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Shoreline Salients and Tombolos on the Santa Catarina coast (Brazil): description and analysis of the morphological relationships

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ABSTRACT

Shoreline salients are low triangular landforms, which project seaward as promontories. The term tombolo is applied when this landform is joined to an island or obstacle. This work presents a literature review of salients and tombolos, with a classification of singular landforms, and discusses the relationships between morphological parameters. It also analyses the planform of these features (sigmoid model and parabolic model) on the coast of the State of Santa Catarina in the south of Brazil. Interpretation of aerial photographs and topographical maps enabled the identification of 15 tombolos and 10 salients. The observed proportions and the symmetry of these landforms are directly related to the geological conditions and predominant wave direction. For salience data, regressions between X/B and B/S presented an R^2 of 0.79. Regressions between the obstacle depth (d) and the average length of incident waves were obtained, and the results (B*d / (L2) ~ S*d / (L2)) exhibited high R^2 values (0.83 and 0.80) for salients and tombolos for data in the literature. The parabolic model was found to be suitable in the analysis of the planform shape of the feature as this model incorporates geometric and dynamic (wave direction) variables.

ADDITIONALINDEXWORDS: *Coastline, Parabolic model, Brazilian beaches*

INTRODUCTION

Shoreline salients are low triangular landforms, which are projected seaward as promontories. The term tombolo is applied when this landform is joined to an island or obstacle (VAN RIJN, 1998). These natural or artificial structures are responsible for modifying waves, across the wave diffraction and refraction.

Over the last few decades, various authors have devoted themselves to a better understanding of the processes acting on, and determining the type of feature formed, with the objective of applying these to the measurement of rigid structures (e.g. offshore breakwater) as a form of beach protection or recovery. In addition to these applications, rigid structures have been used for the last few years as alternative sources of income and leisure, as fishing reefs or artificial reefs for surfing (BLACK and ANDREWS, in press).

This work presents a literature review on salients and tombolos and the identification of these singular landforms, and discusses the relationships between morphological parameters, as well as the application of the planform models (sigmoid and parabolic) on the coast of the State of Santa Catarina, southern Brazil.

ENVIRONMENTAL SETTING

The study area covers the coastline of Santa Catarina between Laguna (28°29´S and 48°45´W) and Itapoá (26°05´S and 48°40´W) (Figure 1). The local waves are of short periods (4 to 7 s) with an average height of between 0.5 to 1 m from E to NE, while the most energetic swell waves are generally of long periods (9 to 15 s) with an average height of 1 to 2 m, coming from a S to SE direction (ALVES, 1996). The local tide is micro-tidal, with a mean range of around 0.8 m and a maximum tide of 1.2 m. The meteorological influence of the sea level is very important, as storm surges can raise it to around one meter above the astronomical tide (TRUCOLO, 1998).

The study area is divided into three sectors. Sector 1, extending from the southern extremity of Santa Catarina

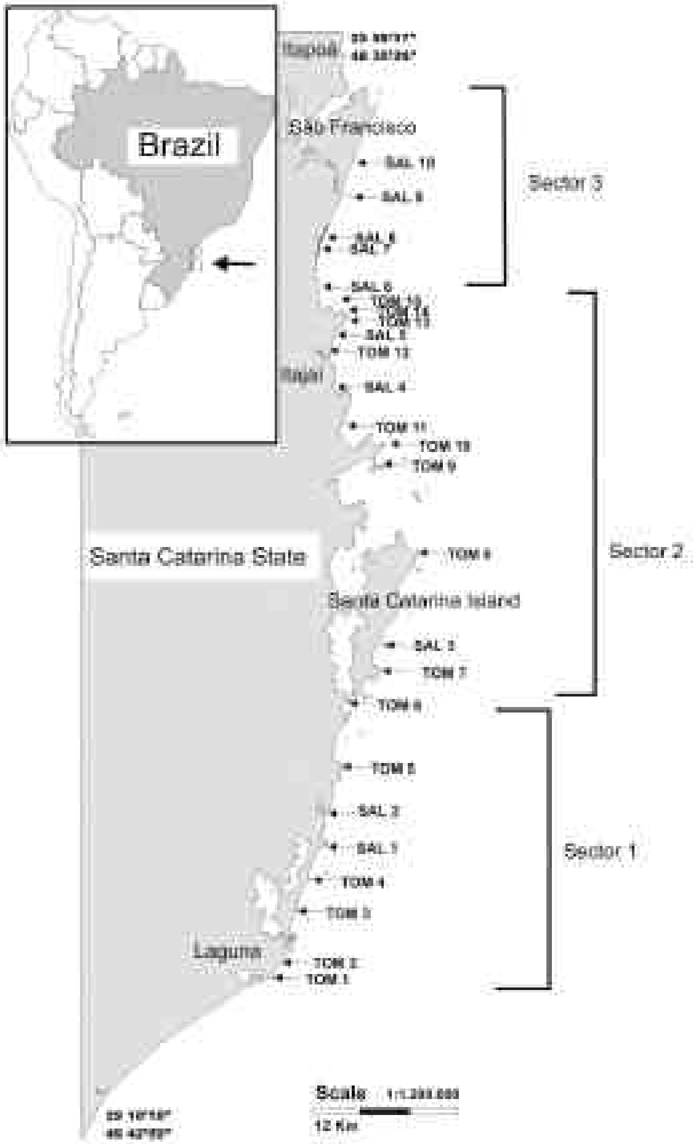

Figure 1. Map of study area showing the salients (SAL) and tombolos (TOM) on the coast of the State of Santa Catarina, southern Brazil.

Island to Santa Marta Cape (Laguna), consists of many macro-compartments in the Santa Catarina coastal plains. It has a series of bay beaches situated between rocky outcrops. This area has extensive coastal plains with remarkable lagoonal systems. The littoral drift in this region is predominantly northward, resulting from the southeast swells (CARUSO, 1995). The aeolian sediment transport is predominately southwestward, due to the northeasterly winds (GIANNINI, 1994). CARUSO (1995) stated that the remnant fragments of the crystalline outcrop are responsible for the occurrence of little islands and rocky outcrops along the coast, producing distinct forms of salients and tombolos. A sequence of beach and foredune ridges formed during the Quaternary is visible along this section. Active sand dunes are well developed above the Pleistocene and Holocene deposits. The inner shelf is relatively narrow, with a 50 m depth contour of not more than 17 km from the shore in most areas, and only 6 km at Santa Marta Cape (MUEHE, 1998).

Sectors 2 and 3 have many large coastal compartments on the Crystalline Scarps (MUEHE, 1998). In these regions, the coast is cut out of Precambrian crystalline rock outcrops, interrupting the continuity of the Quaternary coastal plain (MUEHE, 1998). Headland-bay beaches can easily be identified in these regions. Coastal plains are in the form of barrier island systems, beaches linked to basement rocks, beach and foredune ridges, spits and "chenier" plains (CARUSO and ARAUJO, 1997, 1999; KLEIN and MENEZES, 2001). The inner continental shelf between 2 m and 50 m water depth is relatively narrow (MUEHE, 1998; ABREU, 1998). The nearshore gradient, resulting from the geological inheritance, is shallow near river mouths and embayments, and relatively steep in the vicinity of basement rocks (MUEHE, 1998; ABREU, 1998; 1999; KLEIN and MENEZES, 2001).

METHODOLOGY

Classification and Morphometric Parameters for Defining Salients and Tombolos

Aerial photographs (1:12,500 and 1:25,000) and topographical maps (1:50,000 and 1:3,000) on different scales were digitized (at a resolution of between 200 and 400 DPI), and calibrated according to the resolution (DPI) and the number of pixels on the horizontal and the vertical axes. The parameters B, S, F, J and X were obtained through the use of image treatment software (Figure 2), with the aid of a measurement tool, and the results were presented in meters. The aerial photographs were not referenced, data being obtained from the centre of these where possible, to avoid distortions.

Based on these data, regression analyses were established between the variables (B, X, J, F, S, d, L) and ratios (B/S, X/S, F/J, d/L etc). In addition, outlines were produced of all the features identified on the Santa Catarina coast for classification, through a combination of the existing morphological classifications in the literature (SANDERSON and ELIOT, 1996) and by BLACK and ANDREWS (in press).

Besides the analysis of the data for Santa Catarina, a bibliographical review was also conducted of the main relationships and available data in the literature (e.g. HSU and SILVESTER, 1990; GONZÁLEZ and MEDINA, 1999).

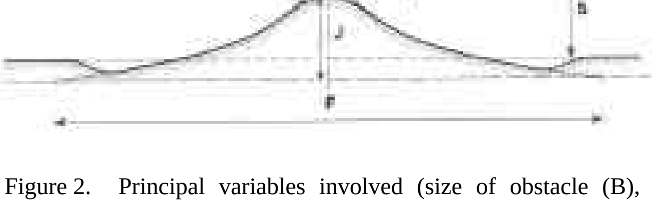

Figure 2. Principal variables involved (size of obstacle (B), distance of this from the coastline (S), alongshore width (F), degree of protrusion of the feature (J) and distance between the feature (apex) and the obstacle (X)) (according to VAN RIJN, 1998).

Analysis of the Planform of Salients Using the Sigmoid Model (BLACK and ANDREWS, in press)

BLACK and ANDREWS (in press) determined the form of salients by obtaining sigmoid curves for each formed feature. These curves were obtained based on the metric values of the alongshore and cross-shore distance for each feature (coordinated X and Y) (Figure 3). These authors obtained a medium equation for all the features, with normalized values based on the degree of protrusion of the features (J), in order to avoid differences arising from the different scales found in the aerial photographs and maps used (Equation 1).

$$Y' = -0.052 + 1.187/(1 + \exp(-(X' - 0.606\ln(1/2^{0.60(} \quad \textbf{(Eq.1)}$$

Where:

$$X' = \frac{X}{J} \qquad Y' = \frac{Y}{J}$$

The proposed equation was applied to two cases, Balneário Camboriú and Navegantes. The results obtained for the Ytheory were related to the Ytrue, thereby determining how far the equation proposed by BLACK and ANDREWS (in press) is capable of determining the form of features analysed.

Analysis of the Planform of Salients and Tombolos - Parabolic Model (HSU and SILVESTER, 1990)

The parabolic model proposed by HSU and SILVESTER (1990) was used to evaluate the assumption that features present symmetrical forms, considering an angle b of equal to 40o, an angle which is equivalent to the arrival of the waves parallel to the obstacle (Figure 3). This model is based on polar co-ordinates and was applied to the features of the beaches of Balneário Camboriú and Navegantes. It should be emphasized that the authors ignored asymmetric features.

The parabolic equation of HSU and EVANS (1989) developed for coastline in static equilibrium, is given by (equation 2):

$$\frac{R}{R_o} = C_1 + C_2\left(\frac{\beta}{\theta}\right) + C_3\left(\frac{\beta}{\theta}\right)^2 \qquad \textbf{(Eq. 2)}$$

Two basic parameters in this equation are the reference wave obliquity b and control line length Ro (Figure 3). Variable b is a reference angle of wave obliquity or the angle between the incident wave crest (assumed linear) and the control line, joining the upcoast diffraction point to the near straight downcoast beach. This is how it is determined from maps, vertical aerial photographs, and even for design purposes using maps. The control line of length R_o is also angled b to the tangent at the downcoast beach end. The

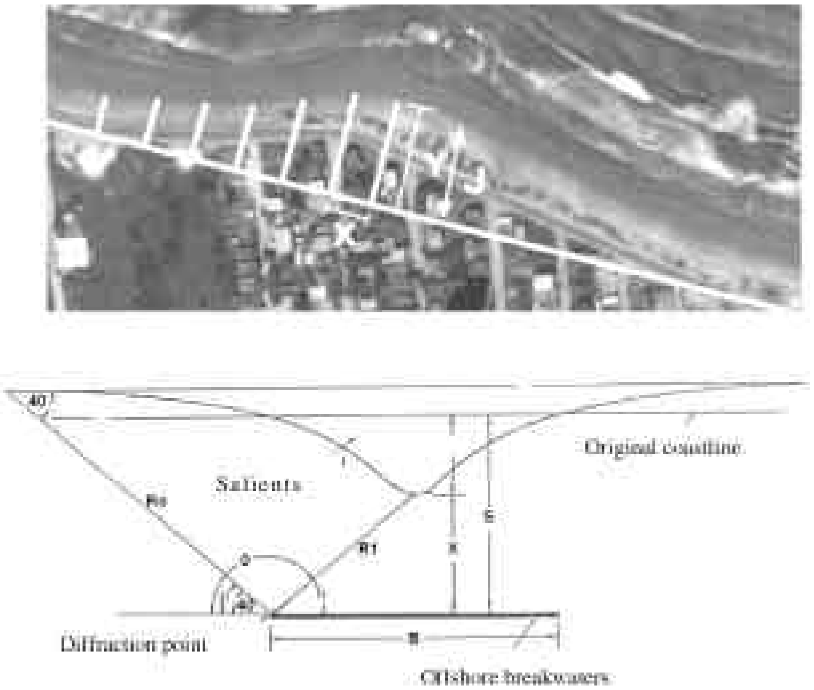

Figure 3. a) Definition of variables X and Y of the BLACK and ANDREWS (in press) model, based on sigmoid curves. X and Y represent the metric co-ordinates, cross-shore and alongshore, starting from a point of origin; b) Definition of variables for the HSU and SILVESTER (1990) model, based on polar co-ordinates.

radius R to any beach point around the bay periphery is angled q from the same wave crest line radiating out from the point of diffraction. The three C constants, generated by regression analysis to fit the peripheries of the 27 prototypes and model bays mentioned above, vary with angle b (see HSU and EVANS, 1989). Examples of bay shape verification were given in SILVESTER and HSU (1993).

RESULTS AND DISCUSSION

Classification of the Features Found on the Coast of Santa Catarina

Along of the study area, 10 salients (SAL) and 15 tombolos (TOM) were identified (see Figure 1). These were predominantly features formed by the influence of islands and headlands originating from remaining fragments of the crystalline rock outcrops (embasement). They presented simple forms.

The outlines established demonstrate a unique distribution in each area. There were differences in terms of the predominance of the salients/tombolos in all the identified features (e.g. Figure 4). In the southern and central sections, there was a predominance of tombolos (75% and 66%) over salients (25% and 34%). In the northern section, tombolos represented 36% and salients 64%. In the southern area (section 1), the features were asymmetric, with a more concave coastline on the northern side, and a straighter coastline on the southern side.

The features identified were classified according to the morphological criteria of SANDERSON and ELIOT(1996) and BLACK and ANDREWS (in press). It should be pointed out that BLACK and ANDREWS (in press) only considered the classification of salients. The classification proposed by SANDERSON and ELIOT (1996) was more similar to this work with regard to tombolos. However, BLACK and ANDREWS (in press) proposed a classification for salients formed on beaches delimited between headlands (bays), this classification being omitted by SANDERSON and ELIOT (1996), among others.

Thus, a combination of the classifications proposed by SANDERSON and ELIOT (1996) and BLACK and ANDREWS (in press) is proposed, taking into consideration only the morphologic aspects. This classification reflects more precisely the morphological features identified on the coast of Santa Catarina (Figure 5). The origin of the obstacle or features was not considered.

Identification of Limits for the Formation of Salients and Tombolos

The parameters obtained for the salients and tombolos on the coast of Santa Catarina, as well as the respective limits, are shown in Table 1. The data for the relationships between

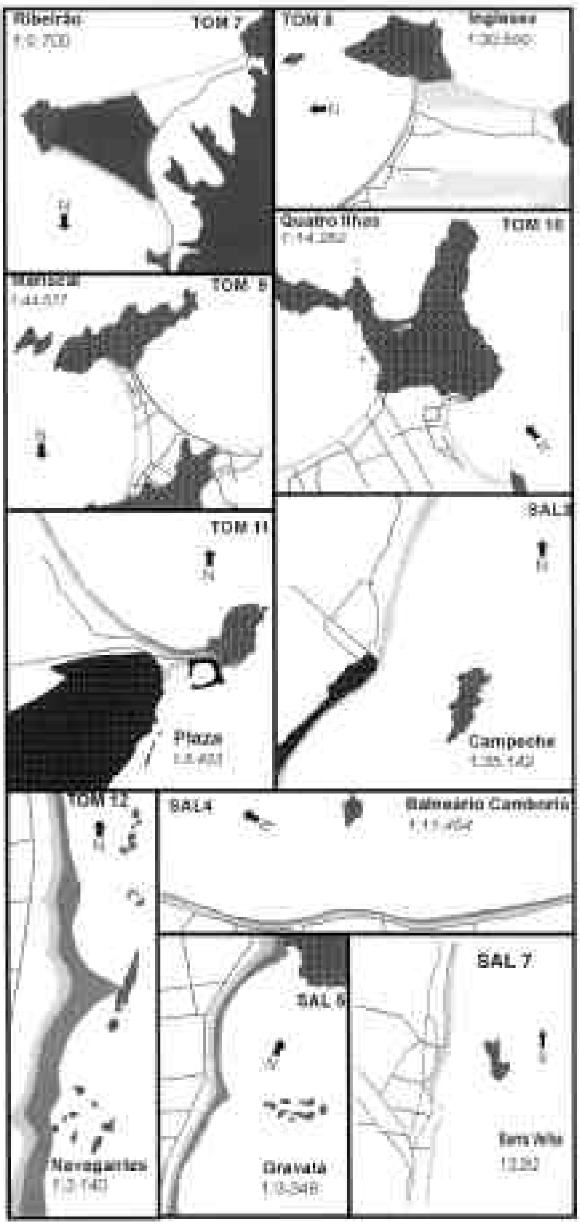

Figure 4. a) Examples of outlines of the features identified on Santa Catarina coastline.

B/S and X/B found for the identified saliencies in Santa Catarina and in the literature are shown in Tables 2 and 3.

The limits were established based on the existing relationships between the size of the obstacle and the distance from the coastline (B/S), on the distance between the obstacle and the apex of the feature and on the size of the obstacle (X/B). Tables 3 and 4 exhibits a comparison between the limits found on the Santa Catarina coast, as well as the principle limits found in the literature. The values for Santa Catarina are similar to those described in the literature, showing that these parameters are important in the formation of the features. However, they are peculiar to each region subject to inherent errors in data collection (e.g. different scales), because there is a certain overlap in the limits of the B/S ratio for salients and tombolos.

For the Santa Catarina coastline, an interval was observed of between 0.185 and 1.608 for salients, similar to that proposed in the literature (see Tables 3 and 4). However, for the formation of permanent tombolos, the values varied between 0.396 and 2.542, showing an overlap of values for the salients, which corroborated the summary of limits presented in Table 4. In other words, there exists a wide variation in the geometric B/S limits, which suggests that the process of formation of these features is also influenced by other factors not included in the geometric analyses.

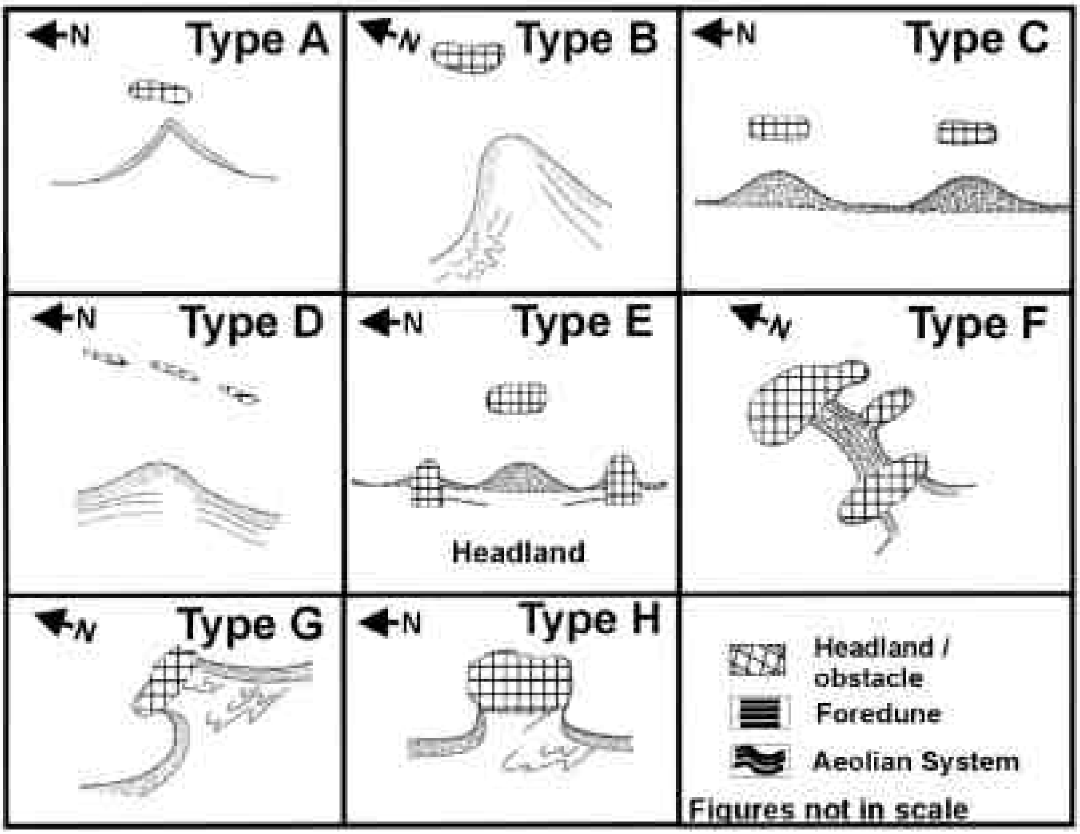

Figure 5. Proposed classification for the features identified on the coast of Santa Catarina. Classification resulting from the combination of the criteria established by SANDERSON and ELIOT (1996) and BLACK and ANDREWS (in press).

Principal Geometric Relationships that Define the Presence of Salients

Figure 6 shows the equations obtained for the salients identified on the Santa Catarina coast is shown. It involves the relationships between B/S and X/B, with their respective R^2. Figure 7 exhibits the values extracted from the existent literature. A similarity is highlighted for the coefficients among the relationships found by different authors. Parameters B/S and (S-J)/B were also analysed, where S-J is equal to X, according to the criteria established by SANDERSON and ELIOT (1996) (see Figure 6).

In the relationships involving parameters B/S and (S - J) / B or X/B for salients, a good relationship between the parameters (R^2 of 0.89 and 0.79 respectively) was verified. The equations and R^2 presented in Figure 6 represent the same analysis, in spite of the difference in values between the coefficients and R^2, this difference is due to an error of measurement while obtaining the parameters from the aerial photographs and maps. The low R^2 values may be related to the unique characteristics of each study area analysed such as. These characteristics may be of greater importance for determining the degree of development of the feature than for the simple relationship between geometric parameters .

Figure 7 shows the comparison between the relationship obtained for the salients formed in Santa Catarina, and the other relationships mentioned in the literature.

The majority of authors restrict themselves to the establishment of a single equation for defining the limits for the formation of salients, which will determine the limits for the area studied. Among the works reviewed, the general consensus is that the distribution of points for the features identified is best defined by an exponential equation. However, different constants were found by each author and for Santa Catarina, the results suggest that local factors (dynamic, geology, wave climate, location, etc.) are responsible for these differences, as well as error in the data collection (different scales).

Based on the relationships found by different authors, as well as the relationship found for Santa Catarina, not only an equation that delimits the formation of salients, but a rather package, was found, which takes into account all the

Table 1. Parameters of interest found for the salients (SAL) and tombolos (TOM) identified on the Santa Catarina coastline. All values are in meters. X=0 for tombolos (-).

Place	SAL/TOM	B (m)	S (m)	F (m)	J (m)	X (m)
Campeche	SAL3	1613	1927	4824	1278	608
São Francisco-Grande beach	SAL10	2202	4623	6990	378	3967
Barra do Sul	SAL9	1660	2323	4944	1137	1238
Barra Velha	SAL7	57	79	158	18	65
Barra Velha1	SAL8	67	78	237	55	13
Bal. Camboriu	SAL4	121	654	941	84	398
Ibiraquera	SAL2	315	662	884	273	375
Imbituba	SAL1	118	330	322	45	285
Itajuba	SAL6	238	148	450	70	85
Itajuba2	SAL6	238	149	455	81	75
Nevega1	SAL5	75	308	577	56	208
Navega3	SAL5	135	336	768	181	274
Penha	TOM15	1000	991	5508	991	-
Mariscal	TOM9	5532	3619	4727	3619	-
Sonho	TOM6	1980	1012	1437	1012	-
Ingleses	TOM8	1528	1525	3361	1525	-
Ribeirão	TOM7	302	763	1142	763	-
Ponta do Vigia (Garapaba)	TOM5	2147	966	3362	966	-
Itapiruba	TOM4	474	240	743	240	-
Navegantes	TOM12	113	114	238	114	-
Navegantes	TOM12	150	136	320	136	-
Navegavegantes	TOM12	135	144	340	144	-
Plaza	TOM11	340	172	173	172	-
Ponta do Gi	TOM3	65	36	142	36	-
Grande beach 1	TOM13	65	36	142	36	-
Grande Beach 2	TOM14	432	176	472	176	-
Quatro Ilhas	TOM10	2008	790	1845	790	-
Santa Marta Pequeno	TOM2	490	662	1685	662	-
Santa Marta	TOM1	1312	938	3429	938	-
Sonho1 beach	TOM6	1715	938	1267	938	-
Sonho2 beach	TOM6	1600	952	1400	952	-

relationships. This, in turn, could determine more precisely the possible formation interval for salients (Figure 8), in spite of the overlap between the maximum and minimum values presented in Table 4.

Analysis of Geometric Relationships Involving other Parameters (Salients and Tombolos)

Relationships between parameters F/B and S/B were established for salients and tombolos, as initially suggested by SUNAMURA and MIZUNO (1987). The result was a low linear regression between the parameters (R^2) for the features formed in Santa Catarina (Figure 9).

An attempt to define a relationship between J/F and S/B for all salients formed in Santa Catarina, as proposed by BLACK and ANDREWS (in press), resulted in a wide dispersion of points, similar to that found by these two authors (Figure 10). However, an average value of 0.175 is suggested for the relationship J/F. This result differed from the value proposed by BLACK and ANDREWS (in press), which was 0.125.

Relationships Involving the Depth (d) and Wave Length (L) (Salients and Tombolos)

Few authors mention the influence exerted by the depth (d) of the obstacle and the average wave length (L) on the type of feature formed. Among the authors that make reference to these aspects are HSU and SILVESTER (1990) and GONZÁLEZ and MEDINA (1999) (see Table 5).

Table 2. Relationships between B/S and X/B for all identified features on the Santa Catarina coastline. The values in bold correspond to the extreme limits (maximum and minimum). X/B = 0 for tombolo (-).

Place	**SAL/TOM**	**B/S**	**X/B**
Campeche	SAL3	0.8371	0.3769
São Francisco-Grande beach	SAL10	0.4763	1.8015
Barra do Sul	SAL9	0.7146	0.7458
Barra Velha	SAL7	0.7215	1.1404
Barra Velha1	SAL8	0.8590	0.1940
Bal. Camboriu	SAL4	0.1850	3.2893
Ibiraquera	SAL2	0.4758	1.1905
Imbituba	SAL1	0.3576	2.4153
Itajuba	SAL6	1.6081	0.3571
Itajuba2	SAL6	1.5973	0.3151
Nevega1	SAL5	0.2435	2.7733
Navega3	SAL5	0.4018	2.0296
Penha	TOM15	1.009	-
Mariscal	TOM9	1.529	-
Sonho	TOM6	1.957	-
Ingleses	TOM8	1.002	-
Ribeirão	TOM7	0.396	-
Ponta do Vigia (Garapaba)	TOM5	2.223	-
Itapiruba	TOM4	1.975	-
Navegantes	TOM12	0.991	-
Navegantes	TOM12	1.103	-
Navegavegantes	TOM12	0.938	-
Plaza	TOM11	1.977	-
Ponta do Gi	TOM3	1.713	-
Grande beach 1	TOM13	1.806	-
Grande Beach 2	TOM14	2.455	-
Quatro Ilhas	TOM10	2.542	-
Santa Marta Pequeno	TOM2	0.740	-
Santa Marta	TOM1	1.399	-
Sonho1 beach	TOM6	1.828	-
Sonho2 beach	TOM6	1.681	-

Table 3 Limits found for the formation of salients on the Santa Catarina coastline and principal limits found in the literature.

Data source	**B/S**		**X/B**	
	Minimum	**Maximum**	**Minimum**	**Maximum**
Santa Catarina data	0.185	1.608	0.194	3.289
HSU and SILVESTER (1990)	0.292	1.330	0.466	3.422
GONZÄLES and MEDINA (1996)	0.100	1.000	0.884	4.000
BLACK and ANDREWS (in press)	0.100	1.000	0.430	10.310

Table 4. Summary of the common parameters from different authors, highlighting the conditions necessary for the formation of tombolos or salients on the coastline.

Authors	**Tombolos**	**Salients**	**Without acretion**
DALLY and POPE (1986)	B / S = 2 - 3 (B = 200 to 300% from S)	B / S = 0,5 - 2 (B = 50 to 200 % from S)	B / S <0,2 (B < 20% from S)
SUNAMURAand MIZUNO (1987)	B / S > 0,67 (B > 67% from S)	0,67 < B / S < 0,28 (B > 67 and B < 28% from S)	B / S < 0,28 (B < 28% from S)
HSU and SILVESTER (1990)	1,33 < B/S < 5,21 (B > 133 and B < 521% from S)	0,292 < B/S < 1,33 (B > 29 and B < 133% from S)	B / S < 0,202 (B < 20,2% from S)
GONZÁLEZ and MEDINA(1996)		0,3 < B / L< 1,5 (B > 30 and B < 150% from L) 2 < S / L< 4 (S > 200 and S < 400% from L)	
VAN RJIN (1998)	B / S > 3 (B > 300% from S)	0,2 < B/S < 3 (B > 20 and B < 300% from S)	B / S < 0,2 (B > 20% from S)
BLACK and ANDREWS (in press)	Island B / S > 0,65 (B > 65% from S) Reefs B / S > 0,6 (B > 60% from S)	B / S < 1 (B < 100% from S) B / S < 2 (B < 200% from S)	
Limits	0,6 < B/S < 5,21 (B > 60% and B < 521% from S)	0,2 < B/S < 3 (B > 20% and B < 300% from S)	B / S < 0,2 (B < 22% from S)

HSU and SILVESTER (1990) carried out an analysis of the relationships between d/B and X/B, in order to determine the influence of the depth on the dimension of the feature, or even on the type of feature formed (salients or tombolos). These authors obtained a low relationship between the variables. Figure 11 shows the relationship between d/B and X/B for GONZALES and MEDINA (1999) data (see Table 6). It demonstrates the low adhesion of the points along a straight line ($R^2 = 0.77$), for the values found in the literature and for the salients analyzed in the bay of Balneário Camboriú, and for a salient and a tombolo formed on Navegantes beach. This suggests that the predominant conditions in each place (geology, of wave climate, dynamics, etc.) influence formation process of the features. Due to the low number of samples, it is suggested that more studies be carried out involving these variables.

GONZÁLEZ and MEDINA (1999) proposed a 2a order polynomial equation, involving B/L and S/L. A direct relationship among these variables is proposed. The results show dispersion in the points, and a low relationship between the parameters (Figure 12). Thus, a relationship was proposed based on the influence of the relative depth (d/L) on the type of feature formed. This relationship was used due to the influence exerted by these two parameters on the processes of wave diffraction on an obstacle.

Multiplication of the d/Lratio for the component terms of the relationship proposed by GONZÁLEZ and MEDINA (1999) (B / L and S / L), results in the following equation (equation 3):

$$(B \times d) / L2 \sim (S \times d) / L2 \qquad \textbf{(Eq. 3)}$$

In this way, the influence exerted by the depth and wavelength on the type of feature formed, was established using the existing data in the literature, which originate in the work carried out by GONZÁLEZ and MEDINA(1999) (see Table 6). These data were used due to the insufficiency of data on depth and wavelength, for the whole study area (Santa Catarina).

By applying the proposed relationship, different results were obtained for the formation of salients and tombolos (Figure 13). An analysis of the influence of the depth and the wavelength on the type of feature formed proved positive, suggesting that these two aspects can condition the formation of both salients and tombolos. This is represented by the values R^2 (0.8309 and 0.8006 respectively). This analysis is of great importance in establishing a relationship that is capable of explaining the appearance of salients or tombolos in any dynamic conditions, since it takes into account the different wave climates predominant in each region.

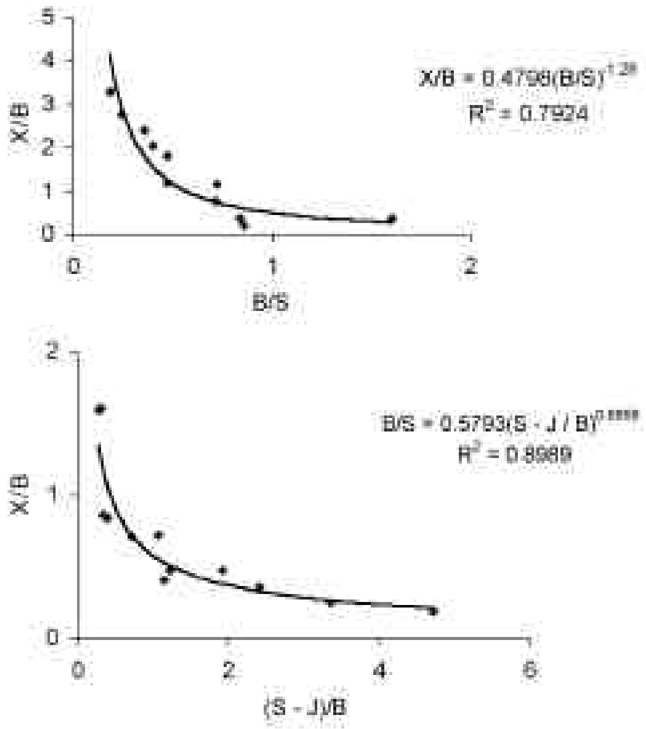

Figure 6. a) Relationship obtained for the formation of salients in Santa Catarina, with their respective degree of regression (R2). b) Relationships obtained between B/S and (S-J)/B for salients formed in Santa Catarina, with their respective R^2.

Using data published by ALVES (1996), on the sea state in the area of São Francisco do Sul (North of Santa Catarina), average values were obtained for the wave period. For south and southeastern waves the average period range from quadrants 7s and 16s. These values, together with the depths, were used to validate the possible relationship between (B*d)/L2 and (S*d)/L2 for the study area. For the calculation of the wavelength (L), these values were considered in shallow waters (around the obstacle) (L = T(g.d)0.5).

The values obtained for the features analysed in Santa Catarina are different from the established limits (Figure 13). In order to define a better relationship it is necessary obtain a larger number of these parameters for the other features identified on the Santa Catarina coast.

It should be emphasized that it would be premature to affirm whether depth and wavelength exert any influence on the features formed in the State of Santa Catarina, and it is suggested that more studies should be carried out. However, the data given in the literature suggest the existence of such a relationship.

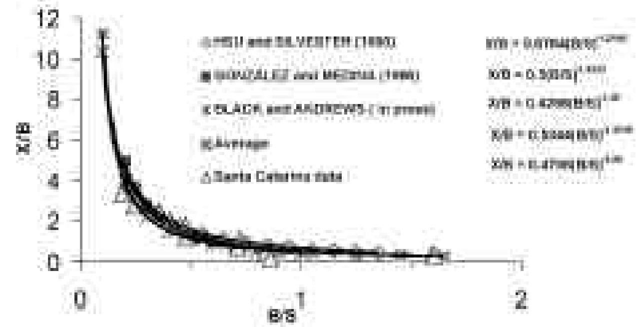

Figure 7. Comparison between the equation obtained for the formation of salients in Santa Catarina, and the other equations taken from the literature.

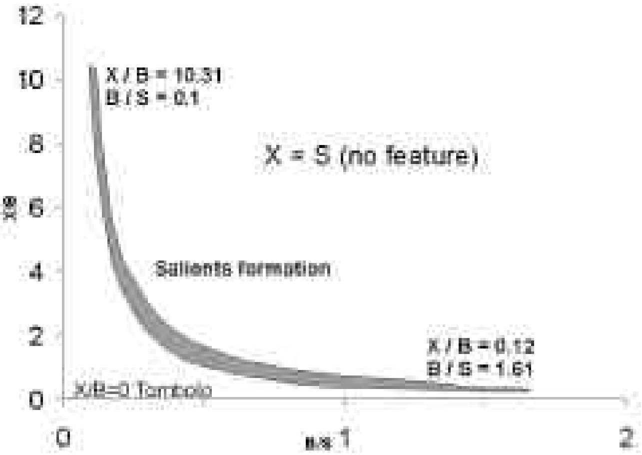

Figure 8. Interval proposed for the formation of salients. This was obtained through the bibliography and from the values found for the features formed on the Santa Catarina coastline.

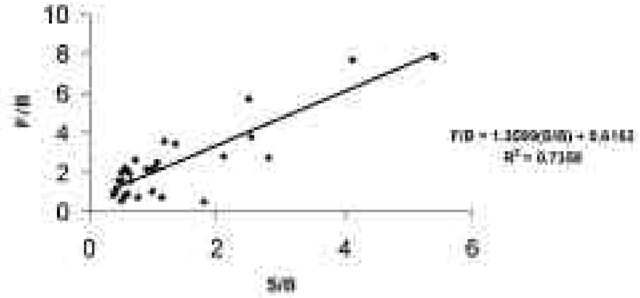

Figure 9. Relationships between F/B and S/B obtained for salients and tombolos formed in Santa Catarina, with their respective R^2.

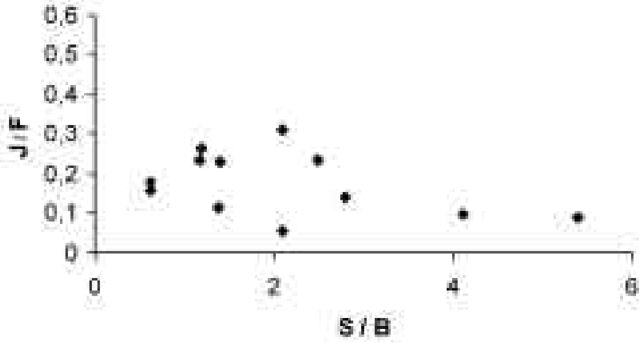

Figure 10. Distribution of the J/F and S/B values found for salients formed in Santa Catarina.

Analysis of Planform of the Salients Using the Sigmoid Model

By using the equation of BLACK and ANDREWS (in press) curves were obtained for the salients found on the Beaches at Navegantes and Balneário Camboriú (Figure 14).

The Y values obtained using the equation were related to the Y values obtained for the features using the aerial photographs (Figure 15). The high R^2 (0.99 and 0.96) were between the values of Y_{theory} and Y_{true}, for both Balneário Camboriú and Navegantes. These values suggest that the equation based on metric co-ordinates, proposed by BLACK and ANDREWS (in press), is a good method of defining the form of the salients on the coastline. However, this model takes into account only the geometric analysis of the salients and ignores data such as depth and wave climate, which are also important in the formation process.

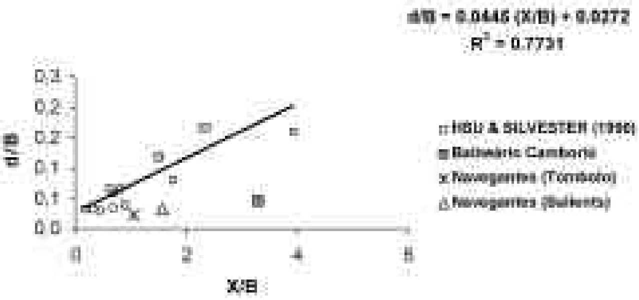

Figure 11. Relationship obtained between d/B and X/B for formed features, based on the work carried out by GONZALES and MEDINA (1999). The distributions of the three features analysed for Santa Catarina are observed.

Analysis of the Planform of Features According to the Parabolic Model.

HSU and EVANS (1989) and SILVESTER and HSU (1993, 1997) developed the parabolic model, based on polar co-ordinates. HSU and SILVESTER (1990) modified this model for the analysis of areas close to obstacles and/or offshore breakwaters, with accumulated sediments on the coastline, in the form of salient or tombolos. The pattern of formation of these features is similar to that found on bay beaches, in terms of the static equilibrium. That is to say, it presupposes that the wave crests reach the obstacle in a parallel way (b is between 30° and 40°). Three features were analysed, according to the criteria proposed for the parabolic model.

Table 5. Examples of rations obtained for different authors.

Authors Rations	**SUNAMURA and MIZUNO (1987)**	**HSU and SILVESTER (1990)**	**SANDERSON and ELIOT (1996)**	**GONZÁLEZ and MEDINA(1999)**
(B/2)/L				X
S/L				X
Bk/(B/2)				X
(F/2)/L				X
S/B	X	X	X	X
B/S		X	X	X
X/B		X		
F/B	X		X	
J/F	X		X	
(S-J)/B			X	
F/S			X	X

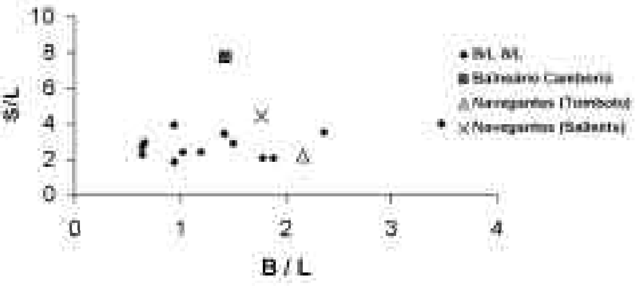

Figure 12. Relationship between S/B and X/B obtained for formed features, based on the data of GONZALES and MEDINA (1999). The distributions of the three features analysed for Santa Catarina are observed.

Navegantes beach (Salient)

Initially, three different points of wave diffraction on the island located near Gravatá beach (Navegantes) were selected, taking a b equal to 40° for each of the points. For all three simulations, the results demonstrated that the formed salient is in dynamic equilibrium, with a notable progression of the coastline estimated by the model in relation to the current coastline (Figure 16).

However, by applying the model with different angles b (b1 58° and b2 28°), a simulated coastline was obtained that was closer to the current coastline (Figure 16).

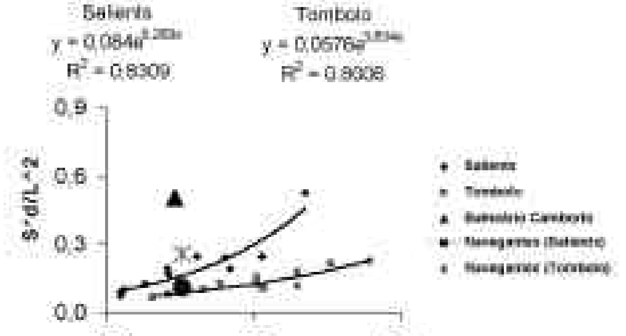

Figure 13. Relationships obtained between (B*d)/L2 and (S*d)/L2 for salients and tombolos, for Values obtained through the work of GONZÁLEZ and MEDINA (1999), including the values found for Balneário Camboriú (salient) and Navegantes (salients and tombolo).

Table 6. Values obtained for B, S, d and L, taken from GONZÁLEZ and MEDINA(1999). All the values are in meters. Salients (SAL) and Tombolos (TOM).

SAL/TOM	B (m)	S (m)	d (m)	L (m)
SAL	518.520	600.470	7.200	149.00
SAL	49.700	120.050	1.300	35.00
SAL	19.800	90.000	0.900	30.00
SAL	19.840	70.060	1.000	31.00
SAL	120.360	179.520	3.500	51.00
SAL	0.498	2.099	0.050	0.530
SAL	0.504	1.008	0.030	0.420
SAL	0.506	2.133	0.030	0.790
SAL	0.498	1.002	0.070	0.530
SAL	0.996	1.092	0.030	0.530
SAL	1.000	2.352	0.080	0.980
SAL	1.495	1.747	0.100	0.840
SAL	1.500	2.920	0.180	1.000
TOM	130.00	90.00	0.800	20.00
TOM	140.00	150.00	0.800	20.00
TOM	160.00	100.00	1.400	25.00
TOM	130.00	60.00	0.800	20.00
TOM	81.60	79.20	0.600	24.00
TOM	151.20	128.80	0.800	28.00
TOM	197.60	148.20	1.500	38.00
TOM	197.60	121.60	1.500	38.00
TOM	286.20	201.40	3.000	53.00
TOM	201.40	100.70	3.000	53.00
TOM	150.00	112.50	5.000	75.00
TOM	200.00	208.00	2.000	80.00
TOM	2.00	1.00	0.030	0.530

Navegantes beach (Tombolo)

The simulation for the Navegantes tombolo was carried out in a similar way. For this feature, two different simulations were necessary, since the beach is divided into two sections (Figure 17). Two small salients delimit the first section, one on each side of the obstacle, while the second comprises the areas apart from these salients. Initially, b equal to 40° was proposed, as suggested by HSU and SILVESTER (1990). The result of the simulation was very close to the current position of the coastline (Figure 17), with a static equilibrium. However, in the simulation carried out for the second section, from which angles b were obtained starting from the straighter portion of the beach (b = 23° and 24°), the current coastline protruded in comparison with the simulated coastline (Figure 17). This protrusion was still within the variation of the tide range. However, it is suggested that these two segments determine the position of the coastline, and the form of the feature, in distinct tidal periods (high tide (first segment) and low tide (second segment)).

Central Beach - Balneário Camboriú (Salient)

After choosing diffraction points on both sides of the das Cabras Island (Balneário Camboriú), the model was simulated taking b equal to 40°. The result of this simulation demonstrated that the formed salient on the central beach is in dynamic equilibrium. A notable regression of the coastline was shown in relation to the position suggested by the model (Figure 18).

However, by using different angles b, a line closer to the current coastline was obtained. These angles are 68o and 71° (b3 and b4 respectively) (Figure 18). The angles found were close to the angles b obtained by KLEIN *et al.* (in press) for the same feature (73° and 74° respectively). The difference in scales between the works is pointed out. KLEIN *et al*. (in press) used aerial photography on a scale of 1:12,500 and the present work used a digitized map on a scale of 1:3,000. This difference in scale directly influences the position of the current coastline, as well as the coastline estimated by the model, as pointed out by KLEIN *et al*. (in press).

It should be emphasized that this model is an efficient tool for determining the planform assumed by the salients, when the angle b is variable. By applying this method, it is possible to estimate the apex (J or X) of the feature studied, and verify the possible depositional or erosional process on the feature (dynamic or static equilibrium) (see Figure 3). It is therefore suggested that for salients, a variable b should be used, while for tombolos a constant b value between between 30° and 40° as suggested by HSU and SILVESTER (1990) would be more appropriated.

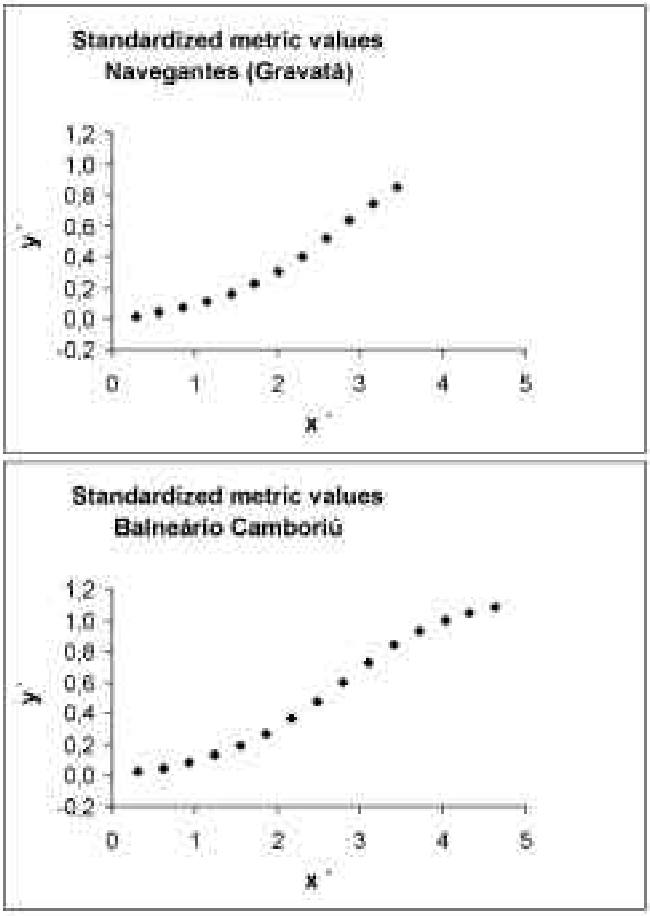

Figure 14. Curves corresponding to the standardized metric values for saliencies in Navegantes and Balneário Camboriú.

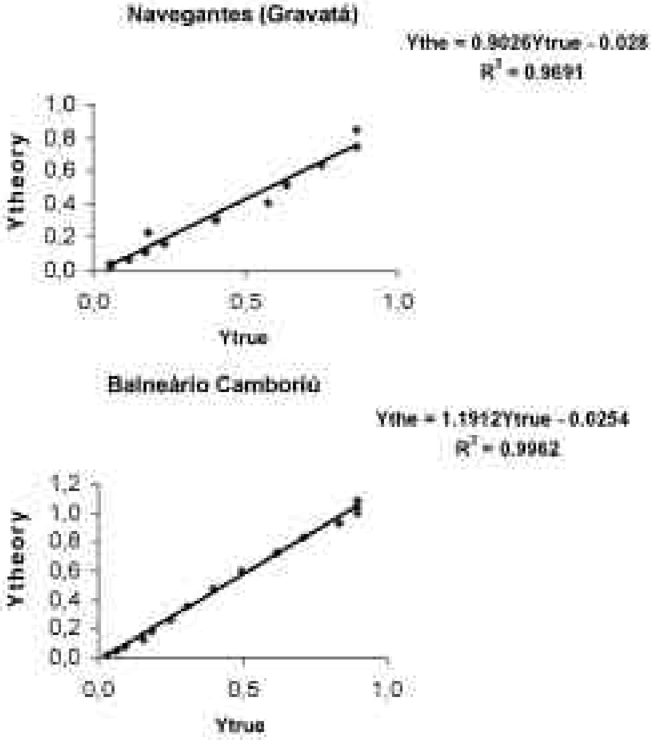

Figure 15. Relationship between Ytheory and Ytrue for analysed features and the respective R^2 for saliencies in Navegantes and Balneário Camboriú.

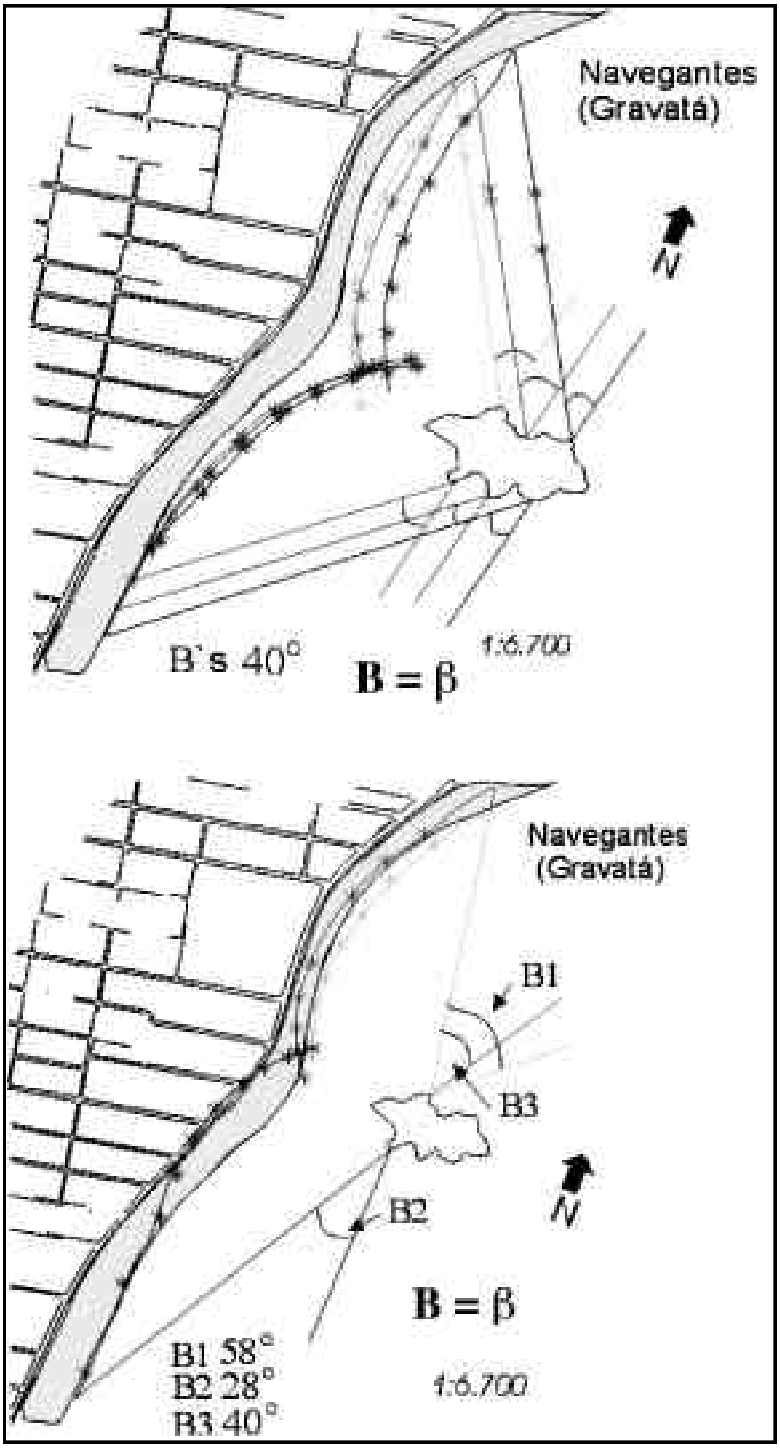

Figure 16. Salient on Gravatá Beach, Navegantes. a) Simulation for three different diffraction points, taking b equal to 40°; b) Simulation for three different b (58°, 28° and 40°).

CONCLUSIONS

The main findings of the present work are:

1. The use of empirical models proposed in the literature is valid, but their inherent limitations should be known, as the constants do change for each place.
2. The classification obtained for the features identified in Santa Catarina, through a combination of the classifications proposed by SANDERSON and ELIOT (1996) and BLACK and ANDREWS (in press), seeks to describe more precisely the features occurring on the Santa Catarina coast, since both classifications present unique descriptions.
3. Among the various relationships established, some presented significant R^2 values, particularly those relating the size of the diffraction structure (B) and the distance of the coastline (S or X). This suggests that these relationships can partially explain certain features of the coastline. However, an attempt to explain the formation of singular features, such as salients and tombolos, based solely on these relationships, may result in error (overlap of limits), due to the fact that the variables such as wave climate and depth of obstacle are not taken into account in the present approaches. It is emphasized that these variables are directly related to the processes of formation of the features of the coastline.
4. The obstacle depth (d), as well as the average wavelength obtained from literature demonstrated that they are important in defining the type of feature formed. However, the features analysed for Santa Catarina were shown to be outside the established limits for the formation of salients and tombolos. This implies that the local factors inherent to each feature analysed (sedimentary input, orientation in relation to waves, local dynamics, type of sediment, tidal variation, etc) should be taken into consideration when determining the type of conformation assumed by the coastline.
5. The model based on sigmoid curves, obtained using metric coordinates, proved to be a good method of determining the form of the salients on the coastline. However, this model has the disadvantage that it considers only the geometric form of the features. It does not take into account other variables, such as depth and wave climate, that have been shown to influence the formation of salients and tombolos.
6. An attempt to define the planform of the features by taking angle b of between 30° and 40°, based on parabolic models, proved to be effective only for tombolos. For salients the angle b should be variable for each area. The modified model of HSU and SILVESTER (1990) is still the most robust for use in different areas, because it takes into consideration the geometry and predominant wave direction of the region studied. From this, it is possible to define the distance of the coast, as well as the size of the obstacle and the resulting feature form.

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