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# Effect of Planform Equilibrium State in the Sedimentology of Headland Bay Beaches

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**ABSTRACT**

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Sandy beaches, when developed between headlands, have a characteristic planform that is a response of predominant wave net direction. These bay beaches are in static equilibrium, when adjusted to wave climate and there is no longshore sediment transport, or in dynamic equilibrium, when there is sediment supply and the longshore sediment transport is active. The coast of Santa Catarina state, Brazil, has characteristics that are excellent to test the hypothesis that bay beaches in static equilibrium can develop longshore grain size grading, if there are different granulometric classes available. On the other hand, dynamic bay beaches do not develop grading due to classes mixing. To analyse the grain size distribution, 515 samples were collected divided in 293 points alongshore the beachface of Santa Catarina's coastline. The results showed that grain size decreases from Barra Velha beach to south of central-north coastline, from this point to southeast grain size increases and to the south it is smaller. Sediments are more selected from the island to the south. Bay beaches in static equilibrium can develop or no grain size lateral grading, for dynamic bay beaches, is the same. The relation between grain size and planform equilibrium is influenced by sediment source characteristics. Static bay beaches can develop grading if granulometric classes are available and so it can be adjusted to wave power energy. Dynamic bay beaches, can present mixing of granulometric classes and a homogeneous longshore distribution, or grading if there is a local sediment supply.

**ADDITIONAL INDEX WORDS:** *Grain size, longshore grading, sediment source.*

## INTRODUCTION

Headland bay beaches are characteristic of rocky shorelines associated with hilly and mountainous coastal topography. The longshore sediment transport, a result of the oblique wave incidence and longshore wave height gradient, is the responsible for the beach shape that assumes an orientation dependent of the powerful and more frequent wave angle incidence (SILVESTER and HSU, 1993). They have a characteristic asymmetric planform; a shadow zone with strong curvature adjacent to the downdrift headland, a gently curved transition zone, and a straight end, that is normal to the angle of incidence of the more energetic waves (HSU and EVANS, 1989; SILVESTER and HSU, 1993; SHORT and MASSELINK, 1999; KLEIN *et al*., 2002).

According to SILVESTER (1974), a coastline becomes stable (or in static equilibrium) when reaches a planform that is adjusted to refracted wave patterns, the sediment supply and the net longshore transport are null. However, a beach out of equilibrium (or in dynamic equilibrium) will have an active sediment input and waves breaking in a certain angle to the coast, resulting in a longshore sediment transport.

These beaches often show along or shore grain size grading, with fine sand and low beachface slope in the shadow zone and coarse sand and higher beachface slope in the exposed zone (KRUMBEIN, 1944; BASCOM, 1951;FINKELSTEIN, 1981; CARTER, 1988). Grading can be achieved by several factors, including wave energy, attrition, longshore sorting, grain density, sediment transport patterns, coastline configuration, sediment source (BASCOM, 1951; KOMAR, 1976; GAO & COLLINS, 1994; BIRD, 1996). Many times grain size grading is masked if there is a continuous sediment input (DAVIES, 1974; VAN RIJN, 1998).

The Santa Catarina coastline (Figure 1), which presents headlands that confine the beaches and determine its orientation with the waves incidence angle, has characteristics that are excellent to test the hypothesis that grain size alongshore grading cannot be developed at headland beaches with fluvial sediment source (dynamic equilibrium). In this case, there is a mixing of grain size classes furnished by the source. Anyway, is possible to have a concentration of material furnished by the river (source) near its inlet, and so grading can be developed. In the same way, sediment changes between cells by longshore current can not develop grading, cause there is a sediment classes mixing. When the sediment source provide a single grain size class, the beach curvature or wave incidence level will not influence its sediment composition. Grading can not be developed if there is no different grain size classes furnished by the source. In another hand, grading can be developed where there is no active sediment supply (static equilibrium), and the grain size classes can be selected by energy wave level.

### Environmental Setting

The study area is the coastline of Santa Catarina State, between Barra Velha beach and Cardoso beach (Figure 1).

The geology is a succession of geological compartments. The coastal deposits were originated from Quaternary sea level high stands (ANGULO and LESSA, 1997; CARUSO *et al*., 1997, 2000), and include bay barrier systems, beaches linked to basement rocks, beach and foredune ridges, spits and "*cheniers*" plains (CARUSO and ARAUJO, 1997, 2000; KLEIN and MENEZES, 2001; KLEIN *et al*., in preparation).

Even though there is no quantitative mineralogical studies in the region to define source areas and sediments dispersion patterns, CARUSO *et al*. (2000) and KLEIN and MENEZES (2001) suggest that the basement rocks are the ultimate sources of the sediments that are deposited in the coastal plain.

The inner continental shelf is narrow (30 to 45 km) and has water depth between 2 and 50m (MUEHE, 1998; ABREU, 1998). There is a variability of nearshore slopes, as a result of geological inheritance (ABREU, 1998; KLEIN *et al.*, 1999; KLEIN and MENEZES, 2000, 2001). Near the river mouths and bays the nearshore slope is low (1:200), while in regions where the basement rock out crops near the coast, it tends to be steeper (1:40) (MUEHE, 1998; ABREU, 1998; KLEIN and,

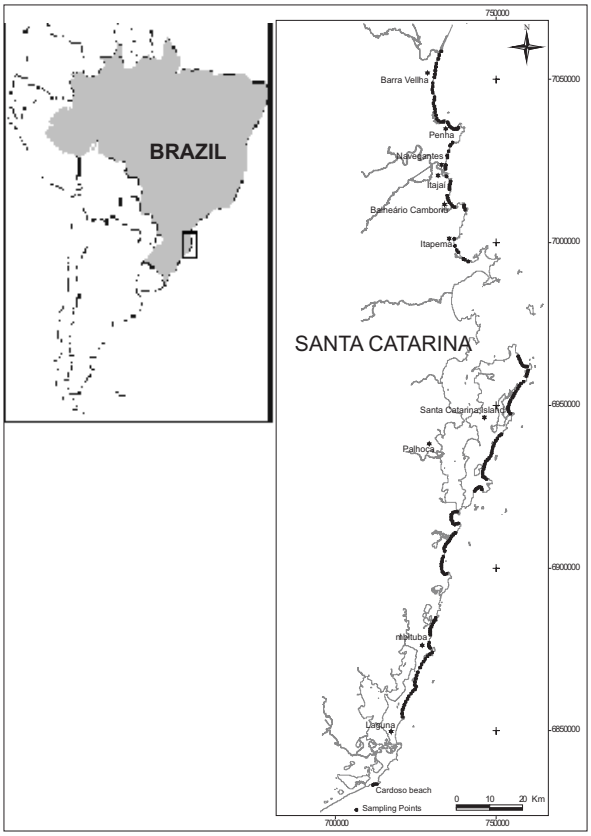


Figure 1. Study area, points show the sampling sites.

MENEZES 2000, 2001). According to CORREA (1980) and ABREU (1998) the inner continental shelf, in this region, mainly presents a sandy texture, with biodetritic gravel in some areas. ABREU (1998) shows that fine sediments are dominant near the coast, mainly near the mouth of estuaries, as a result of the present contribution of rivers basin.

The predominant wind direction is from the northeast, but the strongest winds occur from the southwest, associated with the arrival of cold fronts (NOBRE *et al.*, 1986). Waves arriving from east and southeast dominate the local wave climate, while the most energetic waves are from south-southeast (ALVES, 1996). The littoral drift in this region is predominantly northward, generated by the southeasterly waves. The local mean tidal range is 0.8 meters, with a maximum of 1.2 meters. The storm surges can rise to around one meter (1.0) above the astronomical tide (TRUCOLO, 1998).

## METHODS

To analyze the grain size distribution, 515 samples were collected at the middle position of the beachface, divided in 293 points longshore 28 beaches in the study area. Samples between points the points 1 (Barra Velha beach) and 93 (Balneário Camboriú beach) were obtained in a temporal series (between 1994 and 1996), totalizing 282 samples. In 2002, 233 new samples were collected in these beaches and in the others of the study area.

In laboratory, the content of soluble salt in the samples was removed, the samples were dried and after quartered in sub-samples of 30 to 40 gr. The samples were sieved for approximately 15 minutes, using a battery with 1/4 phi, to obtain a good detail about the granulometric variation of the samples.

The weights of each grain size class were obtained and the software ANGRA - Analisador Granulométrico (MORAES and GRIEP, 1985) was used to obtain the grain size parameters (for this study, mean (Mz) and standard deviation). This software uses the graphic method, proposed by FOLK and WARD (1957).

The data concerned to planform equilibrium are the ones obtained by KLEIN *et al*. (2003), where the authors utilized the parabolic model according to HSU and EVANS (1989).

## RESULTS

### Beach Sedimentology

Figure 2b shows the longshore grain size variation in Santa Catarina coastline. The general grain size behavior is contrasting, and is possible to observe fine to coarse sediments in this area. Grain size ranges from 3.2 (very fine sand in Perequê Beach, point 111) to 0.02 (coarse sand in Armação Beach, point 183). It decreases from Barra Velha (point 1) to Balneário Camboriú (point 93). From this point to south, including the Florianopolis Island east coast, grain size increases till Armação beach (point 186) and southward from this beach, fine to very fine sediments are predominant.

The standard variation values varied between poorly sorted (1.9, Penha beach, point 41) and very well sorted (0.2, Taquaras, point 103). The biggest grain size variations were observed in the central-north coast and in the Santa Catarina's Island. Sediments are more selected southward from the Island (Figure 2c).

### Headland Bay Beaches in Static Equilibrium

Figure 3a shows Armação-Matadeiro beach, located in Santa Catarina Island and according to KLEIN *et al.* (2003), is in static equilibrium. It shows longshore grading, with grain size increasing northward and values that oscillated between 0.02Ø (point 183) and 2.88Ø (point 185), both in Armação beach, relative to coarse sand and fine sand, respectively. The standard deviation decreases toward north, Armação beach. Values diverged between 0.29Ø (point 189) and 0.77Ø (points 180 and 181), sediments are very well selected to moderately selected.

Itapirubá Sul, a beach in static equilibrium, presents a homogeneous grain size distribution, with no sediment grading (Figure 3b). Grain size values oscillated between 2.50Ø (point 292) and 2.69Ø (point 279), fine sand. Standard deviation is from 0.30Ø (point 279) to 0.36Ø (point 280). The sediments in this beach are well selected to very well selected.

### Headland Bay Beaches in Dynamic Equilibrium

Moçambique and Barra da Lagoa beaches constitute a single beach located northward Santa Catarina Island and present longshore grading. Fine sediments are located in the beach extremes and in the central zone there are coarse sediments (Figure 3c). The mean values oscillated from 0.55Ø (point 150) and 2.8Ø (point 155). The sorting level decreased in the central zone of the beach, values of standard deviation are from 0.31Ø (point 139) and 0.84Ø (point 143), moderately selected to very well selected.

In Itapirubá Norte beach (Figure 3d) there is no longshore grading, grain size is from 2.58Ø (point 273) to 2.78Ø (point 277), fine sand.

Sediments are very well selected, with standard variation values between 0.27Ø (point 271) and 0.34Ø (point 273).

## EFFECT OF PLANFORM EQUILIBRIUM IN THE SEDIMENTOLOGY OF HEADLAND BAY BEACHES

According to KLEIN and MENEZES (2001); KLEIN *et al.* (2002), the increase in grain size variability in the study area is due the basement rock outcrops near the coast. The southward decrease in grain size is due to river input, and where sediments were reworked in well developed coastal plain systems (foredunes and beachridges), what also improve the sorting level of the sediments (GIANNINI, 1993). According to MARTINS *et al.* (1972), in the study area the wave energy (height) increase northward from Santa Catarina Island,

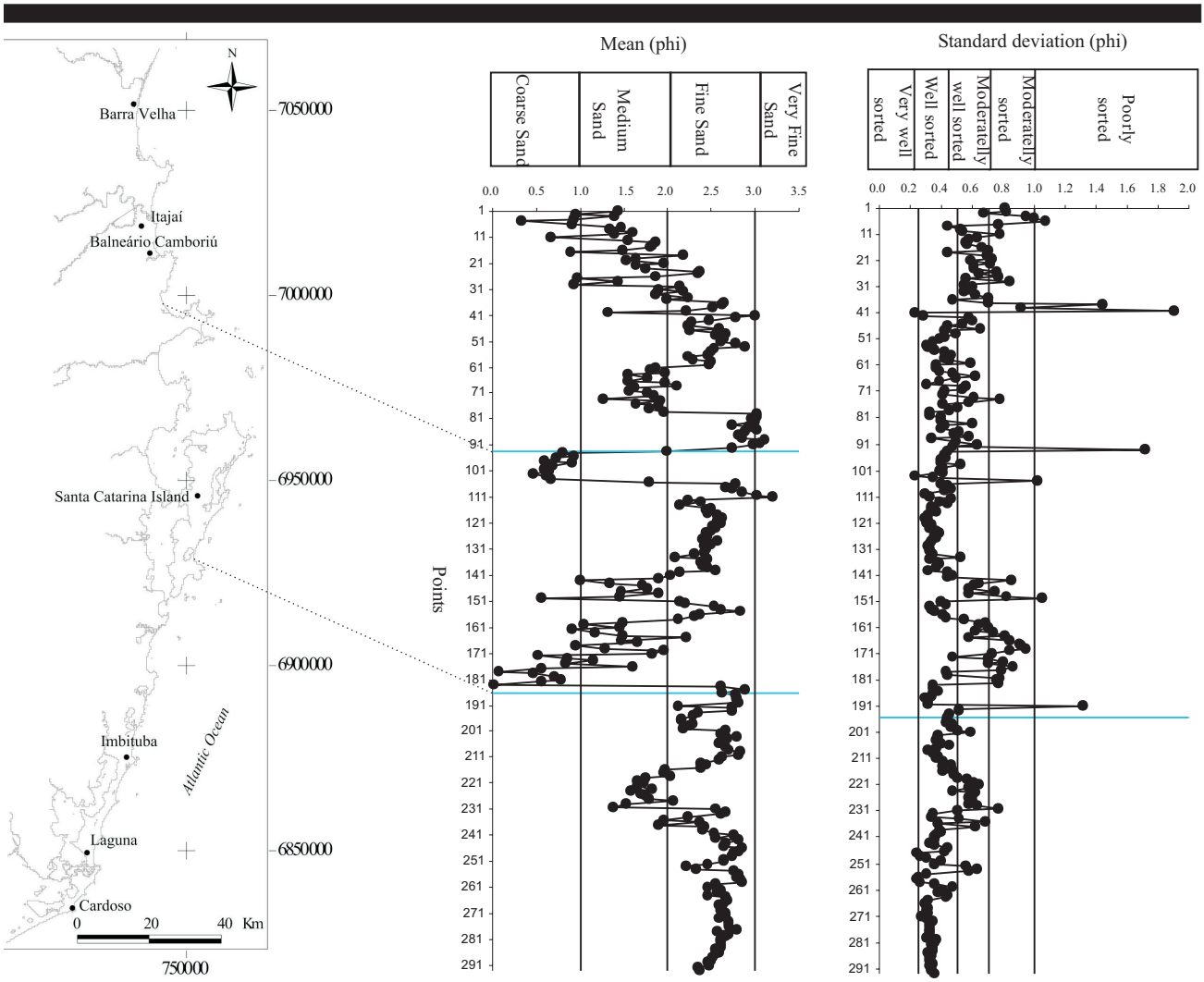


Figure 2. Study area (a), mean (b) and standard deviation (c) longshore distribution.

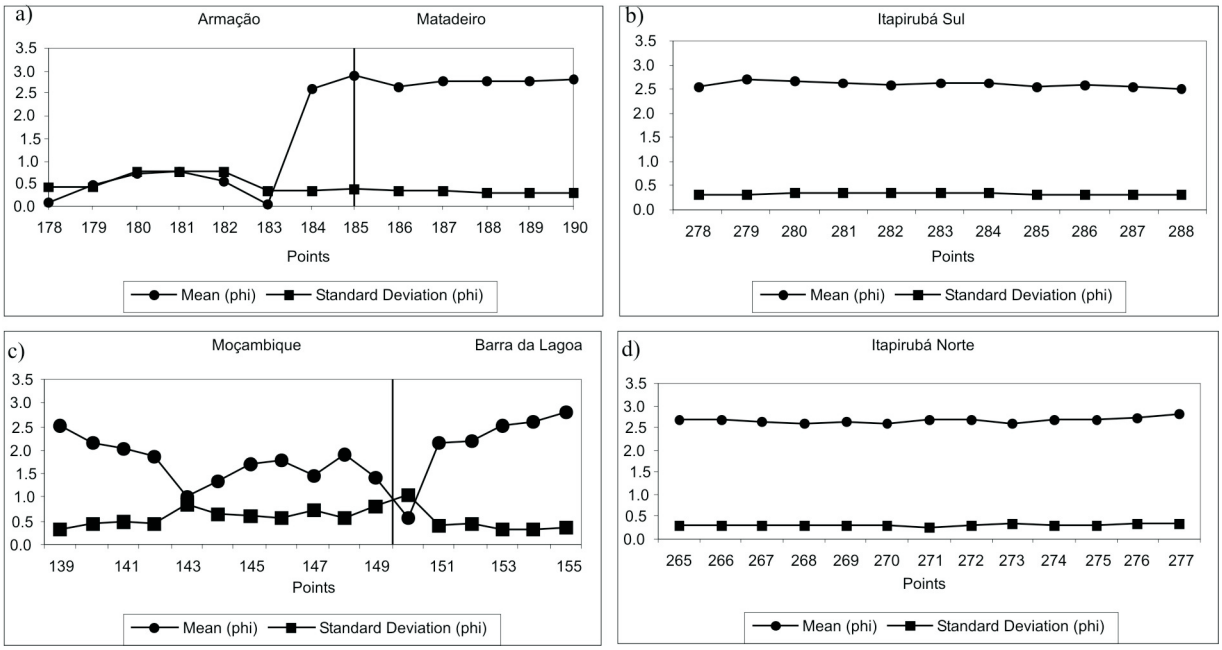


Figure 3. Mean and standard deviation longshore distribution in static equilibrium headland bay beaches a) Armação-Matadeiro, b) Itrapirubá Sul and in dynamic equilibrium c) Moçambique-Barra da Lagoa and d) Itapirubá Norte.

affecting the sorting level and grain size distribution of the beaches. In low energy areas there are more grain size classes with a reduction of sorting level of the sediments than in high energy areas. In the Santa Catarina Island, these authors suggest that the grain size variability is due to the mixing of the reworked fine sand and the coarse sediments originated from the adjacent granite basement. Some studies of the grain size distribution of distinctive segments of the Santa Catarina's Island attribute the variations to longshore transport and sediment source (TORRONTEGUY, 2002; ABREU DE CASTILHOS, 1995) and wave height (LEAL, 1999).

Beaches that are in dynamic equilibrium, not adjusted to wave patterns incidence and longshore transport can develop lateral grading or not. Grading in this kind of beach is due local sediment source, cause is unbelieveble that in headland bay beaches longshore drift can promote longshore sediment sorting (MASSELINK, 1992; MIOT DA SILVA *et al.*, 2000). Long term experiments on currents that could demonstrate sediment sorting are not available in Santa Catarina coastline. Is acceptable that grading takes place if there are local sediment sources in the coastal zone and longshore drift promote mixing of the sediment classes. Hence, to explain lateral grading in dynamic headland bay beaches is necessary to improve studies about sediment sources, cause they are fundamental to explain the sediments distribution patterns (KOMAR, 1976; NORSDSTROM, 1977; CARTER, 1988; SHORT and NI, 1997).
Beaches in static or dynamic equilibrium can develop grain size longshore grading or not (Figure 3). It can be due the presence of grain size modal classes furnished to the beach environment, and does not depend on planform equilibrium state.

Is possible to conclude that the occurrence and location of grain size classes in headland bay beaches does not depend exclusively on wave energy, what was already suggested by NORDSTROM (1977); SHORT (1999); MIOT DA SILVA *et al.* (2000) e KLEIN and MENEZES (2001). The relation between planform state of equilibrium and grain size grading is influenced by sediment source characteristics. Static bay beaches can develop grading if granulometric classes are available and so be adjusted to wave power energy as results obtained by KRUMBEIN (1944); BASCOM (1951); FINKELSTEIN (1981); CARTER (1988). Dynamic bay beaches, can present mixing of granulometric classes and a homogeneous longshore distribution, or grading if there is a local sediment supply, as proposed by KLEIN *et al.*, (in preparation).

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