deposits are formed within a wide range

of environments (e.g. glaciers, submarine canyons, lakes), geographically well separated, and formed under contrasting climate conditions. In a situation of unknown sediment depositional conditions, as in the case of stratigraphic paleo-environmental interpretation, the classification of a sample as being overwash deposited using exclusively grain-size analysis may be rather speculative. However, some textural characteristics can be indicative, as well as the association with other environments. In a probabilistic approach, based on the group definition criteria, a certain sample that was collected on a sequence where a suspicion of overwash deposits exists, can most likely be correctly identified as overwash (Group B4) or erroneously classified as beach berm (Group B3) or as part of ebb delta (Group I2). The misinterpretation as a flood delta deposit (as observed by Hennessy and Zarillo, 1987) or as a dune deposit (as observed by Hobday and Jackson, 1979), is not probable in cases similar to the Barreta Island case as long as other than moment measures are considered. The similarity between berm and washover sediments, already noticed by Andrade (1990), has its nature in the depositional processes involved. The textural signature definition for the barrier sub-environments, where the washover sediments are included, with its relation to the depositional conditions is further discussed in the next section.

6.4.1.2. Sedimentary dynamics and driving mechanisms of textural groups

Because this work is focused on the washovers, which are island morphological features, only the barrier groups will be further analysed in order to define a distinctive textural signature. Even though the Ancão Inlet is an updrift morphology contiguous to the studied washovers (see Figures 6.1 and 6.2), the more direct interactions are between washovers and the beach and dune environments (Figure 6.1), since there is a semi-permanent direct sedimentary exchange between them. The analysis mainly aims to determine the

sedimentary dynamics of the barrier island textural groups, and therefore they were renamed after the agent and/or depositional conditions.

Group B1 (the dunes) is the group with the most distinctive characteristics (Figures 6.9a, 6.9b, and 6.10). The transport agent is the wind, which provides good sorting due to the mass density difference between air and sand. The prevailing winds in the study area are responsible for the deposition of medium size sands, as demonstrated by the mature dunes principal mode. The use of grain-size analysis as a basis for distinguishing beach sands and dune sands has been extensively discussed (e.g. Mason and Folk, 1958; Friedman, 1961; Goldsmith, 1978; Tanner, 1991; Arens, 1994). Group B1 can therefore be renamed according to the forcing mechanism as AEOLIAN Group (Table 6.3).

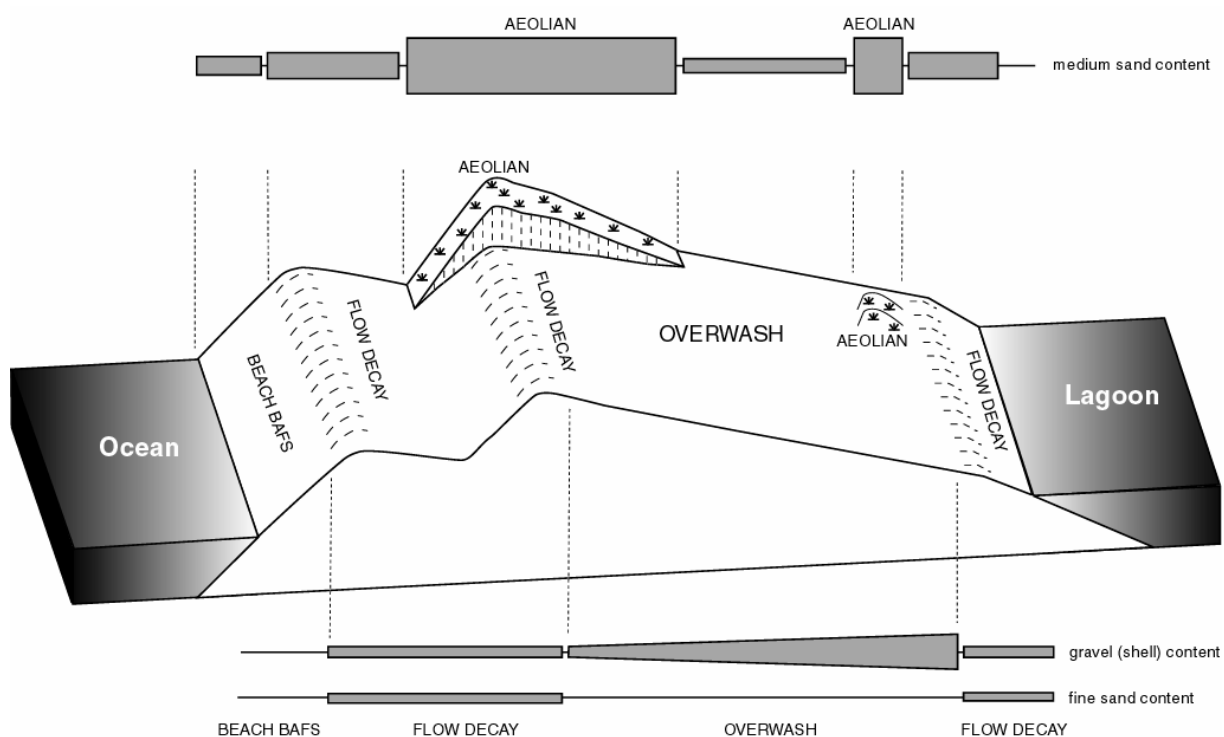


Figure 6.10. Schematic block diagram of the textural groups identified for the barrier island sedimentary environments and its qualitative more relevant relative grain-size contents.

Group B2 (the beach face) has similar sorting to the AEOLIAN Group but the mean grain-size is coarser (Figure 6.6a). The major difference is the mode (both are exclusively

unimodal), which is centred on medium sand for the AEOLIAN Group and on coarse sand for Group B2. GC and FVFC are both almost absent (Figures 6.9a and 6.10). This means that the flow responsible for the transport and deposition of group B2 is more competent than the air but as selective as the air. Under a wave field, on a seaward dipping surface back-and-forth shuffling (BAFS) is the primary force for sediment transport and deposition (Tanner, 1991). The BAFS over a long period result in much better sorting than can be obtained in ordinary water currents (Tanner, 1991). There is commonly an asymmetry in transport effectiveness of water motion near the bottom, so the BAFS phenomenon leads to movement of grains of the same mineral (two different sizes) in opposite directions (May, 1973). The beach face textural characteristics would therefore result from particular combinations of source grain-sizes and cross-shore swash and backwash relative competencies. Miller and Zeigler (1958) presented a model for selective sediment transport by which as the onshore upwash decreases in velocity its sediment load is dropped along the way, conversely backwash velocities increase linearly as it starts from zero at the top of the swash runup. This process leads to increase in grain-size near the breaker point both by higher velocity of the swash and higher velocities of the backwash and sorts the sediments on the beach face. Group B2 can therefore be renamed according to the driving mechanism as BEACH BAFS (Table 6.3).

Group B3 (berm, washover crest, washover terminus) is the group having the most heterogeneous morphological features. Group B3 has similar mean grain-size ranges (slightly coarser) as BEACH BAFS Group, however the sorting is poorer (Figure 6.6a). This is because of the increase in gravel and very coarse sand content (as noted by other authors, e.g. Bascom, 1951), but also of the FVFC (Figures 6.8b and 6.10). The beach face (BEACH BAFS Group) is the direct source of sand for the berm and washover crest (Group B3), and the deposition of the sediments in these two environments occurs at the latest stages of flood tide and early stages of ebb tide. Sediments on the beach face and berm are both transported

and deposited under wave induced currents. However, the berm is sub-horizontal or gently landward dipping and the beach face is always seaward dipping with variable slopes. Therefore, the BAFS, induced by the combination of wave energy dissipation as runup and gravitational backwash, is typical of the beach face. Once the berm crest is overtopped, the water flow can only go landward, where percolation and friction slows the flow until it stops. In this situation the sediments in motion, both as bedload and in suspension will be deposited on this surface (Bascom, 1951). Therefore, the sorting of the berm sediments is poorer than the BEACH BAFS. The washover crest is the more active part of the washover sub-aerial structure. Frequently, in the absence of a berm, the washover crest is located at the maximum winter waves runup and thus acts like a berm. Under these circumstances, the water excursion over the top of the island is minimum, and therefore only the crest is subjected to marine processes. When overtopping occurs vertical accretion is often noticed (Orford and Carter, 1982). Overtopping situations occur on subhorizontal or landward dipping surfaces like the berm or washover crest, and correspond to the last stages of a water flow; therefore, Group B3 can be renamed according to the main driving force as FLOW DECAY (Table 6.3). The washover terminus is included in this group (Table 6.3) because the curve has similar characteristics (Figures 6.9a, and 6.9b), but the processes involved are different. At maximum overwash state this part is completely submerged. At this distal part of the washover, where a steeper landward dipping surface is generally present, the overwash flow is almost completely stopped by the collision with the lagoon waters. Therefore, the washover terminus is also an area of ultimate flow, with probable settling of grains transported by the overwash flow. Therefore, the washover terminus is also a FLOW DECAY area.

Group B4 includes washover (active and inactive) and is the group that represents the actual overwash deposited sediments. The textural Group B4 had the coarsest mean and poorest sorting of all barrier sub-environments (Figure 6.8a). This group is dominated by

VCC, with high GC and almost absent of FVFC (Figures 6.9a and 6.9b). The high content of coarse sediments is partially due to the abundance of shells (entire and fragments). Also, the overwash-generated flow can have relatively high velocities, for example, maximum velocities of 3 m/s (Fisher *et al.*, 1974) and 5.7 m/s, (Chapter 4, section 4.3.2) have been recorded. Overwash flow competency studies by Leatherman (1976) revealed that a 3 m/s (maximum) velocity could transport pebbles with sizes up to about -3.0ϕ , if available. The sediments deposited under overwash flow reveal the combination of an unidirectional moderate to high energy flow with a high shell availability for transport. Therefore, Group B4 can be renamed OVERWASH Group (Table 6.3). Complementary details about the processes occurring in this group are discussed below in subsection 6.4.2, including the analysis of samples collected during overwash events.

The integrated analysis of OVERWASH, BEACH BAFS and FLOW DECAY Groups, must be made with caution. During each monitoring campaign sediments collected on the washover surface were deposited during the last overwash event, which could have occurred several months or just hours before sampling. However, the beach face sediments collected during the same survey were deposited during the last tide. Therefore, grain-size relations should not be derived between spatial-connected but time-separated sub-environments. For instance, the beach and washover crest samples from one of the surveys should not be directly interpreted in terms of cross-shore transport because the deposition timing may be separated by months. On a medium term temporal scale it is more likely that beach sediments were deposited in fair-weather conditions than in storm conditions, since the latter only represent less than 1% of the total wave record (Costa, 1994). However, these storm conditions are crucial to overwash sedimentation. Washover elevation provides protection from fair-weather waves and permits aeolian reworking. The general analysis that was made in this study for

identification and characterisation of textural groups should not be influenced by these small-scale time-dependent variations.

6.4.2. WASHOVER SEDIMENTARY DYNAMICS

The overwash processes imprint a textural signature that was already identified and discussed in the previous subsection (see subsection 6.4.1). The macro-scale textural characteristics of the washover sediments, defined previously as OVERWASH Group, result from the combination of several meso-scale variations. Short-term washover sedimentary dynamics analysis aims to verify how the sedimentary surface evolves during an overwash event and the existence of cross-shore grading by overwash. For this purpose a second set of samples that were collected during overwash events were considered. The surveys conducted at the barrier island that provided these samples (GO.1 and GO.3) were described in section 4.2.1. The post-storm evolution of the washover was also considered in this analysis by the comparison of samples taken hours to days after an overwash with samples taken some months after the overwash.

6.4.2.1. Deposition under overwash flow

The overwash sediments, in a more strict sense, are those on the active washover (Wa of Figures 6.9a and 6.9b), i.e. deposited directly by overwash currents and before any kind of aeolian or lagoon reworking. The source of sediments into this area is the beach face, especially the accumulation generated at the washover crest. The overwash current is constituted by the downward flow of water and sediments that result from a super-elevation of the water level at the coast. During these events, most of the wave energy dissipation is occurring by bottom friction and ultimately by wave breaking and runup on the foreshore. It is

a common and intuitive belief that higher velocity flows would induce coarser sediments transport and deposition (e.g. Friedman and Sanders, 1978). Also, one of the basic maxims of marine geology, is that of “fining down the transport path” (e.g. Dyer, 1986). However, in the study area, during the surveyed period, the washover surface that was subjected to lower-velocity currents than the beach face, and is directly nourished by the beach face had coarser sediments (Figure 6.6a). For an explanation it is necessary to understand the nature of the overwash flows.

Overwashes have very variable water excursions because of the water level oscillation due to the tides, waves, and storm surges. In the study area, because it is a low-lying barrier, the water level variations as a result of spring tides can generate non-storm overwash conditions; however a storm striking the coast would have a similar effect. The succession of events during an overwash and associated sedimentation was described in depth by Leatherman and Williams (1977). Initial surges, corresponding to the early stages of the storm, are probably of small magnitude. The velocity of the bore of water would drop suddenly so as to “freeze” due to large percolation losses. Therefore, these surges would have short intrusion distances due to their initial low energy level and unsaturated conditions of the bed. At the peak of a storm, surges would be more frequent and of much greater magnitude due to the storm tide and increased breaker height. The bed remains essentially saturated at water table conditions as the high-velocity surges continuously passed through the throat to the fan. These surges would be at the highest level of capacity and competency of transport. The position of the breaking wave on the beach would determine the nature of the material put into suspension for subsequent transport to the fan by the overwash surge. During the waning stages of the storm, there would be many marginal overwash surges.

Almost all morphological modifications are noticed during the second half of the flood and at high tide slack, the ebb tide normally does not promote significant changes (Matias *et*

al., 2003). The deposit is therefore formed under variable flow conditions and consequently sediments have an intrinsically heterogeneous nature. Each overwash maximum intrusion strip is marked by the presence of coarse grains, especially shells, which are transported as bedload and that are deposited by the fall of the flow velocity. Simultaneously, it is possible that in the mid portions of the surface, where higher flow velocities were noticed, a selective winnowing of fine and medium sand occurs. As maximum excursion moves through time, during the tidal cycle, and on certain occasions for several days, there is a mixture of the flow conditions. These coarser grains are present on the adjacent beach, which is the main source of sediments to the overwash, but in lower percentages. The mechanism for concentrating coarser grain-sizes is similar to the one occurring in the FLOW DECAY Group (see subsection 6.4.1.1). The presence of high concentration shell deposits on the washover surface was noticed during the fieldwork. The shells are predominantly bivalves, almost flat (in the case of fragments) or concave (in the case of entire shells). The entrainment of bivalve shells depends on many factors, including the number of valves (paired or unpaired), attitude of the valves (if unpaired), and nature of the substrate (Allen, 1984). In samples analysed using sieves the effect of grain shape is to make the samples coarser and poorer sorted (Flemming, 2004). During the GO.1 fieldwork the tracer shells placed on the crest of the washover also gave some insight into the process. After the overwash, only a few shells were found on the mid-fan, some were deposited on the lateral distal fan margins, but most were transported into the lagoon. It is evident that the overwash flow did not have the competency to transport cobble size quartz grains as bedload. The combination between the lost of flow competency in relation to quartz grains, the higher shell transportability, and the unidirectional nature of the flow generates relatively coarse deposits.

6.4.2.2. Textural grading

A frequently mentioned textural characteristic of overwash deposits is the existence of textural grading. Andrews (1970) and Kochel and Wampfler (1989) reported that the overwash sand was graded, with the fining trend towards the distal fan. Leatherman and Williams (1977) found that the presence of cross-shore grading in texture and mineralogy, and the geometry of the deposit are evidence for the loss of transportability of the surge as it travels across the fan surface. However, samples may have a coarsening towards the fan terminus, related to post-storm reworking of the deposit or to the presence of heavy minerals that may mask the true trend (Leatherman, 1976).

In the study area, the samples collected during the intensive campaigns GO.1 and GO.3, during two separate overwash events, did not show such a cross-shore grading. The trend, on the active washover (excluding the fan steep landward dipping prograding surface and the seaward dipping or sub-horizontal crest) is mainly of coarsening toward the lagoon (Figure 6.11).

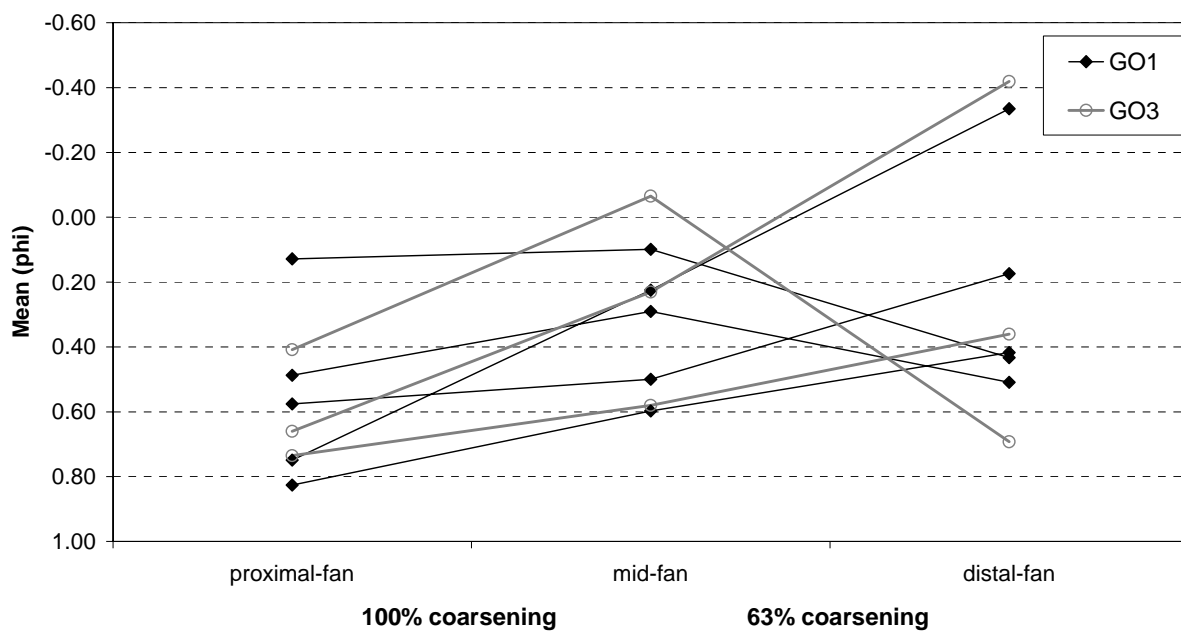


Figure 6.11. Variation of the mean grain-size with the distance to the washover crest. Seaward direction is to the left of the graph. Note that the phi scale is in reverse order.

This apparent contradiction with the transport competency of the flow can be explained by the sediment composition. As the distance to the beach increases, the coarse quartz sand domination typical from BEACH BAFS Group decreases and the GC increases. For the two overwash events, proximal-fan average GC is 0.7%, mid-fan is 2.1% and distal-fan is 7.4%. This increase in GC is probably due to the presence of the previously mentioned shell population. As explained above the shell component of the sediments would increase in the direction of the transport and therefore imprint a coarser character to the distal sediments. The cross-shore coarsening trend is an important textural characteristic that can be useful in paleo-environmental studies. In corers from sandy barriers, correlations between layers presenting textural trends can be made, with the main direction of overwash flow given by an increase in grains that have smaller entrainment values.

6.4.2.3. Post-overwash evolution of sedimentary surface

After the overwash event, the deposited sediments are not further subjected to oceanic water intrusion. The two main post-storm forcing agents are wind and lagoon tidal currents, until a new overwash episode occurs. It was noticed that the inactive washover is coarser than the active washover. This could be attributable to an aeolian reworking of the washover. Leatherman (1976) noticed that selective winnowing of the finer grains would result in a coarsening of the material and the impact a negative skewness to the lag deposit. As in the present study, Davidson-Arnott and Fisher (1992) noticed that sediments deflated from the washover surface formed the source for the small dune ridge that developed at the backfan. The aeolian rework would induce a cut in the grain-size curve, with removal of the finer fractions and partial removal of the grain-size closer to the wind flow competency. In other cases, the aeolian activity on the washover surface induced a reduction in log-normal subpopulations, accompanied by a relative increase in the importance of the dominant

population (Bartholdy *et al.*, 2004). When comparing average active washover sediments to inactive washover sediments an increase in GC and VCC is noticed along with a loss in MC (Figure 6.12). Since medium sand was noticed to be the most important grain-size for embryonic dune sediments, the relative reduction in medium sand could be induced by wind winnowing of the surface. This process, with time, is responsible for an increase in the textural variability of the washover surface because the aeolian accumulations on the back-terrace will have distinct AEOLIAN Group characteristics, the washover crest may remain active with FLOW DECAY Group characteristics and the aeolian washover surface will become coarser and more distinctive with OVERWASH Group characteristics.

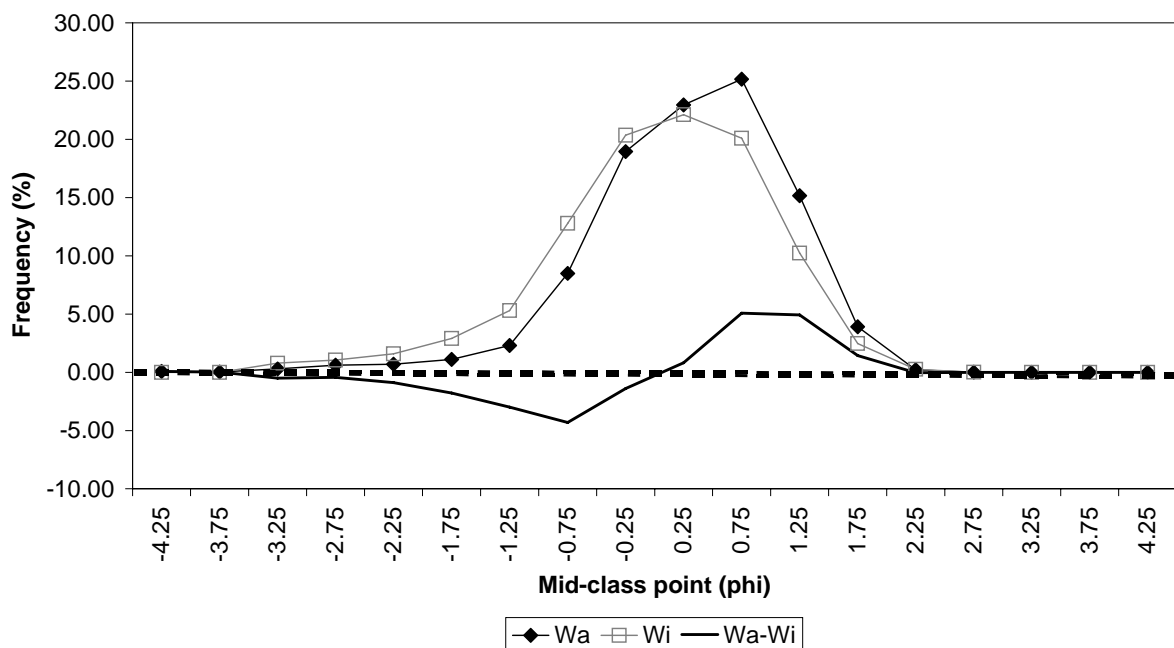


Figure 6.12. Composite curve for the active washover (Wa) and inactive washover (Wi) and the residual curve (Wa-Wi).

In terms of interpreting ancient overwash sediments, this process of aeolian deflation may be identified either by a coarser lag layer at the top of the overwash bed, or by a layer of finer and better calibrated sand corresponding to the dune development on the surface. The existence of one of these two layers is likely to occur since the freshly deposited washover

surface evolves either way. It should be noted that if the washover are not subsequently buried by aeolian deposits, then they constitute a fragile area in the dune field and breaching or even the opening of an inlet is possible. In this case, overwash sediments are probably eroded from the barrier area and deposited at adjacent, newly formed, inlet morphologies. This means that if overwash deposits are preserved in the stratigraphic record then the most probable situations are: (i) dune development over overwash sediments or over an aeolian lag deposit, or (ii) subsequent overwash sequences that cover the washover surface. Both cases could be detected by the identification of the textural signatures previously defined in this work.

6.5. CONCLUSIONS

Two geomorphologic units (barrier island and tidal inlet) were analysed in terms of their grain-size characteristics. Two major objectives were established for this work: (1) definition of a textural signature for the sampled sedimentary sub-environments, and (2) characterisation of the washover sedimentary dynamics.

To accomplish the first objective, a broad integrated approach was made to the grain-size data. To verify the possibility of the definition of textural signatures the relative homogeneity or heterogeneity of the sub-environments was firstly investigated. The grain-size curves were grouped into several sub-environments, disregarding their spatial or temporal proximity. The outlier samples were identified through criteria that permitted the exclusion of only the most contrasting grain-size curves whilst allowing some natural variability. After excluding the outliers (less than 8% of the barrier environments samples and about 11% of the inlet environments samples), the classical grain-size parameters were calculated, as well as other frequently considered quantities (mode, median, d10, d90) and specific grain-size contents (GC- gravel content, VCC – very coarse sand content, MC- medium sand content, and FVFC – fine and very fine sand content).

For the barrier island sub-environments four textural groups were defined (B1, B2, B3, B4) and for the inlet sub-environments three textural groups were defined (I1, I2, I3). The use of the moment measures was not suitable for the definition of sub-environment textural groups. This was achieved by using the specific grain-size contents.

Group B1, that included the mature dunes and the embryonic dunes, had the most distinctive characteristics being dominated by MC, with relatively high contents of FVFC. Group B2 was constituted by the beach face sub-environment, and was dominated by coarse sand with relatively small amounts of GC and FVFC. Group B3 includes the berm, washover

crest and washover terminus, and had intermediate amounts of GC and FVFC, between groups B2 and B4. Group B4, composed by the active and inactive washover sub-environments, had the highest GC and lowest FVFC relative to the other groups.

The most distinctive group for the inlet unit was I3 (inlet channel), dominated by VCC, and had almost no FVFC. The group I1 (flood channel and ebb delta on Ancão side) had high MC and FVFC, while group I2 (ebb delta on Barreta side) had relatively high GC, and intermediate VCC.

The analysis of textural groups shows the most striking grain-size characteristics between sub-environments, despite of the initial geomorphological definitions. This approach also shows the most probable misclassifications in terms of the interpretation of paleo-environments based on the texture of the sediments. Although some degree of differentiation was possible in this study, the integrated analysis of grain-size characteristics, together with mineralogy, sedimentary structures, etc., will provide better and more reliable results. The analysis of specific grain-size contents, with particular emphasis to the tails of the curve, has provided better definition criteria than the grain-size parameters (moment measures).

For the barrier sub-environments a sedimentary dynamics discussion was made based on the textural groups and main active coastal processes. Group B1 is mostly deposited and modelled by the wind, which imprints a very distinctive texture dominated by MC, and this group was named AEOLIAN according to the driving mechanism. The group B2 is deposited under wave swash and backwash processes that sort the sediments and excludes the gravel and the fine sand, and was named BEACH BAFS (back-and-forth shuffling). Group B3 includes sub-environments where the flow is in its last stage: berm (for no-overwash situations), washover crest (for overtopping situations) and washover terminus (for complete barrier overwash situations). This textural group is dominated by the presence of higher FVFC due to the loss of flow competency and higher GC due to high transportability of

coarse clasts. Because of this B3 was named as FLOW DECAY. Group B4 is the coarsest, with the highest GC and VCC, which reflects deposition under relatively high velocity overwash surges with an associated abundance of shells. This group was therefore named OVERWASH.

The washover sediments were further analysed in terms of their spatial and temporal variability. The deposition under overwash conditions, the existence of cross-shore textural grading and the post-storm evolution of the washover sediments were investigated. The sediments deposited under overwash flow have two main grain-size characteristics in relation to the surrounding sub-environments: the existence of high GC and the lack of FVFC. The high contents of gravel results from the combination of high shell transportability and availability with the unidirectional high velocity of the overwash flow. This mechanism tends to selectively transport the shells in relation to the quartz grains, and its high velocity does not allow the settling of the fine and very fine grains. This is the explanation for a coarsening tendency towards the lagoon that was observed in these sub-environments. The washover sediments had the most heterogeneous grain-size characteristics due to the high variability of flow conditions that occur both spatially and temporally. Therefore, a sample taken from an overwash deposit may be the result of the deposition of sediments that were transported by a variety of flow conditions, over several temporal and spatial scales, and therefore heterogeneous.

After the storm, if the washover elevation is higher than the high tide level, then the wind becomes the most important modelling agent of the denuded sedimentary surface. Under these conditions, the more significant textural change in superficial layer of the overwash deposits is the selective removal of the medium sand that coarsens the remnant sediments. The wind generates a lag deposit on the washover surface (still with OVERWASH textural characteristics) and develops embryonic dunes (AEOLIAN textural characteristics). In the

study area, such newly formed deposits were observed at the top limit of the spring high tide mark of the lagoon side. The high concentration of algae at these sites provides both nutrients and the necessary physical obstacle for the development of the embryonic dunes.

The results of the sediment analysis of the Barreta Island sub-environments have provided some insights into the main grain-size characteristics that define the textural signatures. The contents in specific grain-sizes are the key to the definition of the textural groups, and subsequently to the understanding of the dominant physical processes that imprint such signatures. Although the washover sediments were the ones with the highest intra-environmental variability, they can be generally distinguished from other barrier sub-environments and inlet sub-environments. The regional character of the findings of this analysis does not allow an extrapolation to all kinds of overwash-generated deposits, however it presents some textural characteristics that can be useful as a guide to other studies, especially paleo-environments identification, flow deposition analysis, and sedimentary dynamic description.