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Gulf of Cadiz beaches: A comparative response to storm events

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ABSTRACT

The aim of the present paper is to compare the profile response of two mesotidal beaches (Faro, 10 km long, Algarve; La Barrosa, 8 km long, Cadiz) within a single regional physiographic unit (the Gulf of Cadiz) to the same storm event (January, 1996). For this comparison, a series of beach surveys was used, including a total of 10 study sites, five at each study area. The two beaches belong to exposed, mesotidal, sandy shores, and have a similar coastal orientation. However, the response time-scale is different for each one. Faro showed a total amount of 130 000 m^3 of erosion due to the storm, with a complete post-storm recovery after one tidal cycle. La Barrosa had a total sand loss of 80 000 m^3 due to the storm, with a final recovery of 60 000 m^3, 4-6 months after the event. These differences are due to the beaches' different morphodynamic behaviours. Whereas Faro is a reflective beach, with dominant plunging breakers, La Barrosa is mainly dissipative, having spilling breakers. The difference in beach slope and grain size could also be important in determining their response to storm events.

Key words: Coastal dynamics, beaches, sedimentary balance, Gulf of Cadiz.

RESUMEN

Las playas del golfo de Cádiz: comparación en su respuesta ante los temporales

El objetivo del presente trabajo es comparar la respuesta, ante un mismo episodio de tormenta (enero de 1996), de dos playas mesomareales de comportamiento distinto (Praia de Faro, de 10 km de longitud en el Algarve, y La Barrosa, de 8 km de longitud en Cádiz) pero pertenecientes a la misma unidad fisiográfica (el golfo de Cádiz). Para esta comparación se han estudiado una serie de levantamientos topográficos que incluyen un total de diez líneas de perfilamiento, cinco en cada área de estudio. Ambas playas se localizan en costas arenosas, expuestas, mesomareales y con una orientación similar. Sin embargo, el tiempo de respuesta es diferente en cada caso. Praia de Faro mostró una erosión total de 130 000 m^3 *debida a temporales y una recuperación completa tras un único ciclo mareal. La Barrosa presentó una pérdida total de arena de 80 000* m^3 *asociada a los temporales, con una recuperación final de 60 000* m^3 *después de 4 a 6 meses de los temporales. Estas diferencias son debidas al desigual comportamiento morfodinámico mostrado por ambas playas. Así, mientras Praia de Faro es una playa reflectiva con rotura dominante de tipo* plunging, *La Barrosa es predominantemente disipativa y con una rotura de tipo* spilling. *Del mismo modo, las diferencias en la pendiente y el tamaño de grano pueden ser también importantes a la hora de explicar la respuesta de ambas playas ante la llegada de temporales.*

Palabras clave: *Dinámica litoral, playas, balance sedimentario, golfo de Cádiz.*

INTRODUCTION

Although beaches are constantly being remolded under the action of waves, wind and tides, the greatest and most dramatic changes occur during storms (Birkemeier, 1979). Thus, the study of storm effects is extremely important for a good knowledge of coastal hazards and, also, to improve coastal management projects.

The effect of the January 1996 storms was monitored at two localities within the Gulf of Cadiz (figure 1). These beaches were selected because they had been included in long-term monitoring programmes including monthly surveys, providing a database of long- and short-term profile changes along well-established profile lines. Moreover, the two localities have different characteristics with regard to their morphodynamic behaviour, storm response and post-storm recovery.

Faro beach

This beach is located on the Portuguese Algarve coast (figure 1). It is an exposed, sandy beach included on a 10 km littoral spit, the Ancão Peninsula, which constitutes the western end of the Ria Formosa barrier island system. In the eastern part of the study area (sites D and E) the beach is backed by a well-developed dune ridge which averages more than 6 m in height above mean sea level. At the central and western parts (sites A to C), the dune crest was cut and destroyed by man-made structures (roads, car parks and houses). The average beachface slope (*tg* β) is about 0.11°, with beach cusps being a common feature during swell conditions. During storms, overwashes occur at the central and western part of the study area (Martins, Ferreira and Alveirinho-Dias, 1997). Recorded mean annual values of significant deep-water wave height and peak period are, respectively, 0.92 m and 8.0 s (Costa, 1994), resulting in a dominant reflective behaviour according to the classifications of Wright and Short (1984) and Masselink and Short (1993).

Following the strong overwashes and coastal erosion that occurred at Faro during the winter of 1989-1990, beach replenishment operations introduced 240 000 m^3 of sediment (Correia, 1992). At present, after storm events with overwashes, the

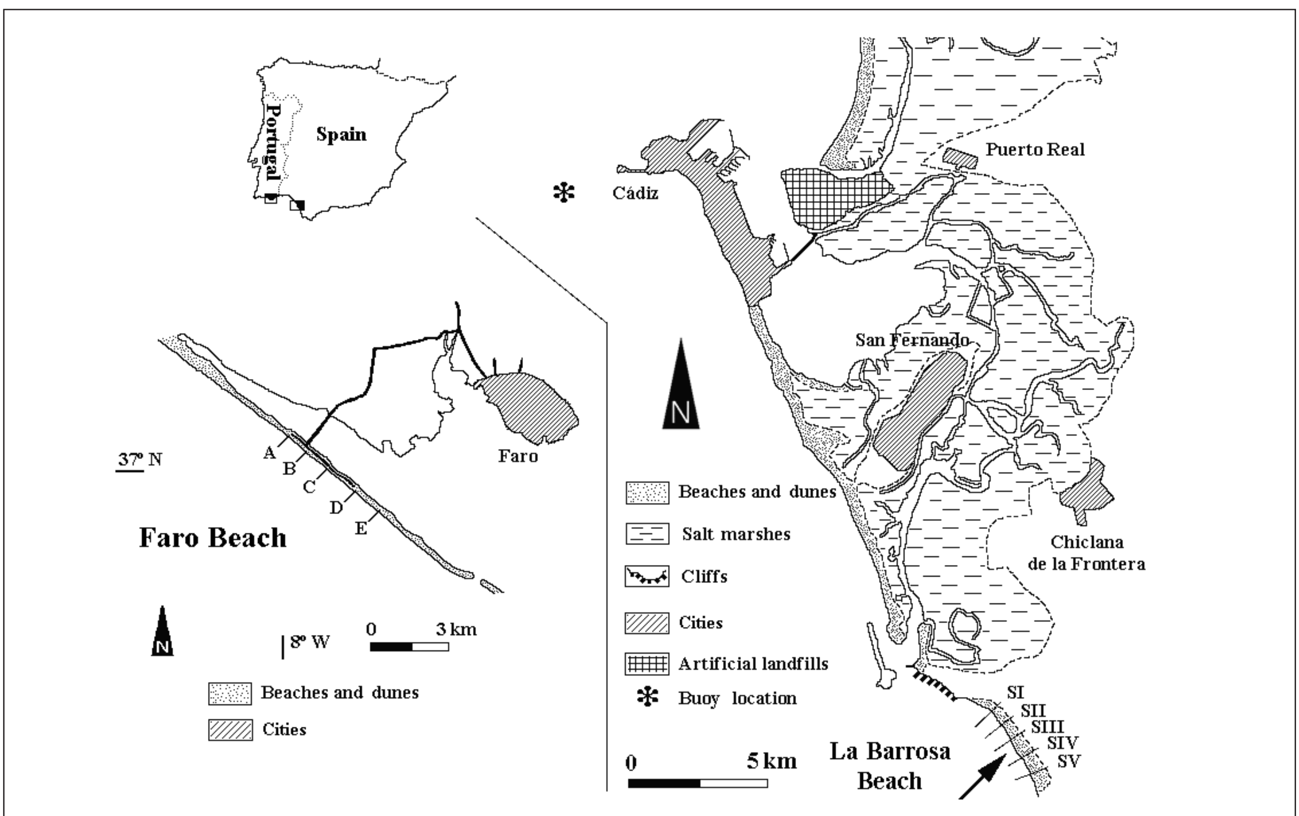

Figure 1. Location map

sand placed by the swash on the road and car parks is relocated at the upper beach near sites B and C.

La Barrosa beach

The second selected beach, La Barrosa, is located in Spain, south of Cadiz Bay (figure 1). It is an exposed beach as well, developed downdrift of a rocky cliff. Its total length is about 8 km, although only the northern 2 km have been studied. Within this zone, two sectors may be distinguished. The northern sector corresponds to an urban beach, including a promenade. It comprises transect I to III, and had been artificially nourished in December 1994, with 460 000 m^3 of sand (Muñoz Pérez and Fages, 1993). This sector suffers high touristic and urban pressure. The southern sector corresponds to an almost natural, undisturbed beach. It comprises transects IV and V, and includes a well-developed dune ridge. It presents a smaller level of touristic and urban influence. For this zone, recorded mean annual values of significant wave height and peak period are, respectively, 0.84 m and 7.0 s. The average beach face slope is about 0.03, resulting in an intermediate to dissipative morphodynamic trend (Wright and Short, 1984; Masselink and Short, 1993).

A summary of typical beach characteristics for each area is given in table I.

MATERIALS AND METHODS

Beach monitoring

Beaches were monitored with monthly profile surveys along five transects (A to E) from May 1995 to May 1997 on Faro, and along five transects (I to V) from December 1994 to May 1997 on La Barrosa.

The present paper compares only a winter period, from December 1995 to spring-summer 1996. Due to the very rapid response to storm events at Faro, some surveys were also obtained immediately after storms in order to determine associated erosion and post-event recovery rates. In order to characterise the consequences of the 23-24 January 1996 storm at Faro, surveys from 10 January 1996 and 24 January 1996 were used. To determine the recovery rates after the storm a complementary survey was made on 25 January 1996.

For La Barrosa beach, the surveys used for the analysis of the event impact were obtained on 22 December 1995 and 24 January 1996, with the recovery rates being given by the summer 1996 surveys.

Erosion and accretion volumes above mean sea level, between surveys, were computed for all the obtained profiles at each location, in order to compare volume change between surveys.

Storm characteristics

Processed wave data for the January 1996 storm were obtained from the Cadiz buoy record, which is part of the REMRO (Spanish Wave Record Network) of the State Ports of Spain's Marime Climate Section (Ministry of Public Works). The location of this buoy is shown in figure 1.

During December 1995 to February 1996, several storms moved into the Gulf of Cadiz. They were included in a period of progressively increasing energy of incident wave-fronts. The second half of January 1996 showed the maximum recorded intensity of storms, with at least four peaks of significant wave height exceeding a value of 4 m (figure 2). During February the wave energy fell to a value below 3 m, which can be considered the average storm level for this region.

Table I. Characteristics of each locality. (*): Above mean sea level; (**): H_{so} is the significant deep-water wave height

Locality	Shoreline orientation	Length of study beach (km)	Profile lines	Mean dune height* (m)	Mean beach width (m)
Faro	N 53° W	3	5	6.15	55
La Barrosa	N 40° W	2	5	4.0	45

Locality	Mean foreshore slope	Mean sand size (mm)	Maximum tide range (m)	Mean H_{so}** (m)	Mean peak period (s)
Faro	0.11	0.5	3.6	0.92	8.0
La Barrosa	0.03	0.28	3.6	0.84	7.0

Although the beaches experienced several changes during December 1995, the most intense transformations occurred during the second peak period, specially between 23 and 24 January. On these days, maximum significant wave height reached 9.4 m and 7.5 m, with associated peak periods of 8.91 s and 11.12 s, respectively.

Beach changes

The Faro profile lines shown in figure 3 were surveyed on days 10 (all transects), 24 (all transects), and 25 (sites A, C and E) January 1996. The 10 January survey can be considered the pre-storm survey, while the 24 January was obtained immediately after the storm. The volume changes between successive surveys are shown in table II. Mean erosion from the upper part of the beach profile was –13.2 m³/m, with a maximum value of –41.4 m³/m at site B. The survey on 25 January was made just one tidal cycle after the previous one. On this day, the beach showed a new berm and a well-developed beach cusp system. The computed mean beach recovery was about 13.4 m³/m, in just 12 h. Knowing, from field observations, that this erosion/recovery behaviour occurred along the entire 10 km of the Ancão Peninsula, it is possible to conclude that a total amount of about 130 000 m³ of sand was moved seawards by the storm, and afterwards replaced at the beach face by swell conditions.

On La Barrosa beach a mean amount of –34.43 m³/m was lost after the January 1996 storms, with a maximum obtained value of –60.1 m³/m at site III (table III). This loss of sand was through the creation of progressively retreating escarpments and other erosional processes, e.g. beach flattening and gullying of dune ridges due to the heavy rain associated with the storm events (Reyes *et al.*, 1996). The total amount of sand lost on the beach face after the January storms was 80 000 m³. The recovery time-span was much longer than in the former case, since it does not adjust to a tidal cycle, but to

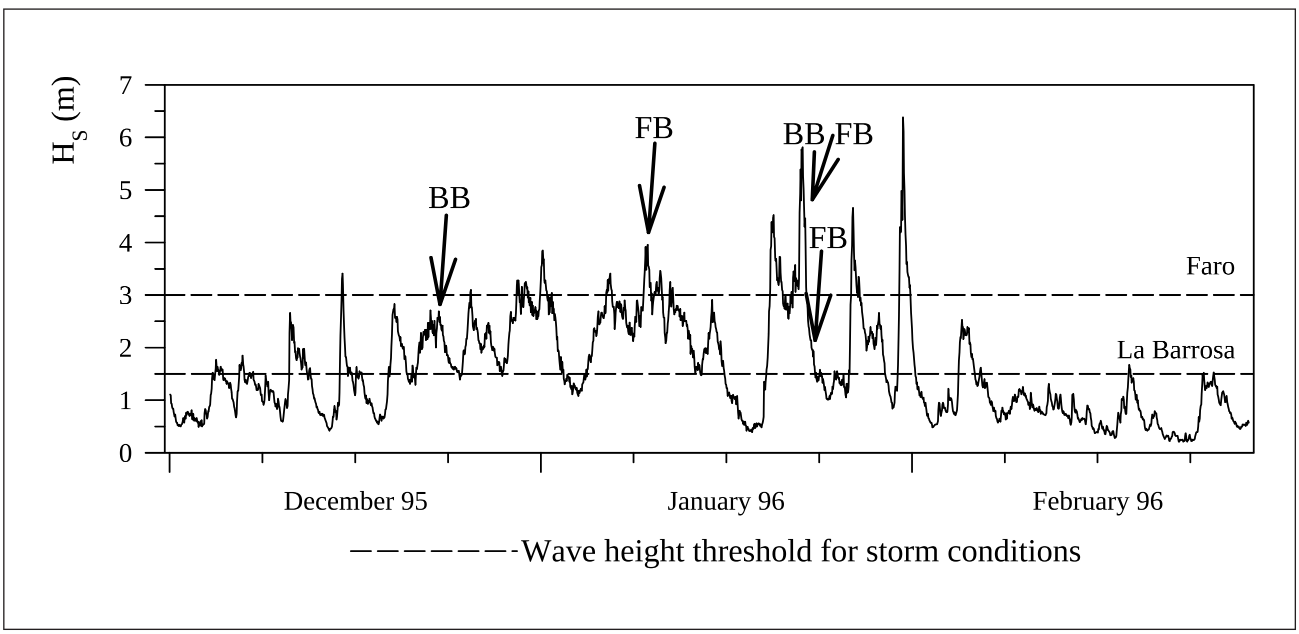

Figure 2. Time evolution of significant wave height recorded at buoy and time-location of the surveys. (FB): Faro beach. (BB): La Barrosa beach

Table II. Volume changes associated with storm erosion and post-storm recovery at Faro beach

	Site A (m³/m)	Site B (m³/m)	Site C (m³/m)	Site D (m³/m)	Site E (m³/m)	Mean (m³/m)	Ancao Penins. (m³)
Storm loss	–5.4	–41.4	–17.1	0.0	–2.2	–13.2	≈ –132 000
Post-Storm recovery	+20.8	–	+10.8	–	+8.7	+13.4	≈ +134 000

Table III. Volume changes associated with storm erosion and post-storm recovery at La Barrosa beach

	Site I (m^3/m)	Site II (m^3/m)	Site III (m^3/m)	Site IV (m^3/m)	Site V (m^3/m)	Mean (m^3/m)	Total area (m^3)
Storm loss	−44.45	−21.23	−60.1	−39.02	−31.24	−34.43	≈ −80 000
Summer recovery	+35.66	+20.61	+32.94	+41.84	+16.05	+23.42	≈ +60 000

a seasonal one, through the progressive arrival of sublittoral bars. Final recovery was achieved in summer 1996, after total onshore transport of 60 000 m^3 of sand. Nevertheless, the final sedimentary balance shows a clear deficit of 20 000 m^3. This response must be considered within a general erosional trend that this beach has shown in recent years (Benavente, 1997; Reyes, 1997) (figure 4).

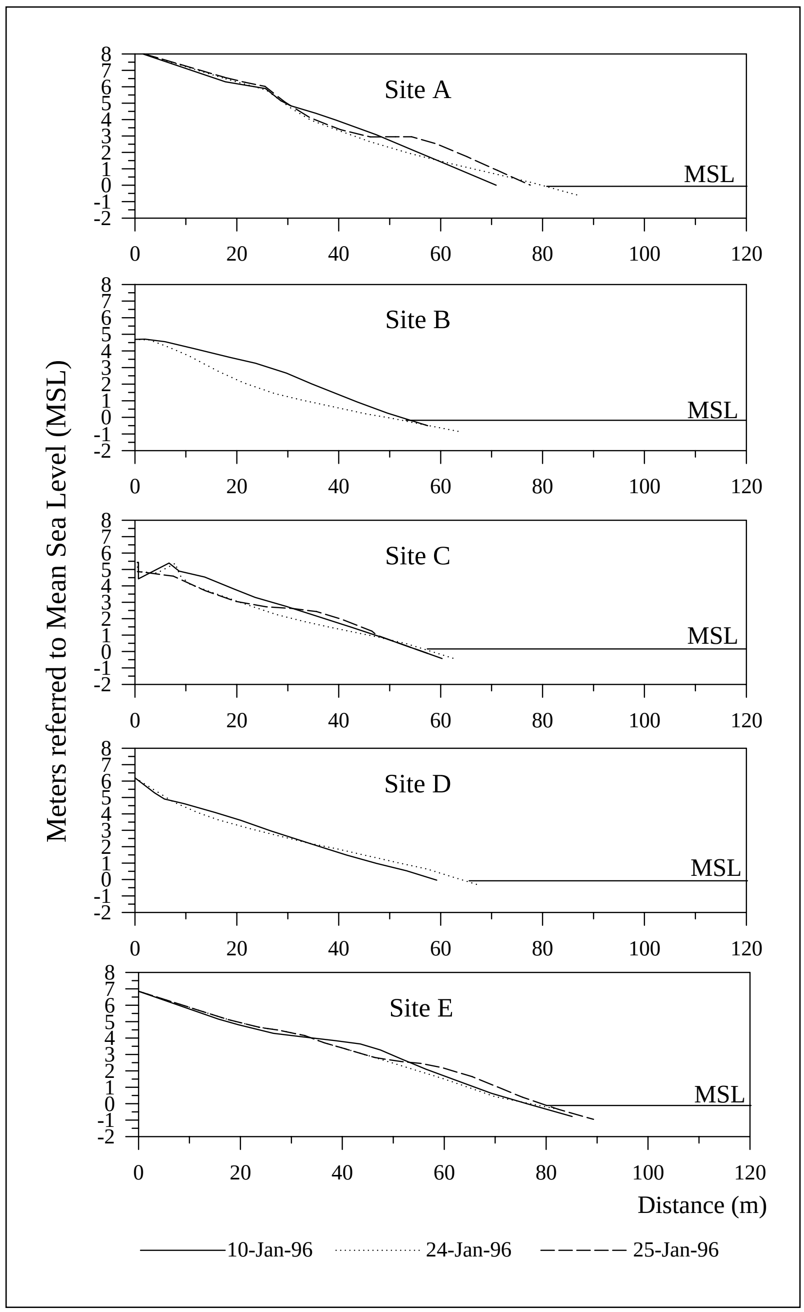

Figure 3. Pré and post-storm profiles at Faro beach

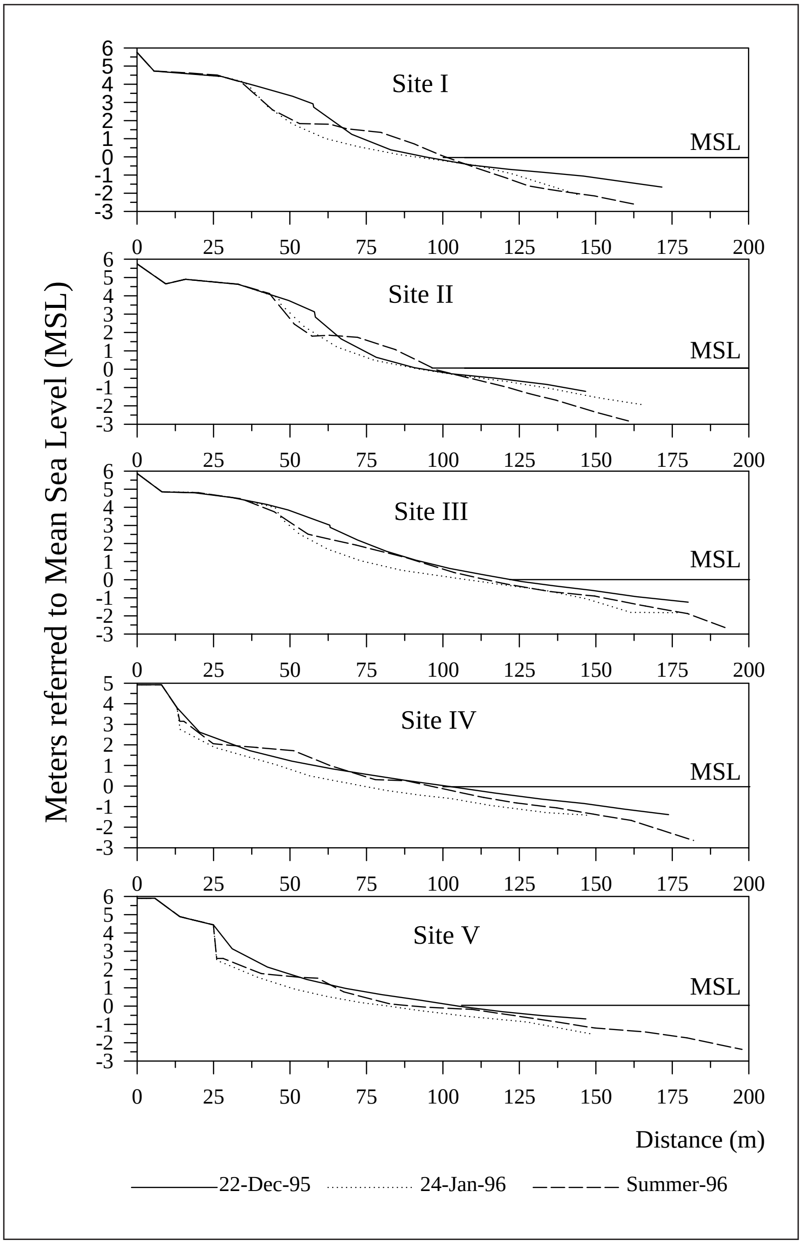

Figure 4. Morphological evolution of La Barrosa beach

DISCUSSION

By comparing tables II and III, it can be seen that the behaviour of Faro and La Barrosa beaches is quite different. Faro did not present sand loss during any monthly period surveyed, including the January storms. In fact, the erosion due to this event had a remarkable spatial variability, and immediately after the peak storm a very rapid sand recovery was observed, allowing a positive sedimentary budget after a single tidal cycle.

On the other hand, La Barrosa beach presented (after a monthly survey period) a higher amount of lost sand, more homogeneously distributed throughout the area studied. In this case, the recovery rate was much slower, requiring a seasonal period (4-6 months) to recover most of the sand; even so, the final sedimentary balance was clearly negative.

In order to discriminate the reasons for the two beaches' different responses, several factors can be considered. Firstly, some initial characteristics must be discarded, since they seem to be quite similar for both cases. Among them are offshore energetic conditions, tidal range and general geomorphological features (e.g. plan beach form, shoreline orientation). Related to these, the wave-front ap-

Table IV. Morphodynamic parameters applied to Faro and La Barrosa beaches. (*): Limits used by Fredsfe and Deigard (1982); (**): Limits used by Carter (1988)

Parameter	Limits			Behaviour	
	Spilling	Plunging	Surging	Faro beach	La Barrosa
ξ_0* (Battjes, 1974)	$\xi_0 < 2.5$	$0.5 < \xi_0 < 3.3$	$3.3 < \xi_0$	1.15 (Plunging)	0.29 (Spilling)
	Reflective	Intermediate	Dissipative		
ε** (Guza and Inman, 1975)	$\varepsilon < 2.5$	$2.5 < \varepsilon < 20$	$20 < \varepsilon < 200$	2.39 reflective	38.4 dissipative

proaching angle could also be discarded as a differential factor.

On the other hand, several other initial factors appear to be different and characteristic for each study area. These factors are mainly related to each beach's previous morphodynamic stage. A quantitative description of this aspect can be made through the introduction of classical morphodynamic indices. The parameters used, shown in table IV, were obtained taking into account the values for H_{SO}, T_p (peak period) and *tg* ß that appear in table I. Two quite different morphodynamic behaviours are obtained from this analysis. Faro beach shows a reflective trend, with dominant plunging breakers, while La Barrosa beach presents a more dissipative tendency, with dominant spilling waves. This dynamic contrast between the beaches is also expressed by the mean grain size (D_{50}), resulting in a coarser sediment for Faro beach than in the case of La Barrosa (table I).

As several authors have already pointed out (Losada, 1988; Kriebel and Dean, 1993; Fucella and Dolan, 1996), reflective beaches are more sensitive to erosive processes than dissipative ones having a smaller response time-scale. Thus, morphological change will occur more rapidly on a reflective beach under the same offshore wave conditions. This, together with the differences in the dominant breakers type, can explain the more rapid changes recorded at Faro, compared with La Barrosa. The unequal mean grain size and beach-face slope could also contribute to these differences. The smaller mean grain size and beach-face slope at La Barrosa should have allowed the formation of sublittoral storm-bars at a certain distance from the shoreline. The return of this sand during fair-weather conditions would require a longer period of time. However, the coarser sediments and the steeper beach profile of Faro beach would limit the spatial range of sand movement on/offshore, reducing the distance of storm bar from the beach face and, consequently, the time span needed for beach recovery.

Finally, the different sedimentary balance recorded at both beaches can be related to other factors and processes that still remain partially unknown: alongshore differences in breaking wave-height (H_b), spatial and temporal variations in waves' approaching angles, importance of infragravity waves, and intensity of littoral drift during and after storm events.

Further field research is needed in order to prove whether the above conclusions are able to justify the beachs' behaviours under different storm conditions. Future tests of storm erosion models for this data should also be made, with the aim of validating the model's results for coastal areas with the same offshore hydrodynamic conditions, but different beach morphodynamics.

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