Holocene aeolian phases and human settlements along the Atlantic coast of southern Spain

Francisco Borja,¹ Cari Zazo,² Cristino J. Dabrio,³ Fernando Díaz del Olmo,⁴ José Luis Goy⁵ and Javier Lario²,⁵

(¹Area de Geografía Física, Facultad de Humanidades, Universidad de Huelva, 21007 Huelva, Spain; ²Departamento de Geología, Museo Nacional de Ciencias Naturales-CSIC, c/José Gutiérrez Abascal 2, 28006 Madrid, Spain; ³Departamento de Estratigrafía e Instituto de Geología Económica – CSIC, Facultad de CC. Geológicas, Universidad Complutense, 28040 Madrid, Spain; ⁴Facultad de Geografía e Historia, Cátedra de Geografía Física, Universidad de Sevilla, c/Maria de Padilla s/n; 41001-Sevilla, Spain; ⁵Departamento de Geología (Geodinámica), Facultad de Ciencias, Universidad de Salamanca, 37008 Salamanca, Spain)

Abstract: A combined geomorphological, radiocarbon dating, archaeological and historical approach permits a refining of the age of the coastal dune systems related to estuaries in the Gulf of Cádiz. Three dune systems are distinguished in this paper. The oldest one, D1, which accumulated under prevailing WSW winds during the first millennium BC, overlays both the occupational horizons of Late Neolithic-Early Copper Age (fourth millennium BC) and the ‘lithic workshop levels’ (fourth to second millennia BC). The middle dune system, D2, containing both Roman and medieval remains, accumulated between the thirteenth or fourteenth centuries and the seventeenth century AD. The youngest D3 system is associated with the time of building of watchtowers in the seventeenth century AD but extends to the present; it is related to SW prevailing winds. We explain the absence of aeolian deposits prior to ~2700 cal. BP as the result of trapping of a large part of the sediment supply in the estuaries, which starved the neighbouring beaches and aeolian settings. Aeolian accumulation reached significant values when sedimentation in the coastal zone changed from being mainly aggradational in the estuaries (~6500–2700 cal. BP) to mainly progradational in spit barriers and related dunes (post ~2700 cal. BP). The present analysis of aeolian systems suggests a non-direct correlation, at least in some cases, between coastal progradation of spit barriers and aridity.

Key words: Foredunes, aeolian sheets, dunefield, spit barrier, radiocarbon dating, historical evidence, archaeological evidence, climatic change, sea-level change, Gulf of Cadiz, Spain, late Holocene.

Introduction

Borja (1997) differentiated three basic types of littoral dunes in southwestern Spain, according to morphogenetic criteria and taking into account the elementary types of dunes present in each case. Foredunes (coastal dunes) are directly related to beaches. Dunefields usually derive from foredunes but their genesis is related not only to aeolian phenomena but also to the nature and development stage of vegetation. Littoral aeolian sheets are formed by a vertical stacking of broad dunefields separated by palaeosols. These types may extend over hundreds of square kilometres where the elementary dune types are mostly transverse and parabolic dunes. Aeolian and hydrogeological processes – particularly the behaviour of non saturated layers – concur with the genesis of littoral dunes.

Foredunes are coastal dunes or dune ridges oriented parallel to the shoreline, occurring at the landward margin of the beach, along the shoreward face of a beach ridge, or at the landward limit of the highest tide, and more or less completely stabilized by vegetation (Bates and Jackson, 1980). Aeolian foredunes occur associated with beach ridges of coastal plains and spit barriers. As the sand of foredunes derives from the upper foreshore and
backshore, it is widely accepted that the age of a foredune is virtually the same as the age of the beach ridges upon which it was accumulated. If beach sediments are dated, this age may be considered as the maximum age of sand accumulation. However, it is not sure that the accumulation of well-developed foredunes lasts the same time as the deposition of the underlying beach deposits.

The spit barrier systems closing the estuaries offer favourable settings for human settlements owing to their proximity to the littoral and natural harbours (Figure 1). For this reason, archaeological remains are relatively frequent.

In the most complete case found in the Atlantic-Mediterranean linkage area, each spit barrier system is formed by four coastal morpho-sedimentary units (spit barriers) that Zazo et al. (1994) named H1 to H4 (Figure 2). Beach crests and swales on the surface of each unit are arranged in sets separated by erosional surfaces and/or particularly large swales that Zazo et al. (1994) called a gap. Numerous radiocarbon measurements allowed to deduce the age of the four spit units (Zazo et al., 1994; 1996a; Goy et al., 1996; Rodríguez-Ramírez et al., 1996; Lario, 1996). In this paper we use the ages of these units expressed as cal. BP: H1 (6500–4700 cal. BP), H2 (4400–2700 cal. BP), H3 (2400–700 cal. BP) and H4 (500 cal. BP; present).

This paper has a double aim: (1) to identify periods of increased and reduced aeolian deposition during the middle and recent Holocene in the Gulf of Cádiz, located at the southwestern Atlantic littoral of Spain (Figure 1) based on the study of dune systems; (2) to place these periods in a chronological sequence based upon radiocarbon dating, archaeological remains and historical data, and to relate them with the climatic and sea-level changes that took place during the last 6500 yr BP.

All radiocarbon data are listed in Dabrio et al. (1999). We use AMS and α-spectrometry radiocarbon data from marine shells, peat and vegetal remains. In order to compare radiocarbon dates with archaeological data all radiocarbon data have been calibrated using the CALIB software (Stuiver and Reimer, 1993). Previously, reservoir effect have been corrected in marine samples (R = −440 ± 85 yr in this area; Dabrio et al., 1999).

Results

Foredunes and associated small dunefields in Ayamonte (Isla Canela) estuarine barrier

The estuarine barrier of the rivers Guadiana (on the Spanish border with Portugal) and Carreras (Figure 3) includes the spit barrier units H2, H3, and H4, present largely in the Isla Canela area. The innermost, oldest recognizable deposits of the spit unit H2 have been dated as 2950 cal. BP (Figure 2), but archaeological remains of lithic industries forming the so-called 'lithic workshop levels' dated as fourth to second millennia BC (Gómez et al., 1993) suggest the existence of an occupation level in the spit prior to 2950 cal. BP (but still H1 in age).

According to this, the accumulation of parabolic dunes and foredunes recognized as D2 began c. 3000 cal. BP, and finished before 930 cal. BP (the oldest age dated in H3 and the overlying related foredunes).

The Isla Canela-Punta del Moral dune system (D3) found south of El Pinillo unit is related to the spit unit H3. Although the oldest age dated in the H3 beach deposits in this area is 930 cal. BP, they contain remains of a human settlement and a mausoleum of Late Roman age (third to fourth centuries AD). These remains suggest that the spit was big enough at that time to accept such stable buildings. The dunes of system D3 incorporate remains of buildings and cover the already deteriorated walls of the mausoleum. This proves that they accumulated after the fourth century. However, we consider that they actually accumulated after the tenth century (post-930 cal. BP) because at that time the spit barrier was still prograding. The most recent age of dune system D2 can be fixed because it is older than the Torre Canela watchtower built in the seventeenth century but is covered by younger (D1) aeolian dunes containing many postmedieval remains of ceramics (Borja, 1992).

The D3 aeolian system consists of foredunes and some poorly developed transverse dunes related to the most recent prograding phase (H2) of the spit which took place in the last 200 to 300 yr, as demonstrated in Torre Canela (see above). The system D3 is best represented to the south, between Punta de la Espada and Punta del Caimán. In this area it is separated from D2 by tidal flats (marismas de San Bruno).

Foredunes and dunefields in Punta Umbría-Punta Arenilla estuarine barrier (Huelva)

The Odiel-Tinto estuary is almost separated from the open sea by a complex estuarine barrier formed by the Punta Arenalilla and Punta Umbría spit systems, and Saltés Island (Figure 4). There are aeolian foredunes and dunes mostly of transverse type, with some parabolic and a few barchans.

The oldest (albeit indirect) indication of spit sedimentation comes from cores (Zazo et al., 1996b) drilled in Las Madres coastal lake. The lake, a former marine bay (lagoon), was already separated from the sea at 6290 cal. BP (Figure 2). We assume that the separation was produced by beach ridges belonging to the H1 unit of Punta Arenalilla spit (much in the same way as present coastal configurations in the area) that do not crop out nowadays. The system D1 in Punta Arenalilla consists of parabolic dunes that migrated under winds blowing from the WSW after 6290 cal. BP. But, as dunes covered a 'lithic workshop level' of fourth to second millennia BC, their age must be necessarily younger, and should be associated to the progradation of the spit systems H2/H4, but when exactly? Radiometric data indicate that the sedimentation of H2 in Punta Arenalilla and Punta Umbría took place after c. 3000 BP. Mapping (Figure 4) allows us to infer that its upper limit is coeval with the oldest beach ridges in spit system H3.

The aeolian system D2 consists of foredune and large transverse dunes, particularly well exposed in Punta Umbría spit. In Punta Arenalilla they cover older (D1) dunes. The youngest dune systems overlaid by these dunes are of H3 age. Dune generation continued until around the seventeenth century when the Torre Umbría watchtower was built.

The youngest aeolian system (D4) includes several ridges of foredunes in Punta Umbría. In Punta Arenalilla there are also barchans, which are exclusive to this area. Dune generation in this system is related to the progradation of the spit unit H4 in the last three centuries.

Figure 1 Location map of the study area and localities cited in the text.
Figure 2  Chronostratigraphy of aeolian phases and human settlements in the Gulf of Cádiz. Note that italic typing indicates calibrated ages.

Figure 3  Foredune systems between Ayamonte and Isla Cristina, in the Spanish (eastern) side of the Guadiana estuary.
Foredunes in Doñana-La Algaida estuarine barrier (provinces of Huelva and Cádiz)

The spit barrier systems of Doñana and La Algaida separate the estuary of the Guadalquivir river from the open sea (Figure 3). A pre-Roman settlement found in La Algaida dated as eighth to second centuries BC (Menanteau, 1979) indicates that sedimentation of the spit until H2 began before this date. In contrast, the oldest radiocarbon dates obtained in La Algaida is 1965 cal. BP (Figure 2), that corresponds to shells deposited later.

The record of aeolian dunes in this area includes small occur

Foredunes of Valdelaguna sand sheet of Cantarranas (Cádiz province)

In addition to the foredune systems of Valdelaguna spit barrier, we have included in our study the Cantarranas littoral aeolian sand sheet owing to the archaeological richness of the area around Puerto de Santa María (Figure 6). The littoral aeolian sand sheet

Figure 4. Foredunes and dunesfields in the complex Os del Tinto estuarine barrier formed by the spits of Punta Umbria and Punta Agridolla. Archaeological data in San José island after Rubio et al. (1997).

San José into some 600 m, Figure 3) demonstrating rates of coastal progradation up to 4 m/yr for the last 300 years.

Figure 5. Foredunes in the spits of Doñana and La Algaida in the barrier of the Guadalquivir estuary. Archaeological data after Menanteau (1979).

Figure 6. The foredunes of Valdelaguna spit (the estuarine barrier of the Guadalquivir river) and the aeolian sheet of Cantarranas close to El Puerto de Santa María.
extends for some 10 km northwest of Puerto de Santa María, and penetrates several kilometres inland.

Archaeological remains included or related to the littoral aeolian sheet were collected in the archaeological sites of Cantarranas (Borja, 1992; Díaz del Olmo et al., 1993) and P-19 in Puerto de Santa María (Borja et al., 1997). According to Borja et al. (1997), the synthetic sequence here is as follows (Figure 2). The sub-stratum consists of Pleistocene calcarenites and/or marlstones, topped by a weathered layer (red soil). Above this is an occupational horizon (Figure 7) of Late Neolithic-Early Copper (fourth millennium BC) age. This horizon is covered by the D1 aeolian deposits. The oldest dated age of the dune system is the first millennium BC because it contains archaeological remains of several cultural phases between the sixth and the second centuries BC. Above these, there are remains of a salt factory for fish used in several periods. The last time this was used was between the fourth and the early second centuries BC (Figure 8).

In the Valdelagrana spit, the dune system D1 is less developed (Figure 6). It is mostly associated with the spit unit H2 whose oldest radiometric age is 2905 cal. BP, but a site of Bronze Age (1850-1650 BC; Figure 2) found in H2 indicates that the spit existed prior to 3500 BP (Gómez Ponce et al., 1997).

Remains of a Roman road constructed between the first century BC and the second century AD (Gómez Ponce et al., 1997) crossing the spit units H2 and H3 (Figure 6) offers further proof of the ages proposed for the spit units.

The foredune system D2 yields late medieval remains corresponding to an interval ranging from the late fifteenth to early seventeenth centuries AD. The dune systems D1 and D2 are separated by a regional discontinuity evidenced by an organic soil. The discontinuity lasted at least from the first century BC to the fourteenth century AD. The most recent foredune system (D3) occurs related to the spit unit H4 that was deposited in the last 500 yr. In Cantarranas, dunes of the system D2 fossilize ruins of houses dated as seventeenth century AD (Borja et al., 1997) and crown the interior morphologies of the littoral aeolian sheet.

**Discussion**

Aeolian dunes occur more or less continuously along the coast of the Gulf of Cádiz, and are particularly well developed between the estuaries of Odil-Tinto (Huelva province) and Guadalquivir (Huelva and Cádiz provinces) rivers, covering the El Asperillo cliffs (Figure 1). Six aeolian units with ages ranging from Late Pleistocene to present have been distinguished. These aeolian units are limited by erosional supersurfaces associated with weathering profiles that are interpreted as periods with aeolian activity when deposition of sand was not significant; this is demonstrated by erosion of the underlying deposits (Zazo et al., 1997).

In this paper we have studied the foredune systems associated with the spit barrier systems of Ayamonte-Isla Canela, Punta Umbría-Punta Arenilla, Doñana-La Alguía, and Valdelagrana, and the littoral aeolian sand sheet of Cantarranas in the Guadalete river mouth. As their genesis is closely related to the recent evolution of the Guadiana, Odil-Tinto, Guadalquivir and Guadalete estuaries respectively (Figure 1), a correlation with aeolian deposits accumulated far away from estuarine settings (Zazo et al., 1997) is only possible for the more recent units, that were deposited after the trapping effect of estuaries decreased and significant coastal progradation took place.

We record the maximum of the Flandrian transgression (~6500 14C yr BP) as the maximum advance of estuarine barriers into the estuary basin (Dabrio et al., 1999), or the maximum sea-level elevation (around the present 0 m level) in non-estuarine Mediterranean coasts (Zazo et al., 1994). After that, up to four spit barrier units were deposited in the most complete cases: H1 (6500 to 4700 cal. BP), H2 (4400 to 2700 cal. BP), H3 (2400 to 700 cal. BP), H4 (500 cal. BP to present) separated by periods of no deposition and/or coastal erosion, indicated by gaps in the prograding pattern.

Only the three youngest spit barrier units have been observed so far along the Atlantic coasts of the Iberian Peninsula, where our study area is located (Zazo et al., 1994; 1996a; Goy et al., 1996). This is due to the prevalence of coastal aggradation as compared with progradation between ~6500 and 2700 cal. BP (Goy et al., 1996; Zazo et al., 1996a). Recent results including the study of 19 drill cores from Odil-Tinto and Guadalete estuaries (Dabrio et al., 1999) have confirmed the generation of the maximum flooding surface inside the estuaries between 7000 and 6000 cal. BP, capping the Flandrian transgressive systems tract. The absence of H1 deposits in the Atlantic spit barrier systems is due to trapping of a large part of the fluvial sediment supply into the central basins of estuaries during the highstand.

Three aeolian dune systems, called D1, D2, and D3, in ascending stratigraphic order, that include foredunes, dunefields and littoral aeolian sheets have been distinguished. The age of these dune systems have been deduced from the ages of the spit barrier systems (H) with which they are associated, and the archaeological and historical remains that they contain.

According to these data, accumulation of aeolian systems (D1) began ~2500 cal. BP (c. 600 yr BC) shortly after a firm emerged substratum of H2 age existed. They formed continuous ridges above the storm surge levels of the beach barriers or littoral aeolian sheets near the estuaries. This is the case of spit 19 (Puerto de Santa María, Cádiz), where the archaeological record includes several cultural phases (Figure 2). The aeolian system D1 ended

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*Figure 7* 'In-situ' Mañá-Pascual A-D amphitheatre of the salt factory for fish (fourth century BC) found in archaeological site P-19 (Puerto de Santa María, Cádiz, Spain). After Borja et al. (1997).
in the early second century BC as suggested by amphorae of the salting factory for fish. The beginning of deposition must coincide with noticeable changes of the coastline which took place at ~2700 cal. BP caused by a shift in palaeowind directions from the W to WSW (Zazo et al., 1996a; Goy et al., 1996). This triggered a large coastal drift to the east. After this time, spits growing to the east and southeast prevailed over the ones accreting in opposite directions in all estuaries (Figures 3 and 4).

The absence of aeolian sediments between c. 6500 cal. BP and c. 2500 cal. BP may be related to the evolution of estuaries and their limiting estuarine barriers in the area. During the deposition of the spit unit H1, most sediments were trapped in the inner parts of the estuaries. This means that sediment supply to the estuarine barriers was not very important and these were largely reworked by lateral shifting of the tidal inlet (estuarine channel). This is a reasonable explanation for the absence of subaerial record of the spit system H1 in the Gulf of Cádiz. During deposition of the spit system H2, sedimentation took place mostly in the axial zones and sediment supply increased, improving the preservation potential of the subaerial parts of the spits (Dabrio et al., 1999).

Archaeological data from site P-19 suggest that accumulation of the system D3 took place between the late sixth and early second centuries BC.

The beginning of the next system is more difficult to establish but, according to data from site P-19, there is a sedimentary hiatus of regional extent marked by an organic palaeosol that separates the aeolian systems D3 and D4. This break in sedimentation has been referred to as the 'Roman-Medieval discontinuity' (Borja et al., 1997). The end of this episode is well observed in all the studied areas as ceramic remains of post-medieval age (late fourteenth to early seventeenth centuries AD) are included in sediments of the D3 system indicating that the probable age of this system is between the fourteenth and seventeenth centuries AD (Figure 2). Prevailing winds during this phase were from WSW.

Sedimentation of aeolian system (D3), began around the early seventeenth century, when the watchtowers were built, and continues at present under prevailing wind directions from the SW.

The only climatic data available were obtained from pollen analysis in the Las Marías coastal lagoon (Zazo et al., 1996b). Vegetation assemblages record a first change from ~6290 cal. BP to more arid conditions c. 4000 cal. BP and a second, and more important, c. 900 cal. BP, when peat ceased to accumulate. Moreover, Stevenson and Harrison (1992) founded main environmental changes at similar ages, but they assumed that these changes are related to human influence. Probably, climatic changes conditioned the agricultural management in this area and both causes together influenced over the abrupt changes in the environment and landscape.

Following Zazo et al.'s (1994) conclusions, the spit barrier units H1 generated during phases of coastal progradation, have been related to periods of still stand of gently falling sea level and more arid climate. The intervening gaps (no progradation and/or coastal erosion) have been correlated with periods of sea-level rise under low-pressure atmospheric conditions. The relations of aeolian dune systems (D) with the coastal units H (Figure 2) suggest that aeolian accumulation began at the end of gaps, when the larger availability of sand favoured wind transport. However, the regional 'Roman-Medieval discontinuity' marked by an organic palaeosol separating the aeolian systems D3 and D4 suggests more humid conditions during most of deposition of system H3 and opposes a direct correlation between coastal progradation and aridity as previously assumed.

Conclusions

Archaeological and historical data supplied in this paper confirm the duration of the accumulation of spit barrier units (H) defined by Zazo et al. (1994; 1996a), Lario (1996), and Goy et al. (1996) in the area connecting the Atlantic and the Mediterranean. In some cases, these remains allowed the ages obtained using radiocarbon measurements to be refined for progradation of any of the spit units (H) in any spit barrier system. Particularly useful were the 'lithic workshop levels' developed between the fourth and the second millennia BC, the Bronze Age sites (1850 to 1650 BC), and the pre-Roman remains (Figure 2). All these yielded ages for the beginning of spit systems (indicative of coastal progradation in a given estuary) more accurate than the existing radiocarbon data.

Our present data indicate that the Guadalquivir estuary kept a more direct relation with the open sea until more recent times (c. 2000 BC) compared with the other studied estuaries.

Three aeolian systems D1, D2, and D3 in ascending stratigraphic order, have been distinguished. The aeolian systems D1 (~2700 cal. BP to ~2000 cal. BP, i.e. first millennium BC) and D2
(fourteenth to seventeenth centuries AD) accumulated under prevailing winds from the WSW. They are separated by a regional 'Roman-medieval discontinuity' marked by an organic palaeosol. The youngest aeolian unit (D2) was accumulated by prevailing winds from the WSW, mostly during the building of the watchtowers of the seventeenth century AD.

The absence of aeolian deposits prior to ~2700 cal. BP is caused by trapping of a large part of the sediment supply to the coast into the estuaries.

Aeolian systems began to accumulate during the gaps separating phases of progradation of coastal units recognized in previous papers (Zazo et al., 1994; 1996a; Larro, 1996; Goy et al., 1996). Gaps correspond to periods of higher sea level during long-lasting cyclonic (low-pressure) conditions. However, the organic palaeosol developed during the regional 'Roman-medieval discontinuity' (~2000 cal. BP to 700 cal. BP), largely coeval with the spit barrier unit H2, discards previously suggested direct correlations between aridity and beach progradation and between humidity and gaps.

However, after the fourteenth century AD, during the accumulation of dune systems D3 and D4 (spit barrier unit H3) the pollen record of Laguna de Las Madres suggests more arid and conditions recognized in the area, but increased anthropic impacts during this time may also be of importance.

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