Holocene Sequence of Sea-Level Fluctuations in Relation to Climatic Trends in the Atlantic-Mediterranean Linkage Coast

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ABSTRACT


The systems of spit bars that crop out in the area of linkage Atlantic-Mediterranean began to accumulate around 6,900 yr BP during the maximum of the Present Interglacial. From the morpho-sedimentological study of these spit bar systems, the study of littoral dynamics (particularly the littoral drift and interchange of “superficial Atlantic water” (SAW) and Mediterranean water), and the results of 14C measurements, we have deduced that (a) the maximum of the Present Interglacial took place ca. 6,500 yr BP, (b) the progradation of spit bar systems relates to climate; anticyclonic conditions increase the entrance of “superficial Atlantic water” into the Mediterranean, and enhance littoral drift favouring progradation. In contrast, the entrance of SAW decreases under low-pressure conditions causing reduced littoral drift, no progradation and, as a consequence, generation of the very large swales or erosional surfaces separating successive spits. (c) In the most complete case, four large prograding bodies called H₁, H₂, H₃, and H₄, can be distinguished, but more ¹⁴C measurements are required to deduce more precise periodicities.

ADDITIONAL INDEX WORDS: Interglacial, sea-level change, bar, littoral dynamics, longshore spit, littoral drift, control erosion.

INTRODUCTION

The general trend of sea-level rises and falls and the regional climatic changes that at long or short term modify the pathways of pressure cells directly affect the interchange of waters between the Atlantic Ocean and the Mediterranean Sea. The study of foraminifers suggests that the influx of Atlantic waters into the Alborán Sea (western Mediterranean Sea) increased during periods of deglaciation in the last 18,000 yr (e.g., Bolling/Allerød warm events) and decreased during periods of climate degradation (e.g., Younger Dryas cool event) (ABRANTES, 1988). There is also indication of a progressive approximation of mean temperatures of these two water bodies since the end of the Termination IB, around 8,500 BP, until it reached an average gradient of 5 °C warmer in the Alborán Sea (WEAVER and PUJOL, 1988).

The more prominent change of fauna in the Alborán Sea took place around 7,100 yr BP with a notable increase of the Atlantic derived Globorotalia inflata. The change has been interpreted as a change from an influx of nonstratified
waters to an influx of a seasonally-stratified body of water (Devaux, 1985).

At present, the main mechanism of influx of superficial Atlantic waters (SAW) is a narrow, fast moving, superficial (less than 100 m deep) current characterized by two clockwise (anticyclonic) eddies in the Alborán Sea (Figure 1) that reach the Spanish and African coasts at fixed points (Parrilla and Kinder, 1987). The maximum income of water and eddy activity occurs in summer due to increased evaporation in the Mediterranean Sea (Cano and Fernández, 1986). Tide gauges record the increment of water influx as a seasonal rise in summer mean sea level in the coastal areas of Alborán Sea under the influence of the incoming mass of water (Figure 2). A sudden fall of sea level occurs in winter months (I.E.O., 1991).

The increase in the income of the relatively cooler, fresher Atlantic water seems to produce marked changes of climatic-oceanographic conditions in the western Mediterranean region. Two types of phenomena have been related to the Atlantic-Mediterranean interaction:

(a) Coastal hazards due to rapid sea-level fluctuations: In periods of increased Atlantic current there is a progressive rise of relative sea level in the zones where the Atlantic jet sweeps the Mediterranean coasts. Periods of inactivity of the Atlantic flow result in sudden fall of relative sea level and, as a consequence, erosion of beach sediments which are deposited at slightly lower topographic heights.

(b) Oceanographic phenomena: An increase of both the incoming of Atlantic water and mixing of waters favours biological productivity in the western Mediterranean.

These short-term factors control the rate and direction of beach and spit bar progradation. They superimpose upon a longer-term tectonic factor that controls the geometry and tridimensional arrangement (i.e., stratigraphic architecture) of coastal units.

The aim of this paper is to analyze the development of spit bars in two littoral zones clearly influenced by the interaction of Atlantic and Mediterranean waters, paying attention mostly to the short-term factors.

The longer-term tectonic factor mostly controls the number of outcropping emergent units (spit bars) that form the systems. In the Mediterranean coast, large systems develop in areas with uplifting trend. By contrast, in the Atlantic area they tend to accumulate in areas with a sinking trend.

This analysis incorporates: (a) morpho-sedimentary aspects, such as the geometry of spit bars as seen in plan, and a first estimate of rates of coastal progradation deduced from systematic sampling and 14C measurements, and (b) the influence of the regional climate or meteorological conditions that directly govern the progradation or erosion of these sedimentary bodies.

**MODEL OF COASTAL DYNAMICS AS RELATED TO CLIMATE**

The present general climatic model of the Iberian Peninsula for a single year consists of an alternation of dry and pluvial seasons.

In summer the Azores Anticyclone moves to the north and anticyclonic conditions dominate pro-
ducing a dry season with larger entrance of superficial Atlantic water into the Mediterranean, relative rise of sea level in the zone of interaction between the Atlantic Ocean and the Mediterranean Sea, and seaward progradation of spit bars and other beach complexes.

In winter, anticyclonic conditions decrease when the Azores Anticyclone moves to the south allowing low-pressure cells to reach the Iberian Peninsula. Under these more rainy conditions the entrance of Atlantic water into the Mediterranean decreases causing the mean relative sea level to fall tens of centimetres in the zone of interaction between the Atlantic Ocean and the Mediterranean Sea. Moreover, the increase of storm frequency and intensity should lead to more or less periodic erosion and destruction of spit bars.

Beach ridges weld onto the shore in the seaward side of spits and open coasts during events of comparatively-higher mean relative sea level, comparable to extreme (secular) spring tides coupled with rough-weather conditions. The intervening swales are thought to represent intervals of slightly-lower mean relative sea level. Repetition of these contrasting conditions produces the seaward progradation of beaches and spits and the addition of new “nails” (inland curved sand bodies) to the far end of spits.

Anticyclonic conditions may persist in the Iberian Peninsula longer than a year if the conjugate action of winter Atlantic polar and Azores anticyclones (that sometimes weld together) prevent low-pressure cells from reaching these low latitudes (drought periods). Extended anticyclonic conditions will allow the generation of beach ridges and the progradation of large spit systems. In contrast, periods of climatic deterioration are marked in the Spanish area by increased precipitation and gentle, relative falls of sea level. Extended periods of this type will be recorded as large swales, defined as narrow depressions elongated parallel to the mean direction of the spit, with no beach-ridge generation.

MEDITERRANEAN AND ATLANTIC BEACH-RIDGE SYSTEMS

Morpho-Sedimentary Units

The studied coastal deposits occur as series of beach ridges and swales of variable width and lateral extent that form spits. In the next pages we use a nomenclature of these morpho-sedimentary units (Figure 3) meant to simplify references; this is not a formal proposal of names.

In a cross section roughly normal to the spit elongation, a spit system consists of several spit-bar units (H) separated by prominent, very large swales (referred to in this paper as major gaps). Spit-bar units consist of sets of beach ridges separated by large swales (i.e., gaps) or erosional surfaces that truncate beach ridges and swales. Each set of beach-ridges includes several beach-ridges. Beach ridges represent single units of beach progradation interpreted as slightly-higher mean sea-level. The horizontal distribution of beach ridges and swales is determined by wave direction.
"SETS" OF BEACH RIDGES AND MINOR EROSIONAL SURFACES, SWALES OR GAPS
NO PROGRADATION (MAJOR GAPS)

TYRRHENIAN IV? (PLEISTOCENE)

SPIT BARS

Figure 4. Spit bar system of Roquetas (Almeria) with location of samples and calibrated radiocarbon ages. Modified after Somoz et al. (1991).
Table 1. Samples. 14C measurements and ages in Mediterranean and Atlantic spit-bar systems. Samples from every spit-bar system are listed from land (above) to sea (below).

<table>
<thead>
<tr>
<th>Spit Bar Systems</th>
<th>Sample</th>
<th>14C Conventional Age (yr B.P.)</th>
<th>14C Calibrated Age (95%)</th>
<th>Age (yr B.P.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mediterranean</td>
<td><strong>R-8</strong></td>
<td>6,450 ± 100</td>
<td>5200 BC-4760 BC</td>
<td>7,150-6,710</td>
</tr>
<tr>
<td></td>
<td><strong>R-7</strong></td>
<td>3,600 ± 100</td>
<td>1760 BC-1320 BC</td>
<td>3,710-3,270</td>
</tr>
<tr>
<td></td>
<td><strong>R-10</strong></td>
<td>2,150 ± 400</td>
<td>780 BC-1050 AD</td>
<td>2,730-900</td>
</tr>
<tr>
<td></td>
<td><strong>R-2</strong></td>
<td>1,870 ± 35</td>
<td>460 AD-630 AD</td>
<td>1,490-1,320</td>
</tr>
<tr>
<td>Atlantic</td>
<td>*R-2203</td>
<td>2,605 ± 50</td>
<td>385 BC-225 BC</td>
<td>2,335-2,175</td>
</tr>
<tr>
<td></td>
<td>*R-2207</td>
<td>1,440 ± 50</td>
<td>900 AD-1040 AD</td>
<td>1,080-910</td>
</tr>
<tr>
<td></td>
<td>*R-2180</td>
<td>1,875 ± 50</td>
<td>430 AD-650 AD</td>
<td>1,520-1,300</td>
</tr>
<tr>
<td></td>
<td>*R-2179</td>
<td>1,460 ± 50</td>
<td>855 AD-1045 AD</td>
<td>1,085-905</td>
</tr>
<tr>
<td></td>
<td>*R-2208</td>
<td>3,145 ± 50</td>
<td>1090 BC-850 BC</td>
<td>3,040-2,800</td>
</tr>
<tr>
<td></td>
<td>*R-2181</td>
<td>2,270 ± 50</td>
<td>40 BC-200 AD</td>
<td>1,990-1,750</td>
</tr>
<tr>
<td></td>
<td>*R-2186</td>
<td>2,120 ± 50</td>
<td>130 AD-390 AD</td>
<td>1,820-1,560</td>
</tr>
<tr>
<td></td>
<td>*R-2182</td>
<td>2,320 ± 50</td>
<td>100 BC-130 AD</td>
<td>2,050-1,820</td>
</tr>
<tr>
<td></td>
<td>*R-2205</td>
<td>2,185 ± 50</td>
<td>80 AD-270 AD</td>
<td>1,870-1,680</td>
</tr>
<tr>
<td></td>
<td>*R-2185</td>
<td>1,860 ± 50</td>
<td>440 AD-655 AD</td>
<td>1,510-1,295</td>
</tr>
<tr>
<td></td>
<td>*R-2210</td>
<td>2,010 ± 50</td>
<td>270 AD-470 AD</td>
<td>1,680-1,480</td>
</tr>
<tr>
<td></td>
<td>*R-2204</td>
<td>1,490 ± 50</td>
<td>830 AD-1020 AD</td>
<td>1,120-930</td>
</tr>
<tr>
<td></td>
<td>*R-2187</td>
<td>1,790 ± 50</td>
<td>530 AD-700 AD</td>
<td>1,420-1,250</td>
</tr>
<tr>
<td></td>
<td>*R-2188</td>
<td>1,850 ± 50</td>
<td>440 AD-690 AD</td>
<td>1,510-1,290</td>
</tr>
</tbody>
</table>

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Note: Samples in every location are listed from land (above) to sea (below)

levels separated by swales (lower mean sea-levels) generated during long-time spans of anticyclonic conditions (Figure 3).

The more prominent swales (major gaps) correspond to long periods of climatic deteriorations. The erosional surfaces can be interpreted as related to rises of relative mean sea level during which storm waves reach the topographically highest parts of the beach profile and partially destroy the seaward, subaerial part of spits and beaches.

The Mediterranean Systems: Roquetas (Almeria) (Figure 4)

To the south of Roquetas, the coast is a low to moderate energy, micro tidal coast with meteorological tides. Tidal range is about 0.45 m. Tectonic and hydrodynamic factors control the development of spits. Faulting induced lagoons in the sinking blocks, whereas, uplifted sides acted as rocky headlands that served as a base for spit growth. The hydrodynamic factor is multiple. Because there are no major rivers in this coastal segment, there is limited sediment supply to the shore through littoral drift. Particularly easterly winds and moderate wave action induce a littoral drift and generalized progradation towards the south-east (GOY et al., 1986; SOMOZA et al., 1991).

Morphological Expression

Spit bars (H) are limited by gaps (zones of no progradation) or by erosional surfaces. There are four generations of spit bars (H₁, H₂, H₃ and H₄) in Roquetas. Each spit consists of a series of beach ridges (called a set) separated by minor erosional surfaces (Figure 4). The gap between H₂ and H₃ is particularly wide.

Detailed mapping aimed to identify swales separating beach ridges preceded sampling for 14C. Sampling points were selected in swales close to the area where the spits weld to the mainland. The growth of the system began ca. 6,930 ± 200 yr BP (GOY et al., 1986), (Table 1).

The Atlantic Spanish Coast (Huelva-Cadiz)

Due to the orientation of this mesotidal coast (mean tidal range about 2.1 m) the incoming waves generated by storm and daily winds that blow from the southwest induce a prominent littoral drift to the east and southeast (Figure 5).

Sediment supply to the coast comes from ero-
Figure 5. Holocene spit bar systems in the southwestern Spanish littoral. Modified after Zazo et al. (1992).
sion of poorly consolidated sandy Cenozoic sediments forming the coastal cliffs from near Cape San Vicente (southern Portugal) in the west to Cádiz in the southeast. Building of dams strongly reduced the sediment supply by rivers in the last half century.

Four large systems of spit bars, El Rompido, Punta Umbria, Doñana, and Valdelagrana, enclose large tidal flat and marsh zones. The spits occur updrift of relatively large rivers that act as sediment traps, except in Valdelagrana where the present pattern is somewhat more complicated. After detail mapping we sampled three of these spits for ¹⁴C dating (Table 1).

Spit systems include several generations of spit bars which have been compared to those of Roquetas—and named in the same way—not only because of ¹⁴C dating, but also because of the morpho-sedimentary expression both in the field and air photographs.

**El Rompido System (Figure 6)**

The spit bar system of El Rompido partly closes the estuary of the Piedras River. These systems are much more active at present than in former times. Detailed sedimentological studies and evolution were discussed by DABRIO et al. (1980, 1986), DABRIO and POLO (1983, 1987), and ZAZO et al. (1992).

There are four coalescing units. The two inland, older ones could not be dated yet. Preliminarily, we supposed that they may correspond to H₁ and H₂ (?). The ages of the younger units are similar to H₃ and H₄ (Figure 6). However, according to BORREGO et al. (1993), the maximum transgression took place between 4,500 and 3,500 yr BP, the barrier island off the river mouth generated around 3,500–2,000 yr BP, and the development and rapid growth of the spit occurred in the last 200 yr. We completely disagree with these conclusions for several reasons: (a) there is no indication in the paper about when, where, and how samples for radiometric dating were collected; thus the location of the dated samples and their precise situation in the coastal sequences or morpho-sedimentary units is unknown; (b) the authors do not indicate if these are (or are not) calibrated ages; (c) it is most unlikely that the transgressive maximum took place in different moments along the same coastal segment, only a few hundreds of kilometres long, and many ¹⁴C data indicate an age around 6,500 yr BP for this event; (d) according to our detailed field studies and ¹⁴C measurements, the growth of the spit bar began much earlier than 200 yr BP.

**Doñana System (Figure 7)**

The spits grew from the uplifted block of a NE-SW trending normal fault (Figure 5). Subsidence during Quaternary times favoured the develop-
iment and preservation of the large marshland that forms the Doñana National Park. Eolian dunes moved by southwesterly winds cover at present a significant part of the oldest part of the spit and partly invade the marshland behind it.

**Morphological Expression**

The present visible, and recognizable, morphological expressions of this system of spit bars (Figure 7) are two spits (H₃ and H₄).

We sampled for ¹⁴C dating in swales or gaps across the spits, from the innermost, older parts of the spits to the coast (Figure 7, Table 1) aiming to estimate the age and duration of coastal progradation. To calculate the time required to form a set, we considered only those samples that yielded data coherent with their relative position in the geological map. It was obvious that ages calculated for other samples indicated reworking and re-deposition of bivalve shells from older beach ridges (Figure 7). This meant considering the younger age, according to the direction of progradation, to avoid being misled because of reworking. We could not sample and date accurately the beginning of spit construction, although it is possible to recognize older beach ridges below eolian dunes (Figure 7). The landward (northern) side of the system of spit bars was severed by erosion along the banks of a former meander loop of the Guadalquivir River. Drill data revealed that as the area actively subsides, even in recent times, some of the oldest beach ridges may be at present below sea level and under the marshland of Doñana National Park (Figures 5 and 7).

**Valdelagrana System (Figure 8)**

The Guadalete River debouched in the Bay of Puerto de Santa María-Cádiz during the Holocene transgressive maximum. It formed a delta. After reaching the maximum transgression, spit bars (H₁) grew from the north as a consequence of the progradation of the delta front. In the southern side, littoral drift flowing to the north induced the development of spits attached to the Puerto Real headland. These spits did not completely close the bay, allowing the wave action to shape the delta in a lobate fashion. Spits belonging to the H₂ generation grew from both the north and south sides of the bay. However, they did not connect, and the central part of the bay remained open to the sea. It is interesting to stress the influence of the San Pedro River, a former distributary of the Guadalete River but a mere tidal channel nowadays. The river channel actively shifted across the barrier island and lagoon complex that partly closed the bay. Such a migration deeply and successively eroded the older coastal units. The more recent shift of the river course created space for the deposition of the H₄ episode, forming the present-day Valdelagrana spit bars. Superimposed to this active evolution is the tectonic subsidence related to the Puerto de Santa María and Cádiz faults (Figures 5 and 8).

**SEDIMENTARY UNITS AND ¹⁴C MEASUREMENTS**

The spit systems include four generations of spit bars (H₁, H₂, H₃, and H₄) which are separated by major gaps or erosional surfaces. ¹⁴C measurements date the age of these units, and the duration of spit growth can be roughly estimated from adjacent samples.

These four episodes of intense progradation took place roughly between ca. 6,900 and 4,000 yr BP.
Figure 8. Simplified map of El Puerto de Santa María Bay and Valdevaqueros spit bar system with indication of samples and calibration radiation ages.
(H$_4$), 4,000–2,500 yr BP (H$_3$), 2,500–1,000 yr BP (H$_2$) and 1,000 yr BP–Present (H$_1$). These episodes are separated by events of no progradation or erosion that occurred at ca. 4,000 yr BP, 2,500 yr BP, and 1,000 yr BP as suggested by the scarcity or lack of values of $^{14}$C measurements visible in a plot of relative ages for these units (Figure 9). On the other hand, Zazo et al. (1993) studied Mediterranean Holocene marine terraces corresponding with sea levels of slightly higher highstands and deduced that there are 3 maxima dated as ca. 5,100 yr BP, ca. 3,500 yr BP, and ca. 2,400 yr BP which coincide with three of the generations of rapidly(?)-prograding spit bars (H$_1$, H$_2$, and H$_3$) in the area linking the Atlantic and the Mediterranean (Almería-Cádiz-Huelva).

The best morphologically observed gap periods in the Mediterranean area (Roquetas system) are the ones corresponding to ca. 4,000 yr BP, between H$_1$ and H$_2$ and ca. 2,500 yr BP, between H$_2$ and H$_3$ (Figure 4).

In the Atlantic area (Doñana spit bar), major changes of spit geometry occur separated by major gaps. One of these major gaps separates the sets of beach ridges a and b inside the spit bar H$_3$. The gap separating sets H$_3$ and H$_4$ (ca. 800 yr BP) appears as a notable period of erosion because there are bivalve shells of this age incorporated in the succeeding beach ridges (samples R-2187 and, particularly, R-2188, Figure 7). Partial erosion of sets of beach ridges should correspond to times of sea level rise when the long-period, storm waves can reach the topographically highest parts of the beach.

The best recorded gaps in Valdelagrana are those between H$_1$ and H$_2$ associated to change in the direction of progradation of spits and their long-distance shift in a seaward direction, and between H$_2$ and H$_3$, particularly, in the southern side of the bay. The gap between H$_3$ and H$_4$ is enormous, and it meant the partial destruction of the spit system following a major shift of the San Pedro River inlet.

In El Rompido, the change from H$_3$ to H$_4$ is also very prominent.

**Periodicity of Growth Episodes in Doñana System**

Detail study of Doñana spit bar system evidences that it is composed of a series of beach ridges associated in sets. A set includes four ridges separated by intervening swales. There are five sets named from “a” to “e”. Major swales and/or erosional surfaces separate adjacent sets with different inflexion; they represent no progradation and/or, in some cases, partial erosion of the outer
As each set includes four beach ridges (Figures 3 and 10), we may suggest an average rate of ca. 100 yr for the generation of individual beach ridges, which is consistent with the periodicity of particularly active periods of wave activity and sediment accumulation visualized as large stormy events occurring once in a century. However, we lack the needed statistical precision to adequately back this statement. In this sense, based on thermoluminescence of recent cores, Cini Castagnoli et al. (1988) explain a 206 yr modulation as the sum of waves with 12.06 yr and 10.8 yr periods. This modulation describes the general shape of the sunspot secular variations in the last three centuries, where the modulation modes correspond to sunspot cycles with minimal sunspot numbers (climatic deteriorations). Four modulation peaks with maximal sunspot numbers (climatic ameliorations) are referred to in the last 400 yr. Therefore, we may correlate the four beach ridges generated during a 400 yr span with these four maximal sunspot number periods, and suggest the correlation between solar activity and beach-ridge progradation. The solar minima periods correspond to erosional periods that give rise to swales.

CONCLUSIONS

The study of spit bar systems in the area connecting the Atlantic Ocean and Mediterranean Sea yields some interesting conclusions in three fields.

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**Table 2. Set of beach ridges in the H₁ and H₂ spit bar units of Doñana (¹⁴C measurements).**

<table>
<thead>
<tr>
<th>Spit-bar Unit</th>
<th>Sets</th>
<th>Beach Ridges</th>
<th>Morphology</th>
<th>Radiocarbon Data (non-recycled samples only)</th>
</tr>
</thead>
<tbody>
<tr>
<td>H₁</td>
<td></td>
<td></td>
<td></td>
<td>no data</td>
</tr>
<tr>
<td>H₁</td>
<td></td>
<td></td>
<td>poorly exposed</td>
<td>1,680-1,480</td>
</tr>
<tr>
<td></td>
<td>a</td>
<td>4</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>b</td>
<td>4</td>
<td></td>
<td>1,520-1,250</td>
</tr>
<tr>
<td></td>
<td>c</td>
<td>4</td>
<td></td>
<td>1,120-930</td>
</tr>
<tr>
<td>H₂</td>
<td>d</td>
<td>4</td>
<td>no data</td>
<td></td>
</tr>
<tr>
<td>H₂</td>
<td>e</td>
<td>4</td>
<td>400-Present (watch tower)</td>
<td></td>
</tr>
</tbody>
</table>

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**Figure 10. Idealized profile of sea-level stages, and indirectly simplified section, during the generation of a set of beach ridges in Doñana spit bar.**

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Holocene Sea-Level Fluctuations
Morpho-sedimentary analysis and $^{14}$C measurements indicate that each spit bar system consists of several spits ($H_1$, $H_2$, $H_3$, and $H_4$). The best preserved case-study (Roquetas system, Almerian coast) began to grow around 6,900 yr BP during the Present Interglacial which reached its maximum ca. 6,500 yr BP. Major swales (gaps) due to no progradation or partial erosion of beach faces separate successive spits. In some cases, gaps coincide with reversion of longshore drift (such as the gap separating $H_3$ and $H_4$ in the Roquetas system). A spit comprises several sets or groups of beach ridges and the intervening swales. According to age calculations, the generation of a set lasts about 430 yr and individual beach ridges may be deposited during events separated by about one hundred years.

Generation of spit bar systems is related to periods of slightly fluctuating sea levels (gentle “highstand” and “lowstand”). The income of “superficial Atlantic Water” into the Mediterranean increases in summer when anticyclonic conditions prevail. The greater influx produces a relative rise of sea level in the Mediterranean area near the connection with the Atlantic and a stronger longshore drift that favours the progradation of spit bars.

If winter deep low-pressure cells reach the southern Iberian Peninsula, following the disappearance of Atlantic anticyclones, the influx of SAW diminishes and relative sea levels fall; more frequent and stronger storm waves partly erode beach profiles along spit bars. Climatic deteriorations produce more and regularly spread (not sporadic) precipitation.

Unbalance of seasonal conditions, characterized in Southern Spain by the dominance of anticyclonic conditions observed in the last scores of years, favours the progradation of spit systems because during the scarce, short low-pressure periods, waves are unable to erode these large bodies of coastal sediments.

This assumes a direct link between the generation of morpho-sedimentary units of spit bars ($H$), sea level highstands, and prevailing anticyclonic conditions. Major swales or gaps without sedimentation coincide with non-anticyclonic conditions or with climatic deterioration.

Partial erosion of beach ridges in the seaward side of spits can be related to episodes of sea level rise coupled with severe storms and long period waves.

The spit systems include four generations of spit bars ($H_1$, $H_2$, $H_3$, and $H_4$), dated using $^{14}$C measurements, which are separated by major gaps or erosional surfaces. Episodes of intense progradation took place roughly between ca. 6,900 and 4,000 yr BP ($H_1$), 4,000–2,500 yr BP ($H_2$), 2,500–1,000 yr BP ($H_3$) and 1,000 yr BP–Present ($H_4$). Prograding episodes are separated by other periods of no progradation or erosion thought to have occurred at ca. 4,000 yr BP, and 1,000 yr BP.

In Doñana system, a ca. 400 yr periodicity governs the progradation of sets of individual spit bars separated by gaps.

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**LITERATURE CITED**


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RESUMEN

Los sistemas de flechas litorales aflorantes en el área de conexión Atlántico-Mediterráneo comenzaron a formarse hace unos 6.900 años durante el máximo del Presente Interglacial. Del estudio morfo-sedimentario de estos sistemas de flechas, los análisis de dinámica litoral, en particular la deriva litoral y el intercambio de “agua atlántica”-agua mediterránea, y los resultados de medidas de C¹⁴ se deduce que: (a) el máximo del Presente Interglacial se produjo hacia los 6.500 años BP; (b) la progradación o no de las flechas litorales está relacionada con el clima, de tal forma que bajo condiciones anticiclónicas se produce mayor entrada de “agua atlántica superficial” (ASW) hacia el Mediterráneo, mayores derivas litorales favoreciéndose la progradación; por el contrario, en condiciones de bajas presiones se produce menor entrada de “agua atlántica superficial”, disminución de la deriva, no progradación y por consiguiente formación de los grandes surcos y las superficies de erosión que separan las flechas; (c) en el caso más completo se pueden diferenciar cuatro grandes cuerpos progradantes, o flechas, denominados H₁, H₂, H₃ y H₄, pero se requieren más medidas de C¹⁴ para poder deducir periodicidades más ajustadas.