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Beach Morphodynamics and Profile Sequence for a Headland Bay Coast*

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ABSTRACT

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This paper presents a sequence of beach profile for a headlands and bay coast. Shape analyses of the embayed beach, identification of the predominant wave direction, beach and nearshore profiles, sedimentology characteristics, hydrodynamic conditions at the beaches, morphodynamics and morphometric data for 17 beaches on central-north coast of Santa Catarina, Brazil, were obtained. Beaches are classified in three main groups: (1) exposed; (2) semi-exposed; and (3) sheltered. The exposed beaches had an indentation ratio smaller than 0.39 and the dominant south waves are approximately parallel to the coast (angle smaller than 40°). The beaches can be divided into three mainly groups. (a) Reflective beaches have coarse sand (0.59mm–0.94mm) and steeper nearshore slope (1:40) associated with a very narrow coastal plain (<1Km). (b) Intermediate beaches with one nearshore bar have medium sand (0.30mm–0.45mm) and gentle nearshore slope (1:100–1:200) and a developed coastal plain—island bars systems. (c) Dissipative beaches have fine sand (0.20 mm) and a gentle nearshore (1:200) morphology. When two or more nearshore bars are present the coastal plain contains foredune ridges. The semi-exposed beaches have a large indentation ratio (0.37–0.49) and the wave has an approximate angle greater than 40°. They are partially exposed to southerly waves. There is a alongshore beach morphodynamic change that is function of distance between headlands, shape of bay, wave breakers, grain size and relative tidal range. When $H_b \ll H_o$, in the diffraction zone, reflective conditions (coarse grain) or dissipative/low tide terrace to mud flat conditions (fine grains) are possible. Generally, in the central position ($H_b \geq H_o$) the beach is a dissipative non-barred system or low tide terrace (fine sand). In the case of medium sand, the beach is reflective. Sheltered beaches are influenced only by diffracted waves or local wind waves. They are totally sheltered from the more energetic ocean waves that come from the south. Normally, the wave approximates with an angle greater than 50° and RTR is large. They can be divided into: (a) reflective (coarse and medium sand) and (b) dissipative non-barred or low tide terrace (fine sediment). However, further research is necessary for sheltered beaches, because it is very difficult to include them in the classification proposed in the literature. These types of beaches are in the low limit between wave and tidal dominated environments and a small change in the wave height results in a modification from tidal to wave domain and vice-versa and for this type of beach the source of sediment and consequently grains size define the beach shape and slope (concave or convex). In direction to a more universal classification will be necessary intrudes the shape of beach in the parameters.

ADDITIONAL INDEX WORDS: *Embayed beaches, Brazilian sandy beaches, sheltered beaches.*

INTRODUCTION

Global studies of oceanic sandy beaches require many variables responsible to understand the processes and its morphodynamic behaviour. Short (1999) suggests five major parameters: tidal range, wave height, wave period, grain size and beach length/embaymentisation which are incorporated into seven equations that can be used to describe the major features of beach systems. These equations include, among others, beach type, beach slope, number of bars and embaymentisation parameter. However, further studies on different sandy coasts, especially those presenting headland and bay geomorphology, are necessary for developing a global model (Short and Masselink, 1999), owing to the range of exposure to different wave and tidal conditions. In this case, the range of alongshore beach morphology (beach profile sequence) is a result of distance from headland, shape of bay, wave obliquity, indentation ratio, longshore grain size distribution and nearshore slope. The propose of this paper is to elucidate a beach profile sequence for the coastal zone of an east coast swell environment with headlands and bay geomorphology.

ENVIRONMENTAL SETTING

The study area is located on the central-north coast of the State of Santa Catarina between 26°30′ S and 27°20′ S, located on the coastal macro-compartment of the Crystalline

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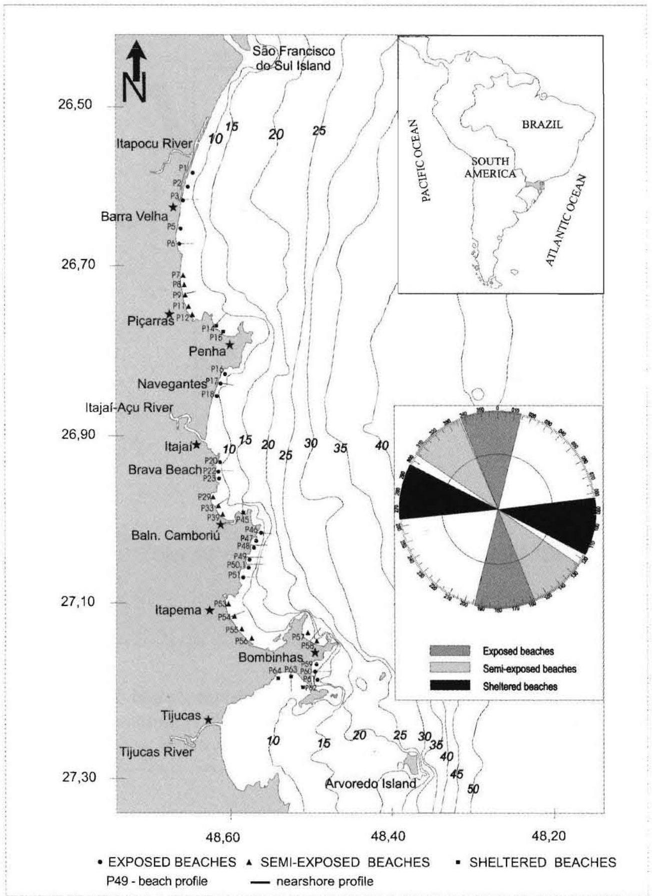


Figure 1. Map of study area showing beach profile and shoreface measurement program conducted on the Central-North coast of the State of Santa Catarina, Brazil, between January 1994 and February 1996 (depth is in meters). Note the beach classification in relation to the wave exposition and beach orientation in relation to the north.

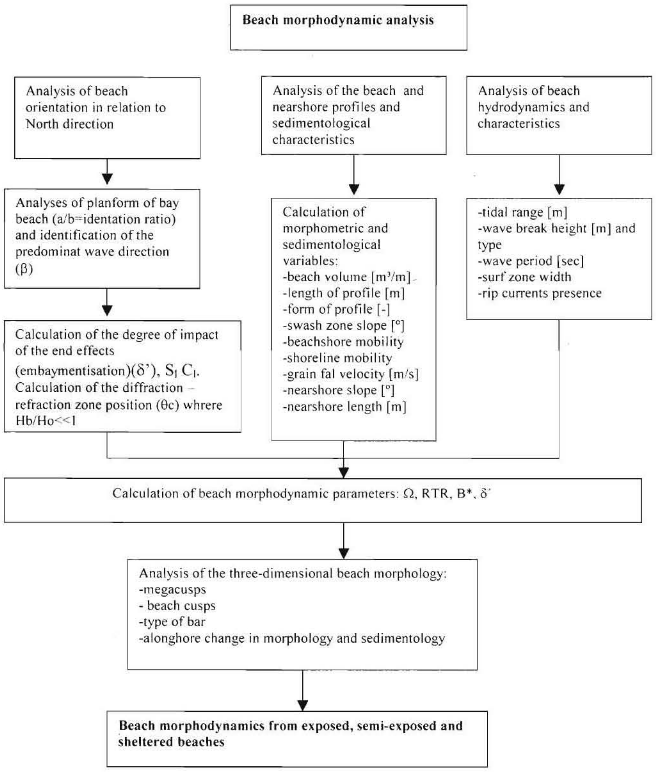


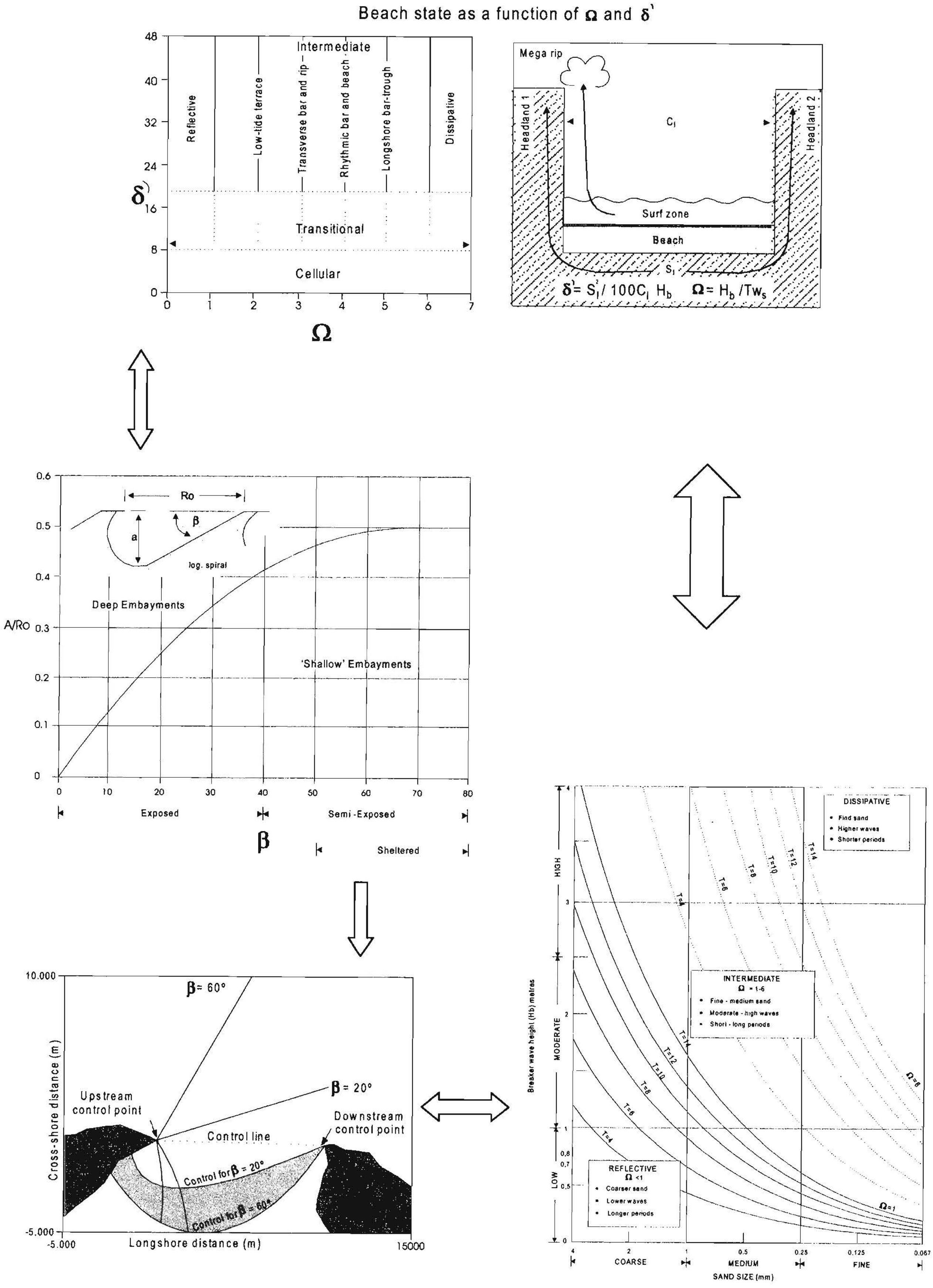
Figure 2. Overall methodology employed in this study.

Scarps (MÜEHE, 1998) (Figure 1). Northeasterly winds are predominant, with secondary southwesterly winds, associated with the arrival of cold fronts (NOBRE *et al.*, 1986). The direction of more energetic incident waves is south-southeasterly (ALVES, 1996). The local tide is microtidal, mainly semidiurnal with small inequalities, with a mean range of around 0.8 m and a maximum tide of 1.2 m (SCHETTINI *et al.*, 1996; CARVALHO *et al.*, 1996; TRUCOLO, 1998). The meteorological influence of sea level is very important as storm surges can raise it to around of one (1) meter above the astronomical tide (SCHETTINI *et al.*, 1996; CARVALHO *et al.*, 1996; TRUCOLO, 1998).

In this region, the coast is cut out with Pre-Cambrian crystalline rock outcrops, interrupting the Quaternary coastal plain continuity (MÜEHE, 1998). A series of confined bays open to the ocean occurs, initially, towards the northeast, such as the Camboriú and Itapema/Porto Belo bights, and towards the east, such as the Tijucas Bay. There are also parabolic shaped embayments (Penha and Picarras beaches) (HOEFEL, 1998; KLEIN *et al.*, in preparation). The coastal plains consist of barrier island systems, beaches linked to the basement, foredune/beach ridges, spits and "*cheniers*" plains (CARUSO and ARAUJO, 1997; CARUSO and ARAUJO, 1999; CARUSO *et al.*, 1997). These are associated with relative sea-level variation during the Quaternary (ANGULO and LESSA, 1998).

The continental inner shelf is narrow (between 30 and 45 Km), and between 2m and 50m deep (MÜEHE, 1998; ABREU, 1998). Islands and rocky outcrops, formed by basement rocks, are also present (MÜEHE, 1998). The nearshore slope is a result of the geological inheritance (ABREU, 1998; MENEZES, 1999; KLEIN *et al.*, 1999). It is low near river mouths and bays (1:200), while in regions of basement rock it tends to be steeper (1:40) (MÜEHE, 1998; ABREU, 1998; MENEZES, 1999; KLEIN *et al.*, 1999).

The beaches present a multitude of environmental settings due to their distinct geographical orientation, level of exposure to incident waves and sediment distribution (MENEZES and KLEIN, 1997; MENEZES, 1999; KLEIN *et al.*, 1999; KLEIN and MENEZES, 2000). Generally, the beaches are relatively sheltered from the more energetic southerly waves as most of them are located between headlands that modify incident waves to varying degrees (MENEZES and KLEIN, 1997; MENEZES, 1999; KLEIN *et al.*, 1999; KLEIN and MENEZES, 2000). In the coastal classification proposed by HAYES (1979), based on the mean tidal range and mean wave height parameters, the beaches are wave-dominated in the exposed areas and


Beach state as a function of Ω and δ'
48
40
32
24
16
8
0
δ'
Reflective
Low-tide terrace
Transverse bar and rip
Rhythmic bar and beach
Longshore bar-trough
Dissipative
Intermediate
Transitional
Cellular
0 1 2 3 4 5 6 7
Ω
Mega rip
Headland 1
Headland 2
Cl
Surf zone
Beach
Sl
δ' = Sl²/ 100Cl Hb   Ω = Hb /Tws
0.6
0.5
0.4
0.3
0.2
0.1
0
A/Ro
Ro
β
a
log. spiral
Deep Embayments
'Shallow' Embayments
0 10 20 30 40 50 60 70 80
Exposed
Semi-Exposed
Sheltered
β
10.000
-5.000
-5.000
15000
Cross-shore distance (m)
Longshore distance (m)
β = 60°
β = 20°
Upstream control point
Downstream control point
Control line
Control for β = 20°
Control for β = 60°
Breaker wave height (Hb) metres
HIGH
MODERATE
LOW
4
3
2
1
0,8
0,7
0,5
0
DISSIPATIVE
• Find sand
• Higher waves
• Shorter periods
INTERMEDIATE
Ω = 1-6
• Fine - medium sand
• Moderate - high waves
• Short - long periods
REFLECTIVE
Ω <1
• Coarser sand
• Lower waves
• Longer periods
T=4
T=6
T=8
T=10
T=12
T=14
Ω=1
Ω=6
4 2 1 0.5 0.25 0.125 0.067
COARSE
MEDIUM
FINE
SAND SIZE (mm)

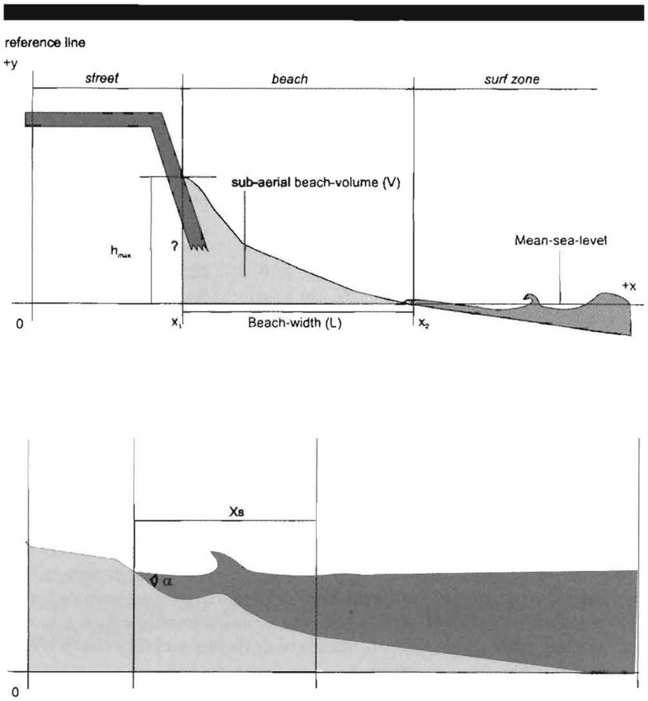


Figure 4. (a) Morphometric variables calculated from beach profiles (subaerial beach volume (V) [m^3/m]; subaerial beach width (L) [m]; and subaerial dimensionless beach shape (F) [-]; (b) wide of surf zone (χ_s)[m].

mixed-energy in the sheltered areas of the bays (TEMME *et al.* 1997; KLEIN *et al.* 1997; KLEIN and MENEZES, 2000).

SAMPLING AND ANALYSES

Beach Exposure—Indentation Ratio and Identification of Predominant Wave Direction (β)

The method employed in this study is presented in Figure 2 and 3. The ratio of bay indentation (a) to headland spacing (Ro) is a result of the obliquity of the dominant wave crests to the headland alignment (β) (SILVESTER and HSU, 1997). The obliquity of the dominant wave crest to the headland bay beach is defined as the angle between the shoreline of the downdrift section of the bay and the headland alignment. As seen in the inset of Figure 3, the highest indentation (a) is measured normal from the control line (Ro) to the point of largest retreat of the shoreline (SILVESTER and HSU, 1997). This is obtained by drawing a tangent parallel to the control line, which is asymptotic to the beach (SILVESTER and HSU, 1997). Figure 3 shows the relationship between a/Ro and β.

This information was obtained by aerial photo interpretation on 1:12.500 scale from years 1995, and charts on 1: 50.000 scale.

Table 1. *Theoretical limit values of declivity of the beach face for the morphodynamic stages (KLEIN, 1997).*

Stages	Ω limit	tanβ limit
Dissipative	$\Omega > 6$	tanβ < 0.061 (3.5°)
Intermediate	$1 < \Omega < 6$	061 < tanβ < 0.15
Reflective	$\Omega < 1$	tanβ > 0.15 (8.5%)

Beach Exposure—Degree of Headland Impact

The degree of impact of end effects or embaymentisation is predicted using the nondimensional embayment scaling parameter (δ') (MATENS *et al., in press*; SHORT and MASSELINK, 1999). When deepwater waves enter an embayment with a given width (C_l), between headlands, the wave energy will be redistributed along the embayment shoreline (S_l), such as:

$$\delta' = S_l^2/kC_lH_b \qquad (1)$$

Where k is the surf zone slope and H_b is wave break. The embayment shoreline (S_l) can obtained by aerial photo interpretation. Cellular circulation occurs when $\delta'$is lower than 8, transitional circulation for δ' between 8 and 20, and normal circulation for δ' greater than 20.

Beach and Nearshore Profiles

Between January 1994 and February 1996, a beach-profile measurement program was conducted on the central-north coast of the State of Santa Catarina (see Figure 1). In total, 64 beach profiles were obtained and 32 were almost monthly monitored with a levelling instrument, as proposed by BIRKEMEIER (1981). The beach profiles were evaluated by the Interactive Survey Reduction Program, ISRP (BIRKEMEIER, 1986). And in total, 1164 profiles were obtained; and all of them were made one meter equidistant between successive points by linear interpolation between the data points, using the LOD_EQUI program (BRESTERS and REIJNGOUD, 1996).

From the profiles, the following morphometric variables were calculated: subaerial beach volume (V) [m^3/m]; subaerial beach width (L) [m]; and subaerial dimensionless beach shape (F) [-] (Figure 4). The x-axis extends seawards, and the y-axis extends vertically upwards. The origin of the co-ordinates is located at mean sea level at a fixed reference point. The morphological variables are computed using the landward boundary (x1) and the seaward boundary (x2) as recommended by TEMME *et al.* (1997). The landward boundary (x1) is constant per profile. The locations of these points were determined using the profile envelopes as shown in Figure 4. The profile-envelope is defined by the maximum and minimum height at each cross-shore distance. In these profile envelopes the points without morphological changes can be identified (essentially zero). The location of x1 is chosen so that this part of the profile is not included in the analysis.

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Figure 3. Classification of beach state—indentation ratio, embayment scaling parameters, omega, breaker wave height and sand size (after SILVESTER and HSU, 1993; 1997; SHORT, 1999; MATENS *et al.*(*in press*); SHORT and MASSELINK, 1999).

Table 2. *Average results from morphodynamics and morphometrics parameters obtained for 17 beaches.*

Beach	Pn	N	M	θ	Hb	T	Ws	Ω	Ω_t	RTR	B*	a(m)	Ro	a/Ro	β′
Itajuba*	5–6	15	23	2 to 182	1.0	8.0	11.90	1.43	2.19	0.86	13	—	—	—	<20
Taquarinhas*	46	16	22	178 to 358	1.0	8.0	14.00	1.36	1.08	0.73	4	637	1637	0.389	38
Taquaras*	47–48	17	22	158 to 338	0.8	7.0	12.30	1.22	0.67	1.06	2	637	1637	0.389	38
Estaleiro*	49	11	17	14 to 194	0.7	7.5	8.95	1.31	1.28	1.15	8	—	—	—	<20
Estaleirinho*	50.1	13	23	4 to 184	1.0	7.5	11.20	1.57	1.13	0.79	17	—	—	—	<20
Barra Velha**	1–4	39	23	13 to 193	0.8	8.5	6.21	2.18	2.26	0.98	41	—	—	—	<20
Praia Brava**	20–23	15	20	6 to 186	0.7	7.5	4.36	2.83	3.6	1.19	15	—	—	—	<20
Ilhota**	51–52	17	22	345 to 165	0.8	7.0	7.79	2.04	0.82	0.93	30	250	825	0.300	32
Naveqantes***	16–19	20	20	14 to 194	0.8	9.0	1.74	7.68	15.00	0.91	75	—	—	—	<20
Mariscal***	60–62	22	22	360 to 180	0.5	8.0	2.15	4.23	21.50	1.50	20	995	3500	0.284	36
Picarras†	7–12	50	19	157 to 337	0.4	7.0	4.06	2.40	3.80	2.02	6	1850	3900	0.470	55
B. Camboriú†	29–44	74	27	142 to 322	0.5	6.0	1.61	10.00	38.00	1.66	3	750	2025	0.370	40
Itapema†	53–56	37	20	324 to 144	0.3	7.0	2.81	3.65	19.90	3.32	19	3200	7350	0.435	51
Bombas†	57–58	17	22	304 to 124	0.3	8.0	2.46	3.12	15.30	1.97	8	1600	3300	0.485	62
Armação††	14–15	15	22	116 to 296	0.5	8.0	4.22	2.45	5.05	1.59	5	1800	4650	0.387	52
Laranjeiras††	45	16	22	83 to 263	0.2	6.0	3.47	1.54	3.83	3.24	5	318	662	0.480	55
Zimbros††	63	24	23	117 to 297	0.1	3.5	7.59	1.44	7.43	6.98	10	1850	3800	0.487	68

* Expose-reflective, ** expose-intermediate, *** expose-dissipative with bars, † semi-exposed (three dimensional beach morphology), †† sheltered. Profile number (Pn), number of field works (N), months (M), beach orientation (θ) [°], wave breaker height (H_b) [m], wave period (T) [s], grain fall velocity (Ws) [cm/s], dimensionless fall velocity (Ω), empirical dimensionless fall velocity (Ω_t), relative tidal range (RTR), bar parameter (B)*, bay indentation (a) [m], headland spacing (Ro) [m], indentation ratio (a/Ro); angle of more energetic wave approximation (β′) [°]; embayment shoreline (S_1) [m]; embayment width (C_1) [m]; embayment scaling parameter (δ′); beach slope (β) [°], nearshore slope (α), beach length (L) [m], shoreline mobility coefficient – standard deviation beach length (σL), backshore mobility coefficient (CVL = L/σL) [%], beach volume mobility (V) [m³/m], standard deviation mobility beach volume (σV), CVV (CVV = L/σL) (%], e beach form (F). Ro, a/Ro, β′ after KLEIN *et al.* (in preparation).

The seaward boundary, the location of the mean sea level (x2) is used in all cases, as a consequence, only the subaerial parts of the profile change are analysed (mobile subaerial zone). The beach volume (V) is defined as the cross-sectional area within the boundaries x1 and x2 per unit length of the shoreline (SONU and VAN BEEK, 1971). The width of the beach (L) is defined as the distance between the boundaries x1 and x2. The shape of the mobile beach is defined as $Q/L.h_{max}$, where h_{max} is the maximum height of the profile. This parameter describes the form of the profile. High values (about 0.7) can be related to a convex profile and low values (about 0.3) for a concave form. A linear beach profile is represented by a value of 0.5 (FUCELLA and DOLAN, 1996).

Seventeen (17) perpendicular bathymetric profiles between 2 and 10 meters were obtained in order to figure out the length (χ_s) and the slope of nearshore study area (see Figure 1 and 4). The depth was obtained with an ELAC–register and the position by triangulation methodology.

Beach Type and Number of Bars

Beach type and number of bars were obtained by relative tidal range (RTR), dimensionless fall velocity (Ω), empirical dimensionless fall velocity (Ω_t) and bar parameter (B*).

The parameterisation of tidal effects was proposed by (MASSELINK, 1993). This author found that a useful parameter (relative tidal range—RTR) to quantify tidal effects was:

$$RTR = TR/H_b \tag{2}$$

Where TR is a spring tidal range. When RTR < 3 the beach is classified as a wave dominated type, a mixed wave-tide beach type for 3 < RTR < 7, and a tidal dominated beach (sand flat) for RTR > 15.

The parameterisation of wave dominated beach type was obtained by dimensionless fall velocity parameter (GOURLAY, 1968; DEAN, 1973) adopted for natural beaches by WRIGHT and SHORT (1984):

$$\Omega = H_b/(W_sT) \tag{3}$$

Where W_s is sediment fall velocity and T^1 is wave period.

The authors relater that when Ω<1, beaches tend to be reflective (steep, barless), becoming dissipative when Ω>6, they tend to be flat and multibarred, and in an intermediate state between the two end members (one or two bars) for 1<Ω<5. The role of the three parameters H_b,T and W_s (grain size) in influencing the beach types is illustrated in Figure 3, which shows the sensitivity to each parameter according SHORT (1999). Increasing H_b and decreasing T and W_s, favour dissipative beaches, while decreasing H_b and increasing T and W_s, favours reflective beaches with intermediate beaches lying in between (SHORT, 1999).

The empirical dimensionless fall velocity parameter was obtained by relates the declivity of the beach face (tanβ) with dimensionless fall velocity parameter, once both vary according to the characteristics of the waves (H_b, T) and of the sediment (W_s). KRIEBEL *et al.* (1991) and MASSELINK (1993) analysing Sunamura's data (1984) proposed: $\tan\beta = 0.15\ \Omega^{-0.5}$. Realising that tanβ is a function of Ω, we substituted the values proposed by WRIGHT and SHORT (1984) with the purpose of determining the limit theoretical value of declivity for the extreme morphodynamic stages (Table 1). KLEIN (1997) proposed:

$$\Omega_t = 0.0225/\tan\beta^2 \tag{4}$$

Table 2 shows the relationship between Ω and Ω_t for the beaches in the study area.

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[1] The wave climete was obtained by visual observation.

Table 2. *Extended.*

S_1	C_1	S_1/C_1	δ'	β	α	L	σL	CVL	V	σV	CVV	F
open	open	open	—	7	1:300	30	8	25	52	14	27	0.55
—	—	—	—	9	1:40	31	4	14	61	13	21	0.52
2590	1390	1.86	150	10	1:40	29	4	15	56	9	16	0.57
1910	1580	1.20	165	8	1:20	31	6	19	54	14	25	0.48
820	790	1.03	21	9	1:40	37	7	19	77	15	19	0.62
open	open	open	—	7	1:250	25	5	22	37	6	15	0.46
3540	3000	1.18	60	5	1:100	24	6	33	26	16	63	0.50
1880	1100	1.70	27	10	1:150	14	4	26	16	4	25	0.50
9510	9360	1.00	60	3	1:200	32	8	24	26	10	40	0.37
5960	3440	1.73	295	3	1:70	39	4	10	39	6	14	0.44
10190	7650	1.33	136	5	1:250	25	4	17	25	6	23	0.45
6260	3440	1.82	123	3	1:185	17	6	32	36	5	13	0.50
15880	7610	2.09	201	3	1:550	31	3	11	20	3	15	0.41
7020	2950	2.40	1590	3	1:35	40	3	8	35	3	9	0.48
6086	3094	1.96	239	4	1:100	32	5	15	36	8	21	0.41
1047	940	1.11	116	3	1:50	26	1	4	25	2	6	0.54
9087	4220	2.15	489	4	1:400	22	1	6	18	2	10	0.47

Finally, the occurrence numbers of nearshore bars was obtained with the bar number equation (B*) (SHORT and AAGAARD, 1993):

$$B^* = \chi_s/g \cdot \tan\beta \; T_i^2 \qquad (5)$$

and confirmed by photo interpretation. This equation indicates that the number of bars in a microtidal environment, increases as the nearshore slope (tanβ), and/or the period of wave during storm (T_i)[2] decreases, and the nearshore length (χ_s) increases. If $B^* < 20$, the beach does not exhibit bars. For B* between 20 and 50 the beach exhibit one bar, between 50 and 100 there are two bars, between 100 and 400 there are three bars, and for $B^* > 400$ there are 4 or more bars.

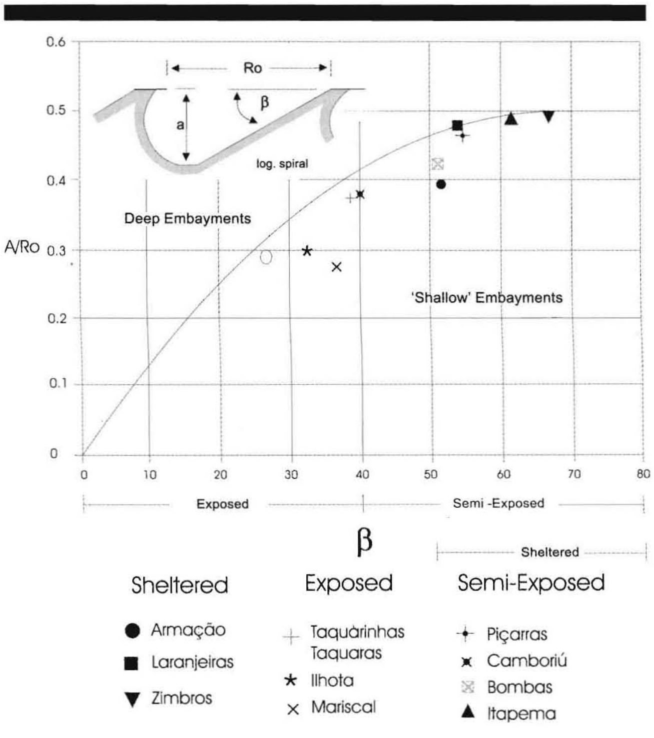

Figure 5. Indentation ration versus angle of wave direction for beaches on the Central-North coast of the State of Santa Catarina, Brazil.

BEACH PLANFORM AND MORPHODYNAMIC CHARACTERISTICS

The parameters used to describe the beach planform and beach morphodynamic characteristics are presented in Table 2.

The ratio of bay indentation (a) to headland spacing (Ro) is a function of the obliquity of the dominant wave crest to the headland alignment (β) (SILVESTER and HSU, 1997) and the degree of the beach wave exposure is also function of these two variables. Large wave obliquity results in a larger indentation and smaller wave exposure, whilst exposed beaches exhibit a small indentation ratio (between 0.28 and 0.39) and small obliquity (less than 40°)(Figure 5). Generally, semi-exposed beaches have a variable indentation ratio (between 0.37 and 0.49) and the wave obliquity between 40°–62°, but with northwest-southeast orientation. Sheltered beaches exhibit a variable indentation ratio (> 0.38) and wave obliquity greater ($>50°$) with east-west orientation. However, all beaches have a nondimensional embayment scaling parameter (δ') greater than 20 (normal circulation)(Table 2).

Figure 6 and 7 shows the beach classification of dissipative, intermediate to reflective, based on wave breaker height (H_b), sand grain diameter and beach slope.

Exposed Beaches

Several beaches in study area are may be classified as exposed, such as: Itajuba, Taquarinhas, Taquaras, Estaleiro, Estaleirinho, Barra Velha, Brava, Ilhota, Navegantes and Mariscal (see Figure 5, 6 and 7 and Table 2). They have north-south orientation (see Figure 1) and are wave-dominated beaches ($RTR < 3$), low energy, and can be divided into reflective, intermediate and dissipative (multiple bars). The role of the parameters H_b, T and W_s (grain size) influencing the beach type is illustrated in Figure 6, showing the sensi-

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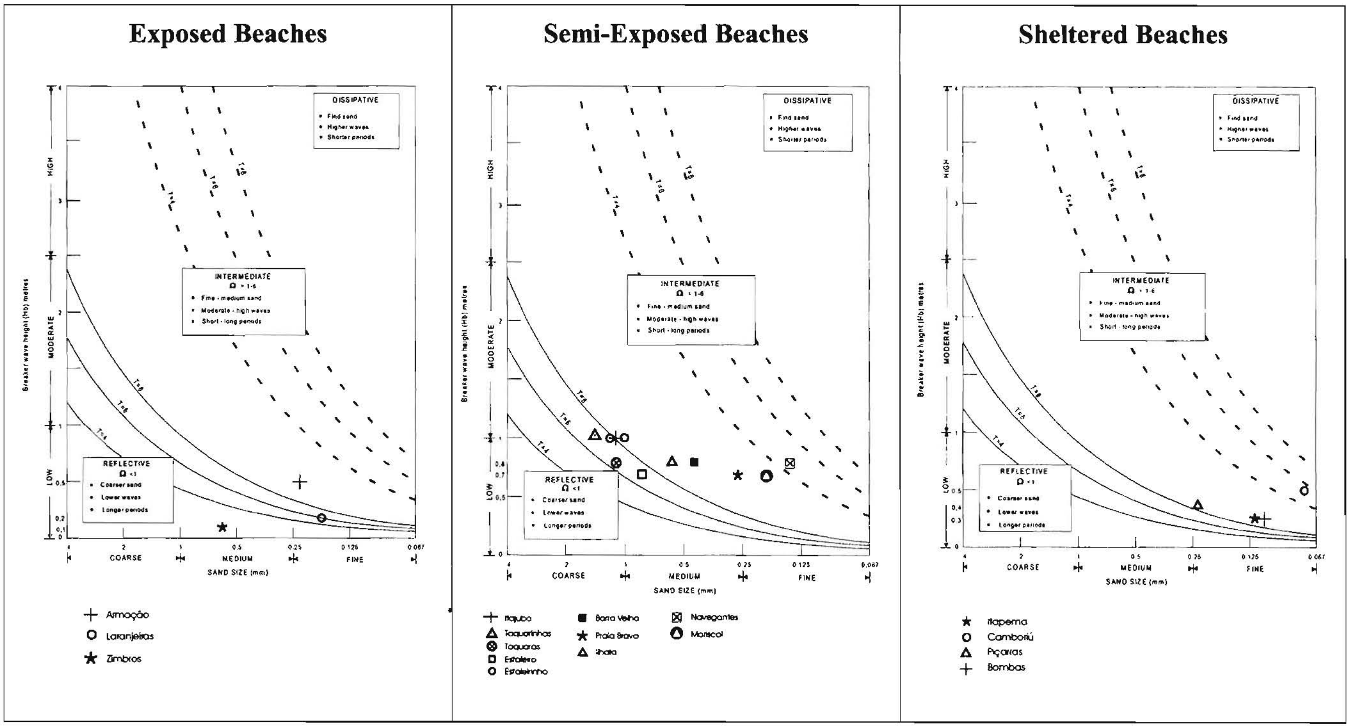
[2] The storm wave period was obtained from ALVES (1996).



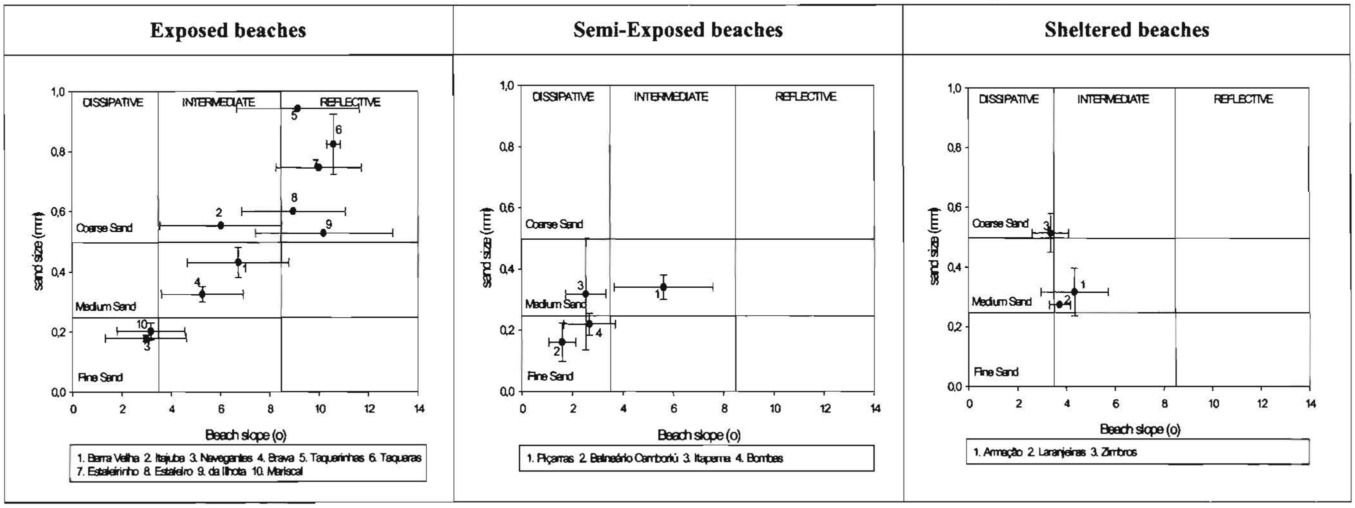
Exposed Beaches

Semi-Exposed Beaches

Sheltered Beaches

Figure 6. Beach classification based on breaker height and sand size for beaches on the Central-North coast of the State of Santa Catarina, Brazil.

tivity of these parameters (SHORT, 1999). Sediment size and waves controls the beach shape and dynamics. Fine sand produces a lower slope (1° to 3°) on the swash zone and a wider surf zone (≈100m) with potential high mobile sand, whilst medium to coarse sand beaches have a steeper slope (5° to 10°) and a narrower surf zone (< 50m). Traditionally, wave height has been directly and positively correlated with beach sediment size (KING, 1973; BASCOM, 1951). However, the exposed and sheltered beaches from the study area do not show correlation positively between grain size and wave height (see Table 2 and Figure 6 and 7). There is a correlation between type of beach and grain size mainly for exposed and



Exposed beaches

Semi-Exposed beaches

Sheltered beaches

Figure 7. Grain size versus beach face slope for different types of beaches (exposed, semi-exposed and sheltered) for beaches on the Central-North coast of the State of Santa Catarina, Brazil.

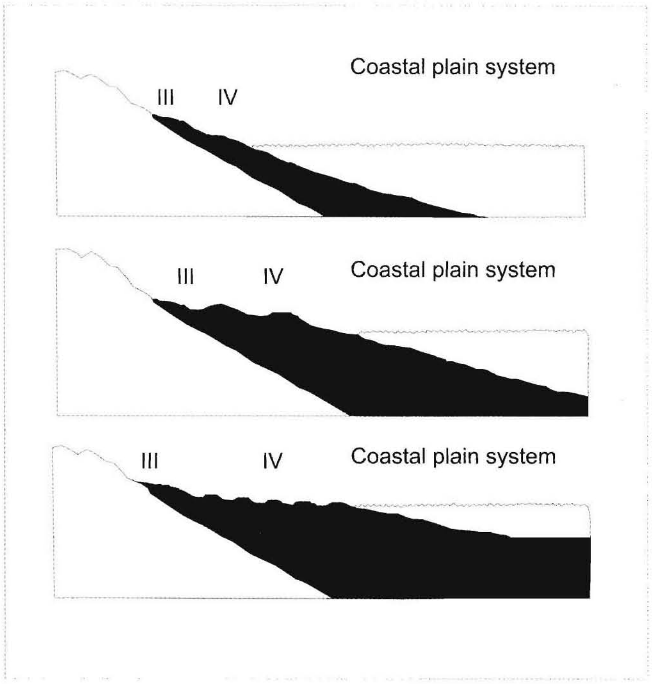


Figure 8. Relation between type of beach and coastal plain system for exposed beaches (a) Reflective beaches; (b) dissipative beaches; and (c) intermediate. (III—Pleistocene deposits, IV—Holocene deposits) (not to scale)

semi-exposed beaches (at exposed area). Reflective beaches are composed by coarse sands (0.59mm–0.94mm) and dissipative beaches are composed by fine sands (0.20mm). Medium sands (0.30mm–0.45mm)defined intermediate beaches.

SHORT *et al.* (1979), WRIGHT and SHORT (1984) and more recently SHORT (1999), indicate that high energy beaches can be composed by fine sand through coarse sediments (see Figure 6). SHORT and NI (1997) found that there was no correlation between wave height and sediment size, if anything the higher energy beaches have finer sand. This relation indicates that in headland bay beaches the average sand size is inherited from geological source and can be not selected by the prevailing waves (SHORT, 1999; KLEIN *et al.*, 1999; MIOT DA SILVA *et al.*, 2000).

Beach type can more directly be associated with geological inheritance through its influence on sediment source and type. In the study area reflective beaches have coarse sediments resulting from reworking of older deposits (fan deltas or old barrier islands systems) (Figure 7 and 8a). Dissipative beaches are associated with beach ridges with fine sediment input (sand) through a river influx (Figure 8b) and intermediate beaches are placed where medium sand reworked from old barrier islands (Pleistocenic deposits) and river sediment input occurs (Figure 8c). There is a relationship between nearshore slope and the types of exposed beach. Reflective beaches normally present steeper nearshore slope (1:40) than that intermediate and dissipative beaches (between 1:100 and 1:300).

Reflective Beaches Characteristics

The beaches of Itajuba, Taquarinhas, Taquaras, Estaleiro and Estaleirinho are classified as exposed reflective beaches (see Table 2). Principal beach characteristics observed at Taquarinhas during the study time are presented in Figure 9, as a representative example from exposed reflective beaches.

The general characteristics for all exposed reflective beaches during the study period were: backshore with one or two well developed berms; no frontal dunes; the width of the surfzone between 10 and 30 meters; the wave breaker type are surging (unbroken) and collapsing between 0.7 to 1 meters in height; wave periods between 7 and 8 seconds; swash zone slope between 7 and 10 degrees; spacing of beach cusps between 10 and 35 meters; beach step well developed and composed of coarse material (sand, rocks fragments and shells); beach scarp between 1.5 and 2 meters as a result of the storms actions; converging swash together with the beach cusps; swash zone with coarse to very coarse sand; nearshore zone with a slope between 1:20 and 1:40; average subaerial beach volume between 52 to 77 m^3/m, with a variation coefficient between 16 and 27%; average beach width between 29 and 37 meters, with variation coefficient between 14 and 25%; dimensionless fall velocity—Ω—parameter between 1.22 and 1.57; empirical dimensionless fall velocity between 0.67 and 2.19; and bar parameter between 2 and 17.

The exposed reflective sand beaches exhibited a large subaerial volume. Figure 9 shows the beach profile envelope and the subaerial volume and length change during the study time (*e.g.* Taquarinhas). It exhibits a cyclic change in volume and length. During storm period this beach presented a scarp and a terrace. No bars are presented due a greater nearshore slope (1:40). At Itajuba beach, nearshore slope was about 1: 300, much smaller than other beaches, but with the same morphodynamic and morphometric characteristics as the others reflective beaches discussed in this study (see Table 2). In this case the grain size is the most important parameter to define the reflective stage.

Intermediate Beaches Characteristics

Three beaches are classified as exposed intermediate beaches in the study area: Barra Velha, Brava and Ilhota Beaches (see Table 2). Figure 10 shows the principal characteristics observed at Barra Velha beach.

The beaches mentioned above presented similar characteristics during the study period. The backshore exhibited occasionally one well developed berm (mainly on Brava beach); well developed frontal dunes (Barra Velha); wide surf zone between 35 and 68 m; plunging and spilling breaker with height between 0.7 to 0.8 m and wave period of 7 to 8.5 seconds; longshore bar and trough system, rhythmic and transverse bars; swash zone with slope between 5 and 10 degrees; spacing of the beach cusps range from 10 to 30 m and megacusps from 140 to 200 m; strong rip currents with a similar spacing; swash zone composed by medium sand; nearshore slope between 1:100 and 1:250; average subaerial volume from 16 to 37 m^3/m with variation coefficient from 15 to 63%; average beach width between 14 and 25 m with variation coefficient from 22 to 33%; dimensionless fall velocity—Ω—

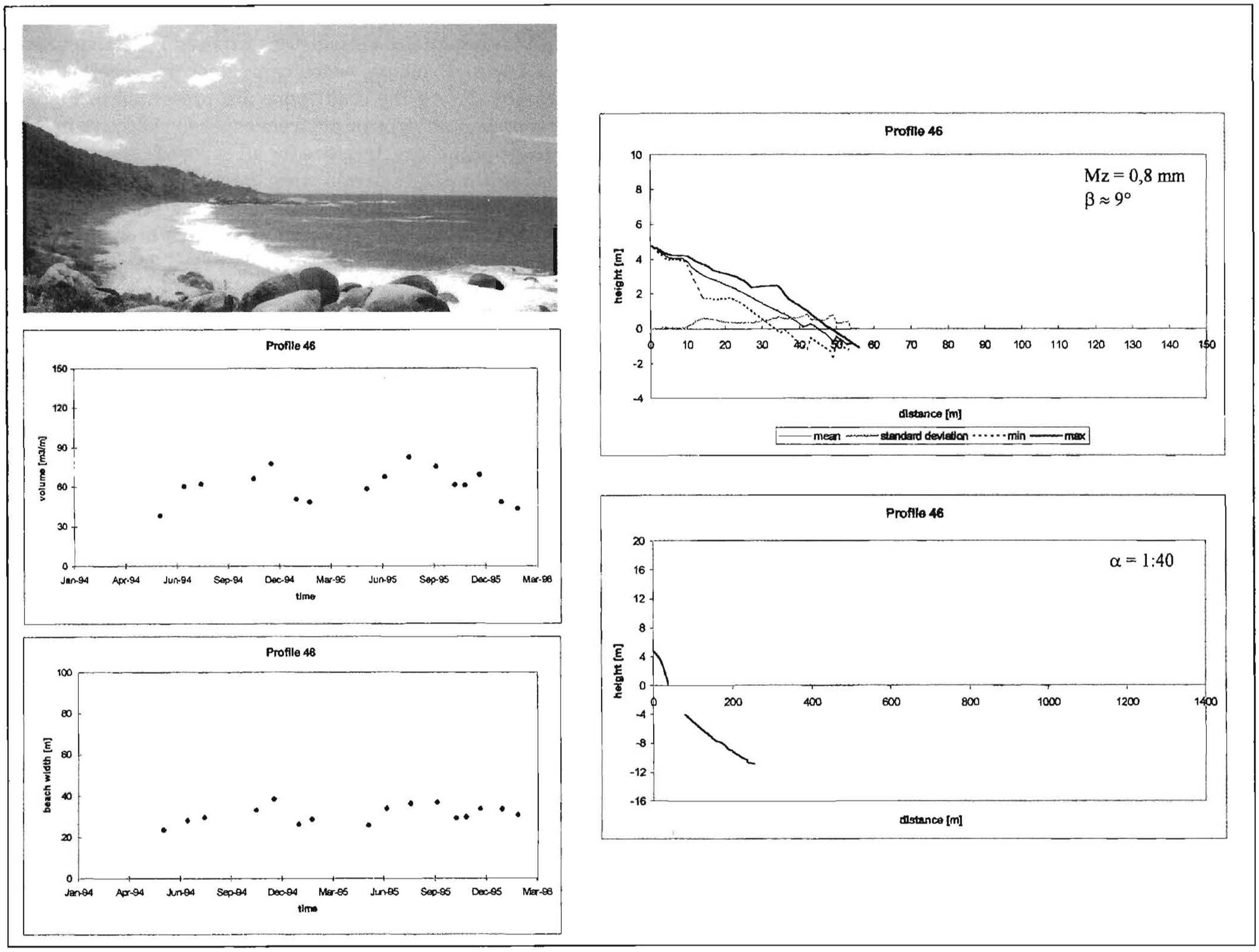


Figure 9. Principal beach characteristics observed at an exposed reflective beach during the study period (Taquarinhas beach). Note the narrow surf-swash zone.

between 2.04 and 2.83; empirical dimensionless fall velocity between 0.82 a 3.06; bar parameter change from 15 to 41.

The bar type varied according to the beach as possible to see in the aerial photographs obtained in November, 1995 (Figure 11). Barra Velha beach showed rhythmic and transverse bars. Brava beach had also longshore intercalated bars with a bar parameter less than 20 (Table 2). Ilhota beach exhibited intercalated bar parallel to the coast. This variation was due to different morphodynamic stages.

Normally, the intermediate beaches are composed of medium sand (0.30mm–0.45mm) with gentle nearshore slope (1: 100–1:200) (see Table 2). The coastal plain presents island bars (barrier beaches and island bar) system (Barra Velha and Brava).

Dissipative Beaches Characteristics

Navegantes and Mariscal are classified as exposed dissipative beaches. The sediment size at Navegantes beach is finer than that at Mariscal beach and the nearshore slope is lower (see Table 2). Figure 12 exhibits the major beach characteristics observed in a dissipative stage for Navegantes beach.

During the study period the following conditions were observed in dissipative beaches: very well developed frontal dunes (mainly Navegantes) with parallel scarp after storms; a surf zone width between 54 and 83 m; a plunging and spilling wave breaker; a wave height between 0.5 and 0.8 m and a period of 8 to 9 seconds; one bar (Mariscal) and multiple bar system (Navegantes with 2 bars); a beach face with an average slope of 3 degrees; spacing of the cusps between 15 and 24 m and megacusps between 165 and 300 m; stationary strong megarip currents; a beach face composed of fine sand (0.17 mm); a nearshore slop of 1:70 (Mariscal) and of 1:200 (Navegantes); an average subaerial beach between 26 and 39 m^3/m with a variation coefficient from 14 to 40%; an average beach width between 32 and 39 m with a variation coefficient

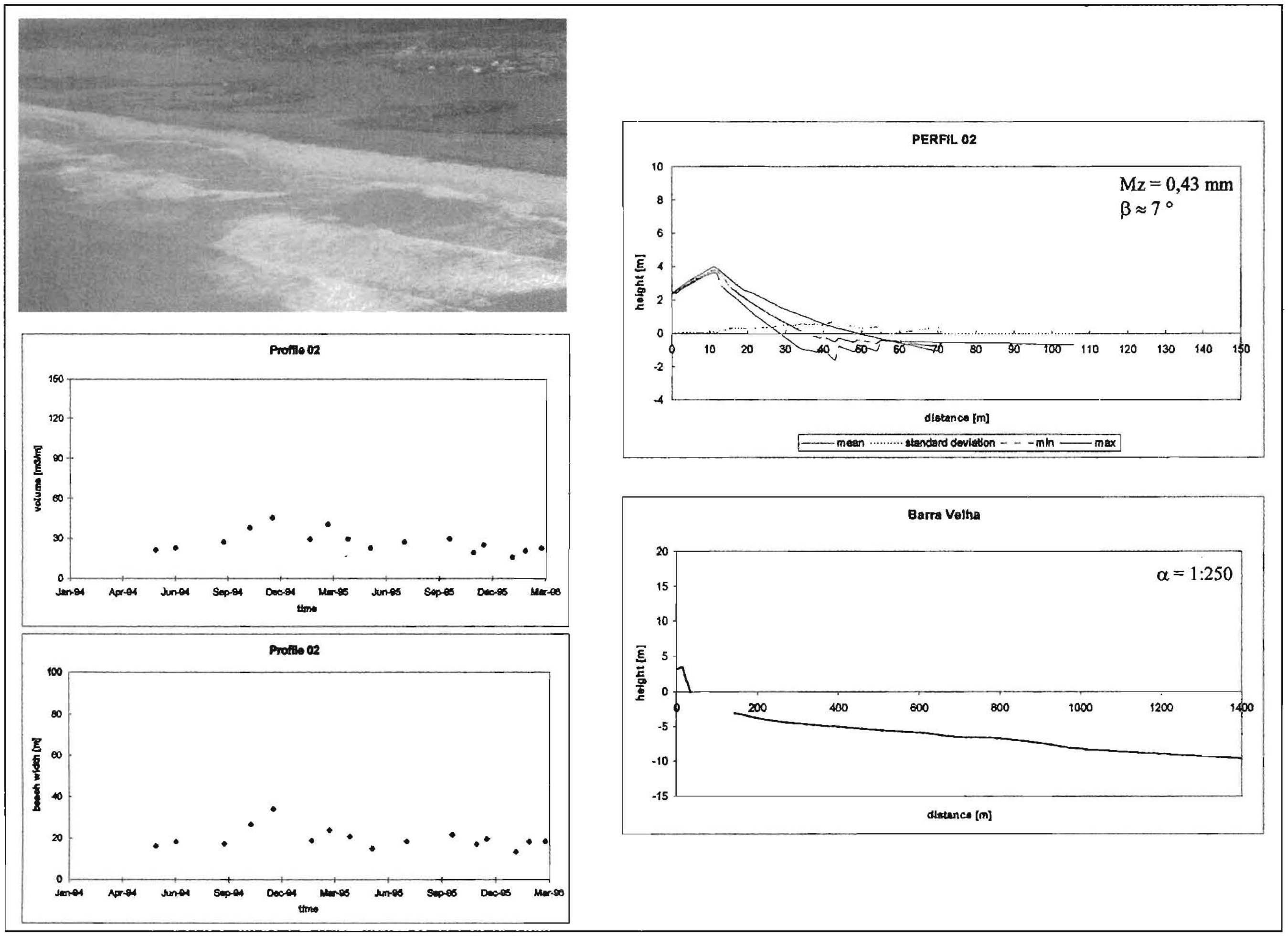


Figure 10. Principal beach characteristics observed at an intermediate beach during the study period (Barra Velha beach). Note the rhythmic shoreline (megacusps) and well developed rip channels.

from 10 to 24%; a dimensionless fall velocity between 4.23 and 7.68; a empirical dimensionless fall velocity between 15 and 21.5; and a bar parameter between 20 and 75.

The Navegantes beach presents a multiple-bar system, which can be observed in the aerial photo (Figure 13 and Table 2). This system is a response of gentle nearshore slope formed by Itajai river sediment supply during the Quaternary period (ABREU, 1998). This area is backed by a very well developed coastal plain (CARUSO and ARAUJO, 1999) comprising Holocene foredune ridges. The alongshore variation in the bar form is a function of longshore ranges in nearshore slope and consequently wave breaker (see Figure 1).

Semi-exposed Beaches

The beaches partially exposed to southerly waves are: Piçarras, Balneário Camboriú, Itapema (see Table 2 and Figures 14, 15 and 16) and Bombas. They have Northwest–Southeast orientation (see Figure 1). Additionally, the Tijucas mud flat is introduced in this analysis to figure assess the influence of the sediment source (river input) in the coastal type.

When indentation ratio and wave obliquity are large a beach may be termed as parabolic beach (*eg.* Picarras and Bombas) or bay beach (*eg.* Balneario Camboriu and Itapema). The third case, with larger indentation ratio and fine sediment input (Tijucas bay), result in a tidal mud flat plan.

The semi-exposed beaches exhibit similar characteristics (see Table 2). Their plan form is a result of the distance between headlands and wave obliquity (SILVESTER and HSU, 1997). Generally there is an alonghore morphological variation (see Figure 14 to 16), that is a result from longhore variation in beach dynamics. The northern part of the beaches bay are more exposed (*e.g* profiles 7, 8 and 9—Picarras and 24, 25, 26, 27 and 29—Balneario Camboriu— Figures 14 and 16) while southern part of the bays are increasingly sheltered (profiles 11, 12 to Picarras and 37, 38, 39 to Balneario Camboriu). The plots of volume change also show that beach dy-

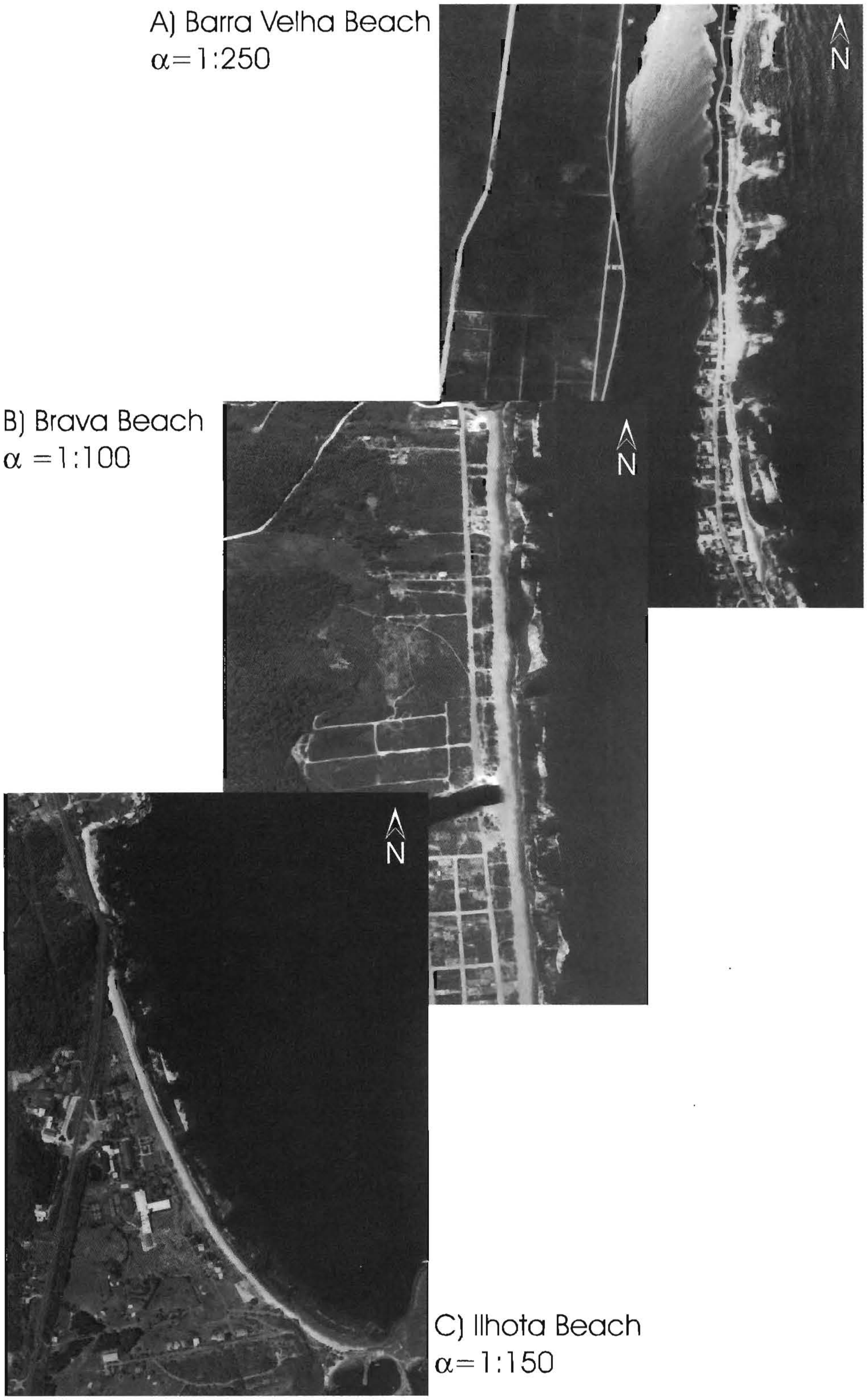


Figure 11. Intermediate beaches with different types of bar system at: (a) Barra Velha beach; (b) Brava beach and (c) Ilhota beach (original scale 1: 12,500).

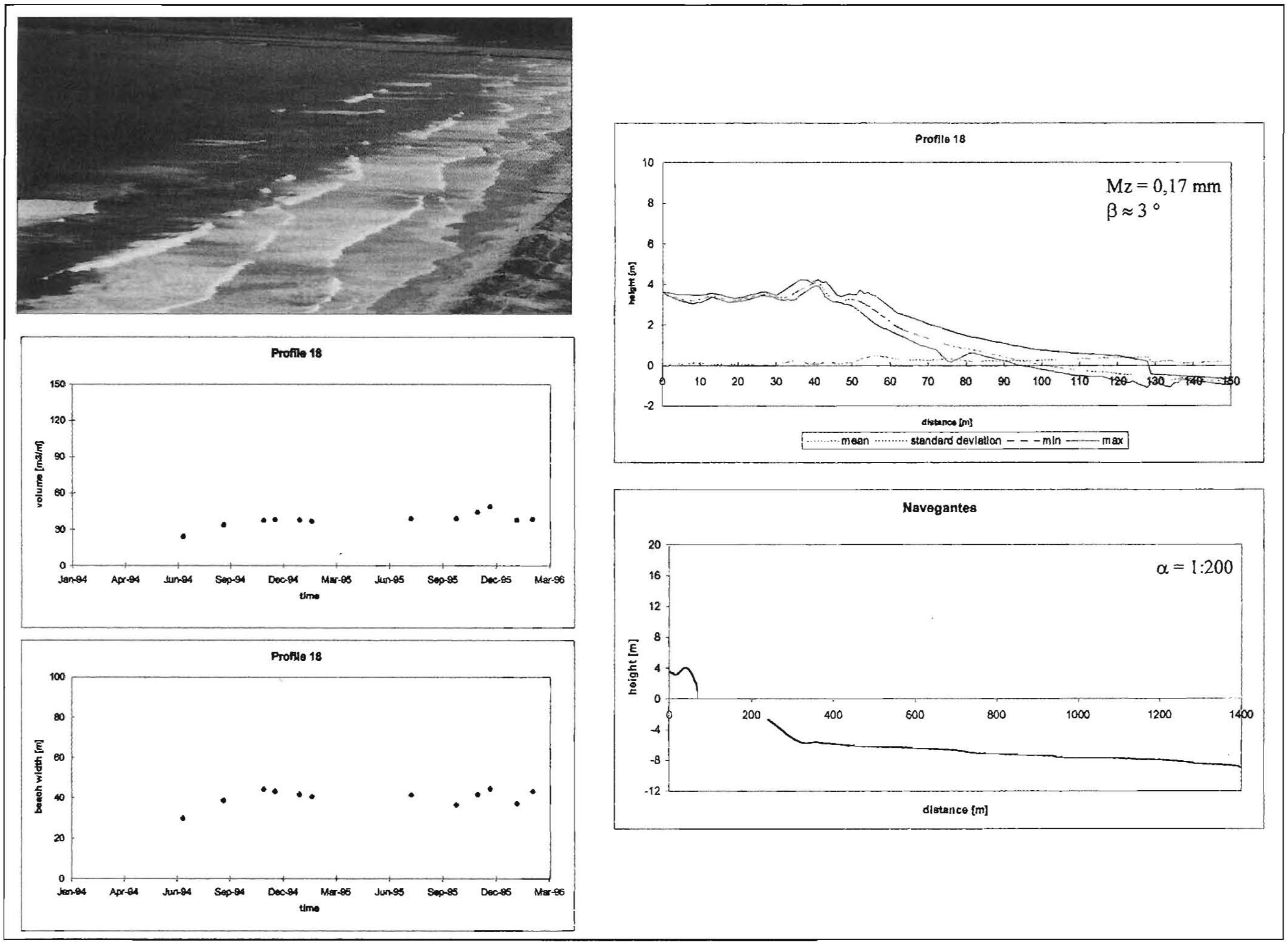


Figure 12. Principal beach characteristics observed at a dissipative beach, during the study period (Navegantes beach). Note the wide low slope surf zone and tow bars.

namics diminishes to the south in response to the lower waves. A large diffraction zone behind the southern headlands occurs. HOEFEL *et al.* (1999) and TEMME *et al.* (1997) present similar results for Picarras and Balneario Camboriu beaches, respectively. REA and KOMAR (1975) and LEBLOND (1979) confirmed the important role of refraction and diffraction in the determination of the shape of embayed beaches with a numerical models.

In Itapema the beach morphology and volume variation is relatively larger in the central area due to the presence of two diffraction areas at both ends of the beach (Figure 16). However, the variations in this parameters at Itapema beach are smaller than other semi-exposed beaches.

Wave energy is low in the diffraction zone behind the southern headland, where the wave action is mild, therefore the relative tidal range (RTR) should be larger (Figure 17). The larger the relative tidal range is, the more important tidal effects become in respect to wave effects. The concept of a relative rather than absolute tidal range provides an effective scaling for the mutual effects of waves and tides (HAYES, 1979; DAVIES and HAYES, 1984; MASSELINK, 1993; MASSELINK and TURNER, 1999). The morphodynamics of a microtidal sheltered zones, in an estuarine and bay beach, can be in many aspects similar to that of a macrotidal beach (MASSELINK and TURNER, 1999), since the difference in tidal range is compensated by the variation in wave-energy (NORDSTROM and JACKSON, 1990; SHORT, *per. com.*). In this type of area the relationships between wave obliquity, indentation ratio, grain size distribution (source) and relative tidal range are very important for the three-dimensional beach morphodynamic and profile sequence.

For a bay with large indentation ratio and fine sediment a flat beach develops near the headlands, occasionally sand with mud co-exists in this zone (swash zone and nearshore), due to milder waves and sediment input from a river particularly (*e.g.* Balneário Camboriú beach). In this case, the sheltered zone must be classified as a mixed energy enviroment (HAYES, 1979) and the length and volume of the beach change from

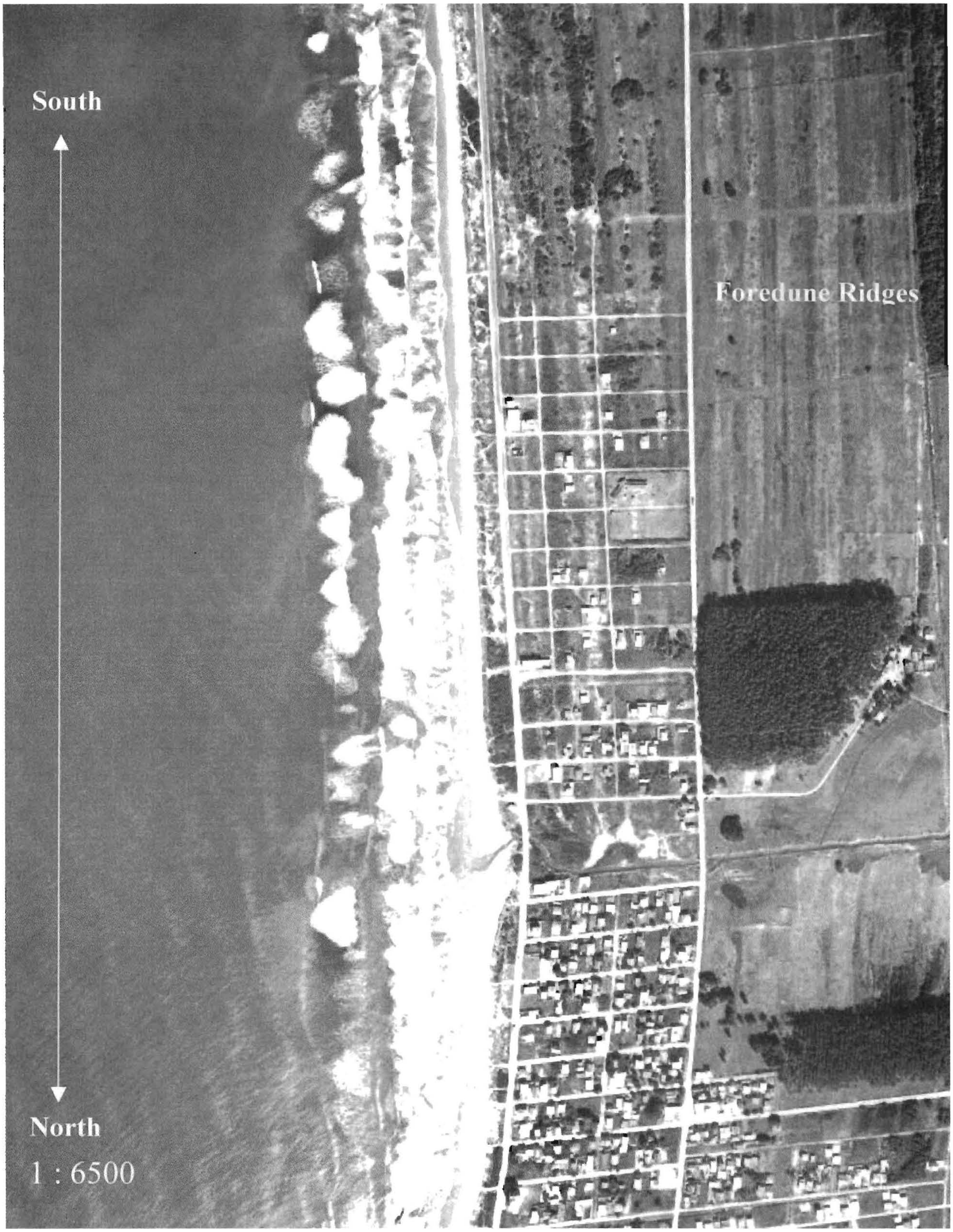


Figure 13. Multiple bars system at Navegantes beach (Original scale 1:12,500). Note the foredune ridge system on the coastal plain.

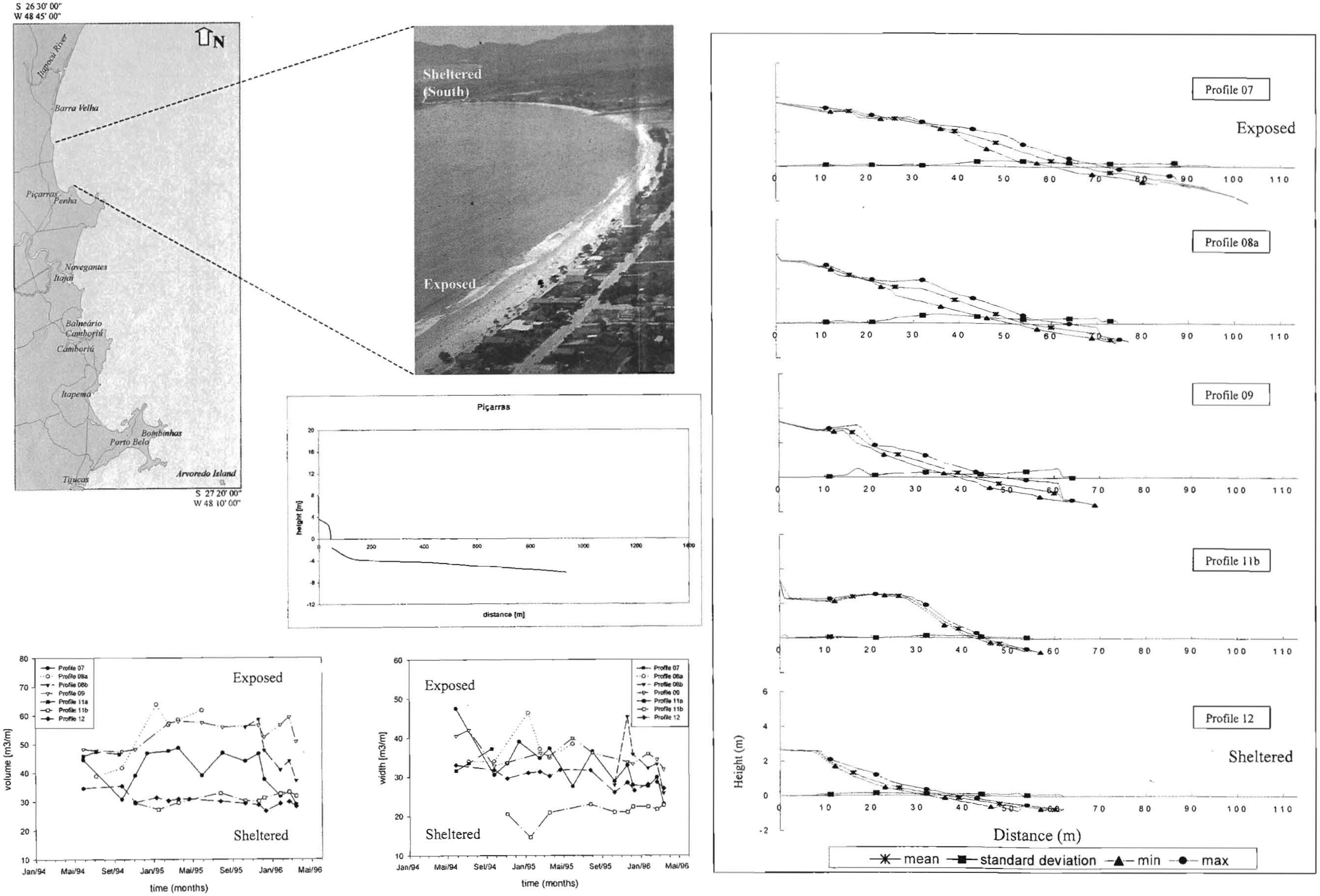


Figure 14. Principal beach characteristics observed in a semi-exposed/parabolic beach stage, reflective to dissipative, during the study period (Piçarras beach).

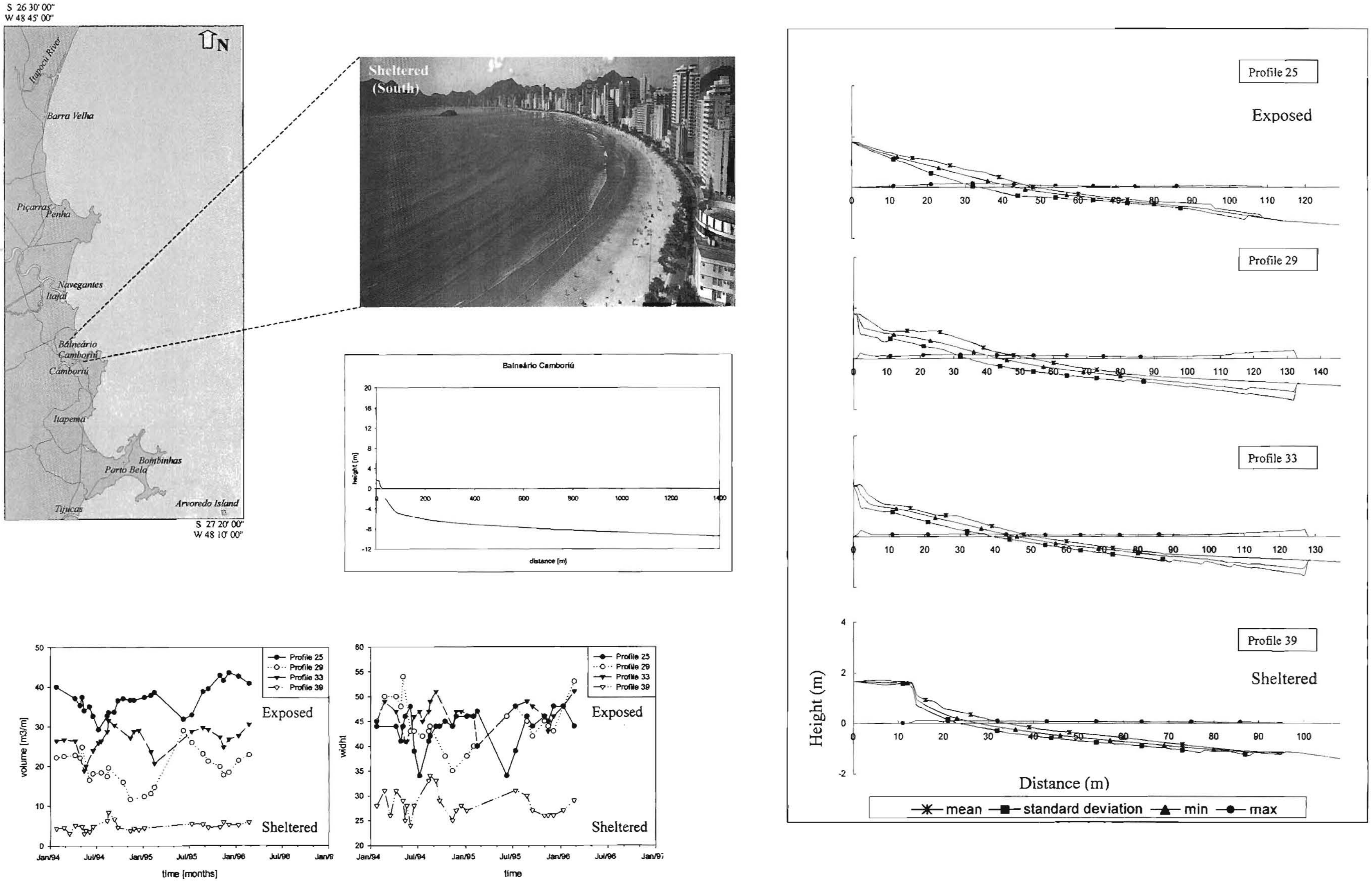


Figure 15. Principal beach characteristics observed in a semi-exposed/bay beach stage, dissipative, during the study period (Balneario Camboriu). Picture looking south.

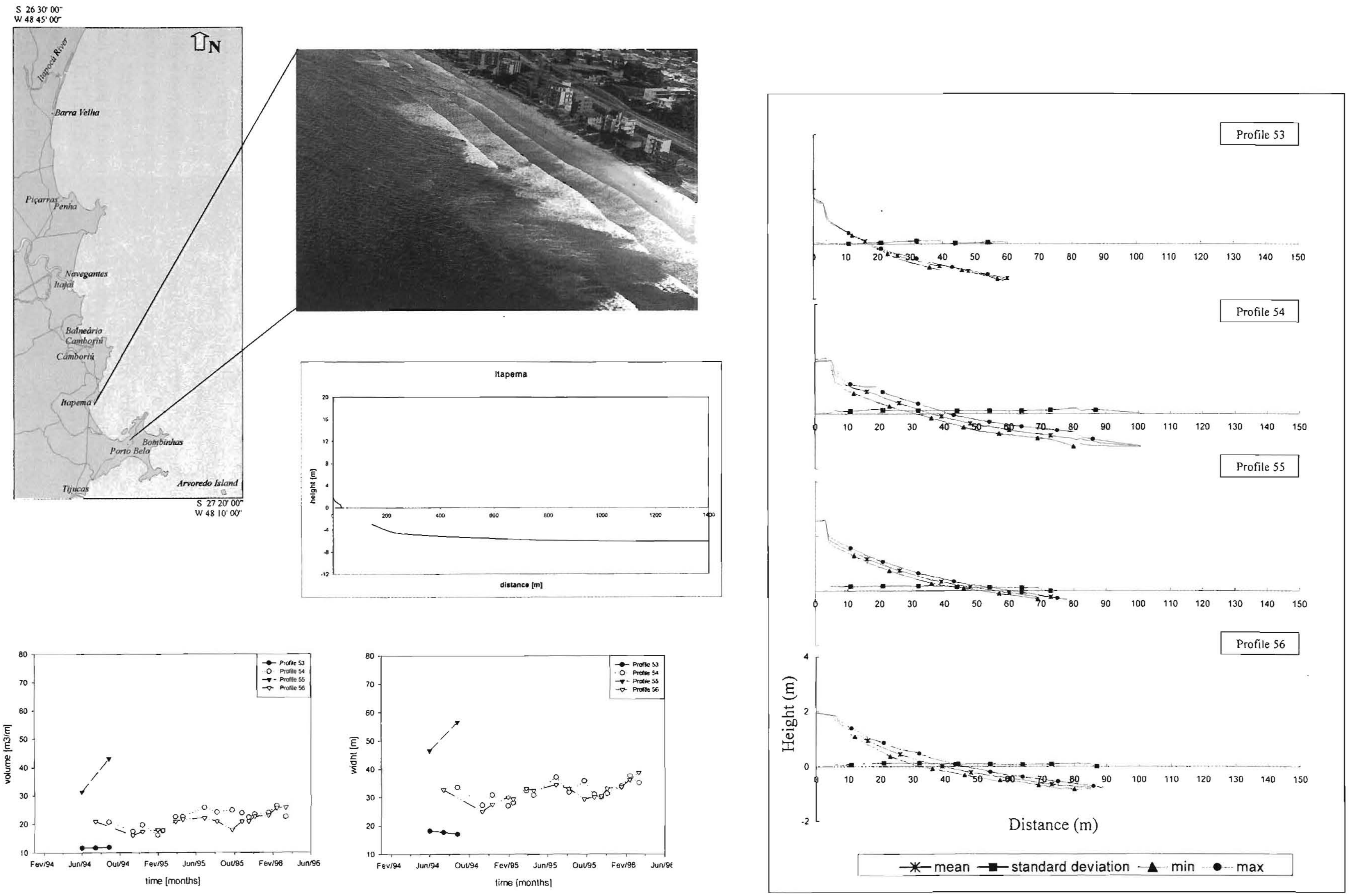


Figure 16. Principal beach characteristics observed in a semi-exposed/bay beach stage, during the study period (Itapema beach).

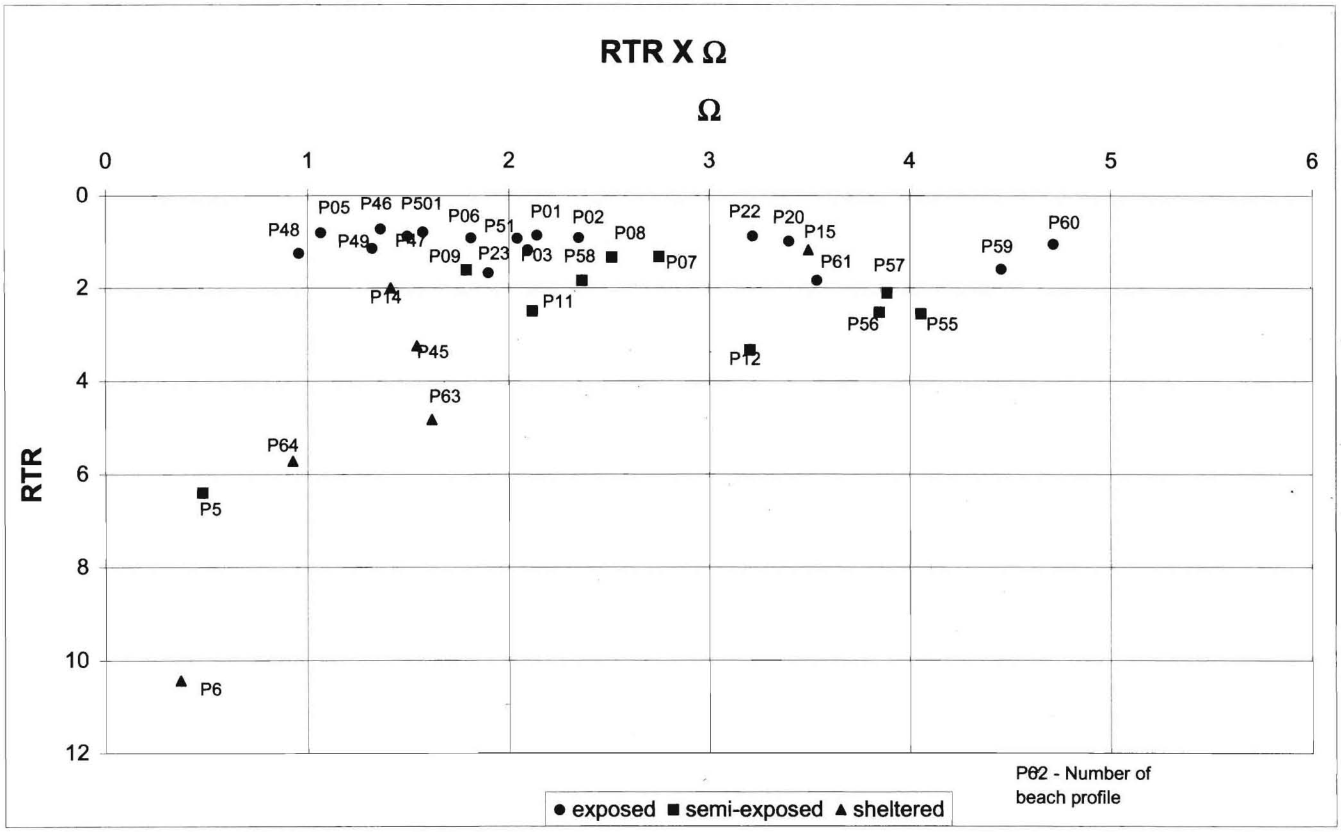


Figure 17. Parameter Ω versus relative tidal range for beaches during study period.

sheltered to exposed zone (see Figure 14 to 16). With wave increases, more sediment in the form of berm or bar takes place. Frontal dunes can also be developed in order to dissipate the wave energy during extreme events (beach buffer system).

Embayments can range from tidal flats to high-energy beaches depending on the level of the waves versus tidal energy (SHORT, *per. com.*). An extreme example in the study area is given at the river mouth in Tijucas Bay (Figure 18). The combination of fine sediment input (mud) from Tijucas River, low wave energy (sheltered zone) and gentle nearshore slope (1:400) results in a subaerial beach (ridge) with coarse sediment (*chenier* deposits), deposited during periods of high energy (CARUSO and ARAUJO, 1997; SCHETTINI and KLEIN, 1997). Also present is a tidal flat with mud ridges in the intertidal and supratidal zone. The resultant coastal plain is composed of *cheniers* complex (CARUSO and ARAUJO, 1997). For the other semi-exposed beaches, the coastal plains are composed of Quaternary beach ridges (Balneario Camboriu and Itapema) due to the sea level change during the Quaternary period (CARUSO and ARAUJO, 1997; CARUSO *et al.*, 1997; CARUSO and ARAUJO, 1999) and sediment input from rivers.

The principal beach characteristics in semi-exposed beaches observed during the study period were: backshore area with one berm (exposed zone); surf zone width between 5 and 110 m (sheltered to exposed zone); plunging and spilling wave breaker type; wave breaker height between 0.1 and 0.5 m and period between 6 and 8 seconds; beach face slope between 3 and 5 degrees; length of beach cusps range from 10 to 28 m; rip currents presented on the exposed zone; grain size range between fine and coarse sand; nearshore slope range from 1:35 (Bombas) to 1:550 (Itapema); average subaerial volume between 20 and 36 m^3/m with deviation of 9% to 23%; average beach width between 17 and 40 m with deviation of the 8% and 32%; dimensionless fall velocity between—Ω—2.4 and 10; empirical dimensionless fall velocity between 3.8 and 38; bar number parameter between 3 and 19; and relative tidal range between 1.66 (exposed) and 3.32 (sheltered area) (see Figures 14, 15 and 16).

The morphodynamic stage of the semi-exposed beaches therefore ranges from dissipative/low tide terrace to reflective. Picarras beach shows reflective modal stage (convex to linear beach profile with medium sand) in the north area (exposed) and dissipative/low tide terrace (concave and flat beaches profile with fine sand) in the south area (sheltered). Balneário Camboriú and Itapema Beaches exhibit dissipative or low tide terrace morphodynamic stage, mainly in the summer, with a barless beach profile varying from concave to linear. During lower low tide period a small seepage face occurs mainly on foreshore zone from Balneario Camboriu beach. In this beach during the summer time a ridge and runnel system in low swash zone (low tide) and rip currents occurs (HOEFEL and KLEIN, 1998).

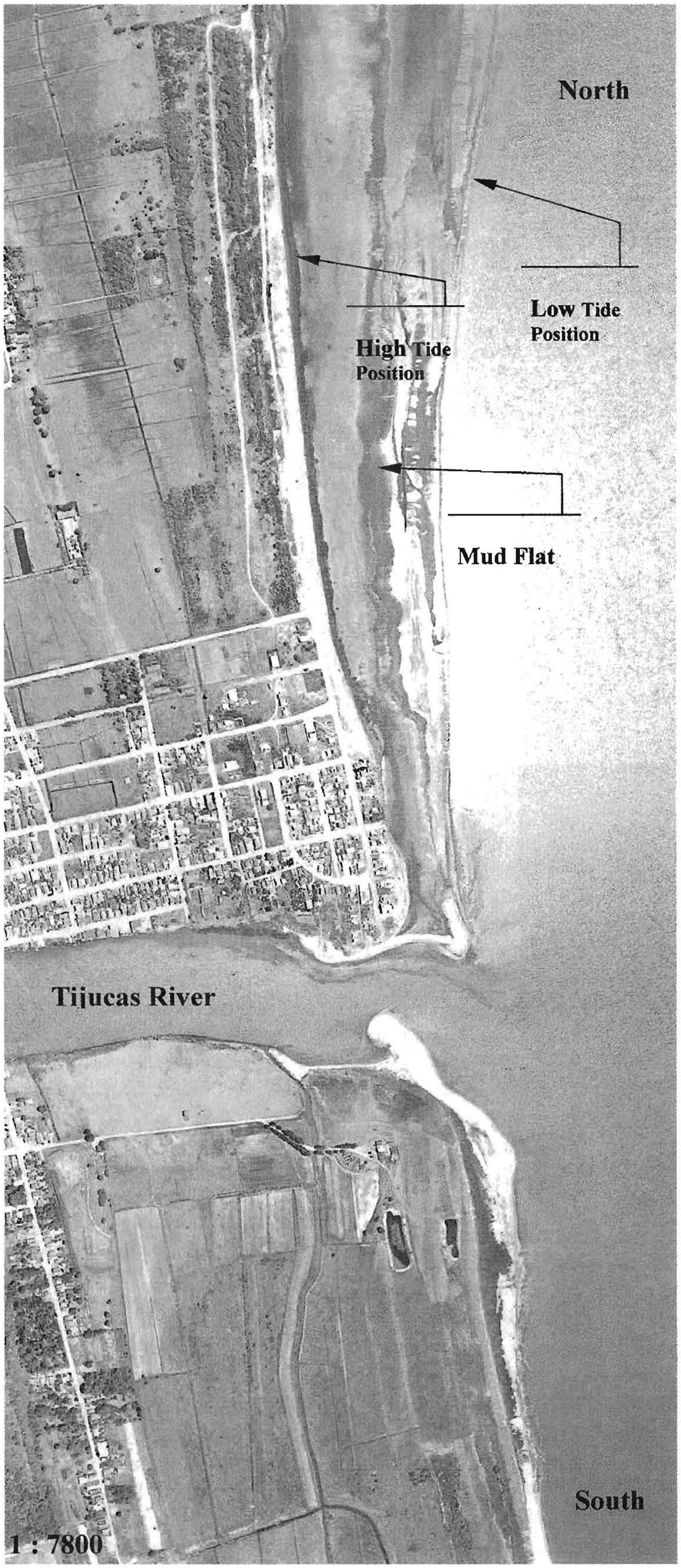


Figure 18. The tidal flat and mud ridge at the river mouth in Tijucas Bay.

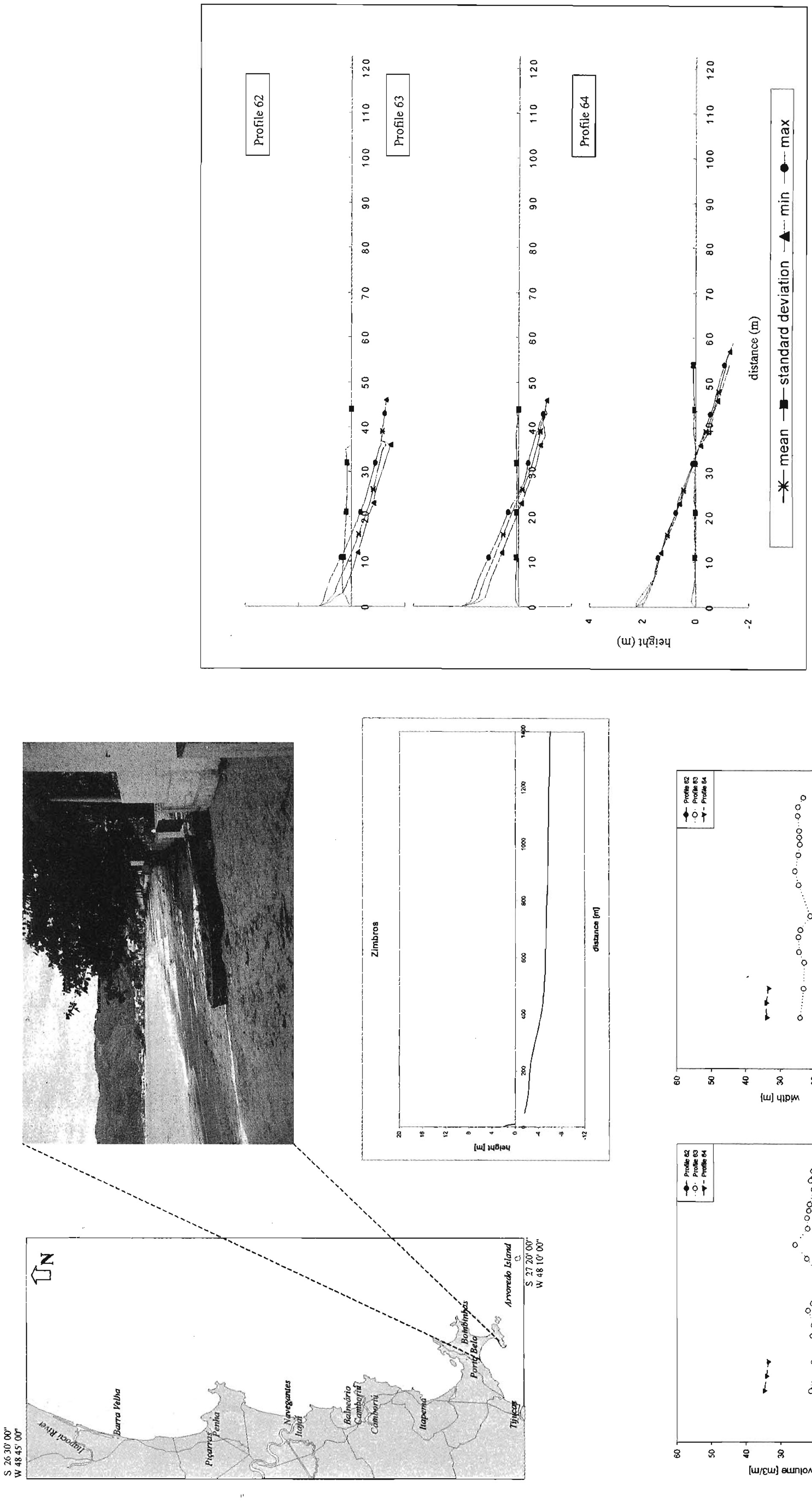


Figure 19. Principal beach characteristics observed in a sheltered beach stage, during the study period (Zimbros beach).

Table 3. *General morphodynamic characteristics of headland bay beaches.*

Characteristics	Exposed Reflective	Exposed Intermediary	Exposed Dissipative	Semi-exposed	Sheltered
Relative Tidal Range (RTR)	0.9	1	1.2	2.25	3.9
Wave break height (H_b) [m]	0.9	0.8	0.7	0.4	0.3
Wave period (T) [s]	7.6	7.7	8.5	7	5.8
Approximate Surf Zone Width [m]	10–30	35–68	54–83	5–110	5–15
Wave breaking type	Collapsing/ Surging	Plunging/Spilling	Spilling Plunging	Spilling Plunging	Spilling Plunging Surging
Rip currents	Present	Strong	Strong and stationary	Presents (change)	Absent
Bars	Absent	1	1 to 3	Absent (change)	Absent
Beach slope (β) [°]	7–10	5–10	3	3–5	3–4
Inner Shelf Slope/Nearshore Slope (α)	1:88	1:166	1:135	1:255	1:183
Beach form	Convex to Linear	Convex to Linear	Concave to Linear	Change	Change
Cusps length [m]	15–30	10–30	14–24	10–28	10
Megacusps length [m]	Absent	140–200	165–300	Absent	Absent
Foreshore grain size	Coarse sand	Medium sand	Fine Sand	Fine to coarse sand	Fine to coarse sand
Ws (cm/s)	12	6	2	2.73	5
Frontal Dunes	Absent	Presents	Presents	Absent (change)	Absent (change)
Omega parameter (Ω)	0.60	2.4	6	4.79	1.8
Empirical Omega (Ω_t)	1.3	2.2	18.3	19.2	5.4
Average mobile beach length (L) [m]	32	21	36	28	27
Standard deviation from average mobile beach length (σL) [m]	3	6	5	10	5
Average mobile subaerial beach volume (v) [m_3/m]	60	26	29	29	26
Standard deviation from average mobile subaerial beach volume (σv) [m_3/m]	10	11	8	8	9

Sheltered Beaches

Armação, Laranjeiras and Zimbros beaches are classified as sheltered beaches. They have west–east orientation (see Figure 1). The volume changes in these beaches are very small when compared with expose and semi-exposed beaches (Figure 19). This happens as a result of constant wave climate in this type of beaches. Similar results for Santa Catarina Island area are presented by DIEHL (1998).

The sheltered beaches during the study period had the following beach characteristics: surf zone width between 5 and 15 m; plunging and spilling wave breakers; wave breaker height between 0.1 and 0.5 m and period of 3.5 and 8 seconds; beach face slope range from 3 and 4 degrees; 10 m beach cusps length; grain size range from fine to coarse sand; nearshore slope range from 1:50 and 1:400; average beach volume between 18 and 36 m^3/m with deviation between 6% and 21%; average beach length between 22 and 32 meters with deviation from 4% and 15%; dimensionless fall velocity between 1.44 and 2.45; empirical dimensionless fall velocity between 3.83 and 7.43; number bar parameter from 5 to 10; and relative tidal range between 1.59 and 6.98.

The larger the relative tide range has, the more important became for tidal effects relative to wave effects or water level change (see Figure 18). The morphodynamics of microtidal estuarine/sheltered beaches are in many aspects similar to that on macrotidal beaches (MASSELINK and TURNER, 1999), since the difference in tidal range is compensated by the variation in wave-energy (NORDSTROM and JACKSON, 1990; MAKASKE and AUGUSTINUS, 1998). The shorter wave periods detected at Zimbros beach were a result from its geographical position. Generally, the waves were generated by local winds. This beaches can be only classified in relation its morphology (profile shape). HEGGE *et al.* (1996) proposed seven (7) different morphology for sheltered beaches in Australia coast. They and FUCELLA and DOLAN (1996) suggested a relation between concave profile and dissipative conditions and convex profile and reflective beach type. But the results presented here showed that it is difficult to include sheltered beaches in the morphodynamic classification proposed by WRIGHT and SHORT (1983) and SHORT (1999) using the dynamic approach (see Omega in the Table 2). These types of beaches are in the low limit between wave and tidal dominated environments and a small change in the wave height results in a modification from the wave to tidal domain or vice-versa and also in the Omega parameter (SHORT, *per. com.*). For this type of beach, the source of sediment and consequently grains size, define the beach shape and slope (concave or convex). In direction to a more universal classification will be necessary introduces the shape of beach in the parameters. The results shows that for sheltered beaches the empirical Omega are more realistic (see Table 2 and Figure 6 to compare). In this case the surf scaling parameter should give a better morphodynamic beach classification, because it is a descriptive equation of the state of the waves and beach gradient (SHORT, 1999). A non-dimensional parameter to define the morphology should also be introduced to compare the wave and tidal environment beaches at the same scale (ELIOT, *per. com.*).

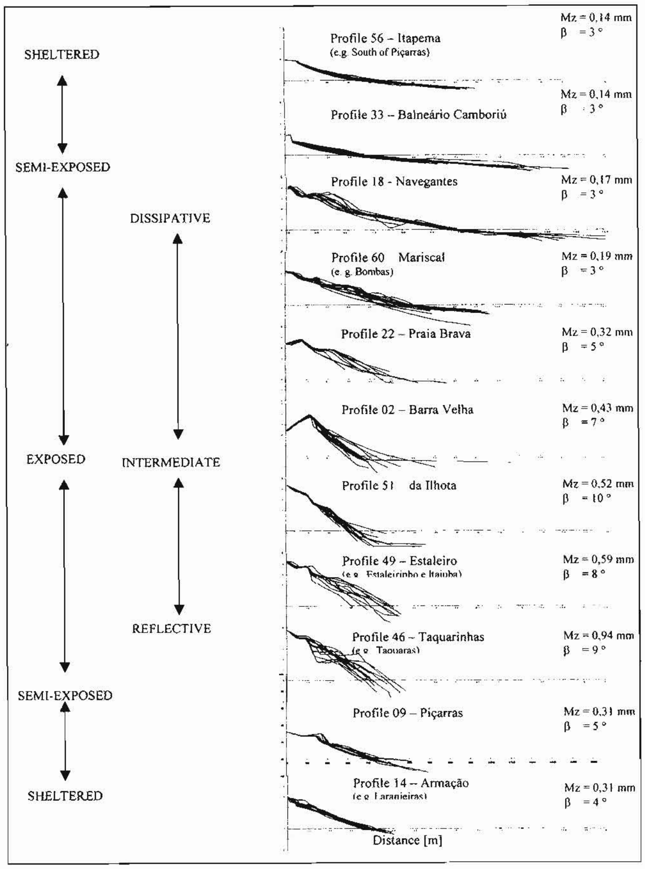


Figure 20. The model sequence of beach profiles and types of beach for headland bay morphology, in east coast east coast swell environmental, showing examples of beaches from central north of Santa Catarina State, Brazil.

BEACH PROFILE SEQUENCE MODEL

Based on the descriptions for the three major types of beach state, the average values for each beach parameters can be summarised. This is presented in Table 3 and Figure 20. Table 3 provides the general morphodynamic and morphometric characteristics of the headland bay beaches in microtidal-east coast swell environment with a wide shelf. Figure 20 shows a model sequence of beach profiles or alonghore morphology variation and the types of beach associated with headland bay beaches with east-coast swell environment. Beach type and mobility is a function of distance between headlands, shape of bay, wave exposure, grain size (source), nearshore slope and relative tidal range.

Two types of reflective beaches can be observed. In exposed areas, they have large quantity of subaerial sediment and high mobility, due to the change in wave climate and consequent beach erosion and accretion. During storm events, scarps forms to 2 m height and the sediment deposits in the form of a terrace, because the nearshore beach slope is too steep to form bar systems (1:20 to 1:40). A bar system occurs only occasionally on Itajuba beach (nearshore slope 1:300). These reflective beaches exhibit a convex to linear profile with one or two berms composed of coarse sand. Normally, steep slope with coarse sediments and well-developed beach cusps are present.

The reflective beaches in semi-protect and sheltered beaches are stable as described by SHORT (1979) and SHORT (1999), as the wave climate range is smaller in the shadow zone (result of diffraction zone and more interaction with gentle slope). The beaches have medium to coarse sand, and exhibit convex to linear profile, with less sediment volume. Frontal dunes are not present.

Intermediate conditions are more frequent on exposed beaches with medium sand. They contain only one nearshore bar that can be longitudinal, transverse or rhythmic, and the mobile subaerial volume and its changes are less than on the reflective beaches because the wave energy is dissipated mainly on the bar (beach buffer system). After breaking at the bar, waves reform and breaks again in the swash zone with less energy. Strong rip currents occur and these are responsible for local rip embayment erosion as reported by SHORT (1999). The beach profile is linear and with short to well developed frontal dunes formed mainly by overwash processes, *e.g.* Barra Velha (KLEIN *et al.*, 1999).

The dissipative beaches occur in the three types of exposition. In exposed areas, they are well developed, composed by fine to very fine sand, with two (2) or more bars and well-developed frontal dune. The surf zone is up to hundreds meters wide. During storm parallel scarps in the dunes can be developed as described by SHORT (1999). The beach profile is linear and the subaerial volume change is small. In the semi-exposed areas no bars in the surf zone are present and the profile is from concave to linear with fine sand composition, whilst a low tide terrace with small swash bar in the low tide position can happen during the summer. Rip currents are present in the exposed zone. Normally, the swash zone present backwash ripple morphology similar exposed dissipative beaches. Theses characteristics are representative of an ultradissipative beach, but in minor scale of size than tidal dominated beach classification proposed by SHORT and MASSELINK (1999), SHORT (*per. com.*).

In sheltered areas, beaches are composed by fine to very fine sand and the profile are concave, with narrow beaches and the nearshore zones are composed of very fine sand with mud. Normally, the nearshore slope is smaller than in reflective conditions.

The final type of profile not presented in the model, is a intertidal zone with mud bars with subaerial coarse deposits, which is a result of the combination of fine sediment input (river), very slow nearshore slope and sheltered conditions.

CONCLUSIONS

Beach morphodynamics in a microtidal environment with headland bay geomorphology can be classified with the morphodynamic and morphometric parameters highlighted in Figure 21. They are a function of: 1) Geological inheritance (distance between headland and orientation; nearshore and inner shelf morphology; coastal plain morphology; sediment source); and 2) Hydrodynamic factors (Hb, T, oceanic wave exposition and relative tidal range).

For a coast with headland bay, the alongshore range in

Beach morphodynamics in a microtidal environment with headland bay geomorphology.

Geological inheritance

- headland presence (distance between headland and orientation)
- bay filling (to headland line)
- nearshore and inner shelf morphology
- coastal plain morphology
- sediment source (river, embasement, nearhore zone, old deposits)

Hydrodynamic factors

- shoaling, refraction, diffraction and stress (interaction with nearshore morphology and headlands)
- Hb, T (oceanic wave exposition)
- relative tidal range

Exposed beach

The identation ratio is small and wave are aproximately with a angle < 40°

- reflective:coarse sand and greater nearhore slope with very narrow coastal plain . More steeper and without berm near the headland and with one or two berms far the headland occurs. (eg. Estaleiro toTaquaras)
- intermediate beach with one bar: medium sand and medium nearshore slope. Coastal plain developed with island bars (e.g. Barra Velha and Brava).
- Dissipative beaches:fine sand and nearshore morphology very gently. Presence of two or more bars. Coastal plain very well developed with beach ridges. (e.g Navegantes)

The beach three dimensionality is a function of Longshore variation in grain size and wave break height.

Semi-exposed beaches

The identation ratio is large and the wave aproximately with a angle > 40°

There is a three dimensional beach morphodynamic. It is a function of wave break and grain size and relative tidal range. When $H_b >> H_o$, in difraction zone is possible reflective conditions (coarse grain) or dissipative to mud flat conditions (fine grains). Normally in the central position ($H_b = H_o$) The beach is dissipative non barred system or low tide terrace (fine sand). With medium sand is reflective.

When the identation ratio is big and there is fine sediment input is possible beaches with mud bar (RTR is bigger) (eg. Tijucas). In this case the coastal plain is composed by chennier.

Sheltered beaches

Is influenced only by diffracted waves or local waves. Normally the wave aproximately with angle > 50°. RTR is big.

-reflective: coarse and medium sand

-dissipative non barred or low tide terrace with sand flat (fine sediment).

Figure 21. Beach morphodynamic parameters for beach classification in a microtidal environment with headland bay geomorphology, based on geological inheritance and hydrodynamic factors.

beach geomorphology is a function of headland distance, shape of bay, wave obliquity, indentation ratio, grain size distribution and nearshore slope. Both models presented by SHORT (1999, pg.8) and CARTER (1988, pg. 214) are possible dependant on geological inheritance and hydrodynamic characteristics of the study area.

The beaches are classified as: (1) exposed, (2) semi-exposed or (3) sheltered. In the exposed beach, the indentation ratio is small and waves approximate parallel to the coast. They can be divided into three types. First, (a) reflective beach, occurs with coarse sand and steep nearshore slope with very narrow coastal plain. Steep backshore without berm near the headland or with one or two berms far the headland can also occur (Estaleiro to Taquaras). This type of beach is present when the bedrock is exposed at the coast.

Secondy (b) intermediate beach have one bar with medium sand and medium nearshore slope. Coastal plain developed with island bars (Barra Velha and Brava). And, thirdly, (c) dissipative beaches have fine sand and gentle nearshore morphology with the presence of two or more bars. Coastal plain is very well developed with foredune ridges (Navegantes). The three dimensionality in these beaches is a function of longshore variation in grain size and wave breaker height.

In semi-exposed beaches the indentation ratio is longer and the wave obliquity is usually greater than 40°. A three-dimensional beach morphodynamics is presented and it is a function of wave breaker height and grain size and relative tidal range. When $H_b \ll H_o$, the diffraction zone may be in reflective condition with coarse grain or dissipative/low tide terrace to sand-mud flat condition with fine grains. Normally, in the central position ($H_b \geq H_o$) the beach is dissipative without bar or low tidal terrace (fine sand), but reflective with medium sand. When the indentation ratio is larger and with fine sediment input from river, beach and mud flat with mud ridges (RTR is larger—*eg.* Tijucas) are possible. In this case, the coastal plain is composed by *chenier* systems.

Only diffracted waves or locally-generated waves influence sheltered beaches. Normally, waves approach the beach with angle greater than 50°. RTR is larger (>2). Again, they can be divided into: (a) reflective mode with medium to coarse sand with convex to linear profileand (b) dissipative mode non-barred or low tide terrace (fine sediment) with concave to linear profile.

The present sequential beach profile model is a first approximation. Studies in other areas with the same geographical characteristics are necessary to provide more information and the model validation. The present model can be applied to define the type of coastline uses and when combined with the parabolic model from SILVESTER and HSU (1997), it can be used to make better nourishment and coastline designs projects in this type of coastline.

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