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SEA LEVEL AND CLIMATE CHANGES IN THE CABO DE GATA LAGOON (ALMERIA) DURING THE LAST 6500 YR BP

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ABSTRACT

The Holocene evolution of the lagoon of Cabo de Gata in the geodynamic framework of the south-eastern Iberian Peninsula is presented for the first time. The work is based on detail geomorphological mapping of the Quaternary deposits, and radiocarbon measurements of samples collected in the spit barrier systems.
The genesis of the Cabo de Gata and Roquetas lagoons is connected to the joint action of three factors. (1) Neotectonics, that controlled the occurrence of lowlands. (2) The general glacio-eustatic, Holocene transgression, that brought the sea level to elevations 1.5-2 m above its present values and, eventually, flooded the lowlands during the Flandrian maximum ca. 6500 yr BP. (3) The climate (humidity/aridity) that influenced the sediment supply to the coast and also the small fluctuations of sea level after the Flandrian maximum.
Four spit-barrier units have been distinguished. Deposition of the two older ones (H_1 and H_2) took place between ca. 6500 and ca. 2500 yr BP under longshore drift towards the NW. Both units enclosed a lagoon that is placed to the NE of its present position. The more recent units (H_3 and H_4) close the present lagoon and were deposited between ca. 2300 and present under longshore drift to the SE.
A more humid period has been identified during the Gap separating units H_1 and H_2 (ca. 4400-4200 yr BP) when most holocene alluvial fans were deposited. Aridity increased after ca. 2500 yr BP when aeolian dunes began accumulating under prevailing winds from the SW. Although pollen diagrams record clear man-induced impacts, there is strong evidence of natural changes of climatic parameters also taking place. These are recorded as shifting wind directions, reversion of longshore drift both in Cabo de Gata and Roquetas at ca. 2500 yrBP, and the beginning of aeolian dune accumulation.

INTRODUCTION

Two major Holocene phases of coastal progradation have been widely recognised in southern Spain after the transgressive maximum (ca. 6500 14C yr BP), i.e. the maximum flooding coincided with the maximum landward migration of barriers into the estuaries. The first major phase of progradation comprises the spit units H_1 and H_2. The second major phase includes the younger spit units H_3 and H_4. The complete set of spit systems crops out only in the Mediterranean coasts of Almeria (Zazo et al. 1996a, Goy et al. 1996) and the Balearic Islands (Goy et al. 1997). The complete suite has not been observed so far on the Atlantic coast, where no physical record of H_1 has been located in outcrops (Dabrio et al, in press). However, as discussed below, there is circumstantial evidence of its deposition.

Each spit barrier unit (H) has been interpreted as an episode of stillstand or gentle fall of sea level, immediately after episodes of minor relative highstand, and related to periods of increased aridity (less amount of rain and rain spread during the year). The Gaps separating these units are interpreted as events of relative highstand.

This paper deals for the first time with the systems of beach ridges of Cabo de Gata, both from the mapping and chronological points of view. Seven new radiocarbon measurements have been obtained from shells of the marine mollusc *Glycymeris*, using both conventional ^{14}C and AMS (Accelerator Mass Spectrometry) techniques.

Ages expressed as yr BP (Table 1) are normalised and corrected for the marine reservoir effect, which has been calculated to be ~400 yr in the Mediterranean (Sanlaville et al., 1997).

The aim of this paper is the interpretative analysis of the systems of beach ridges of Cabo de Gata in relation with changes of sea level and climate since 6500 yr BP to present in a geodynamic framework that includes the trends of sea level during the Present Interglacial.

Sample code	Laboratory code	^{14}C conventional age (yr BP)	Years ** cal BP	δ13C‰ PDB	Material	Location at Fig. 1
CG-2	GX-21943 *	3350 ± 60	3202	+1,18	shell	①
CG-3	GX-21949	4640 ± 85	4835	+1,90	shell	①
CG-5	GX-21950	2060 ± 115	1608	+1,80	shell	④
CG 96-1	GX-22236	3985 ± 95	3964	+1,80	shell	②
CG 96-3	GX-22237	3205 ± 90	2979	+1,70	shell	①
CG 96-4	GX-22238	2090 ± 115	1663	+1,50	shell	①
CG 96-5	GX-22239	2855 ± 90	2668	+1,20	shell	③

(*) AMS analysis (**) Reservoir effect corrected Shell: Glycymeris
GX: Geochron Labs. Krueger Enterprises Inc., Cambridge, Mass. 02138, USA

Table 1.- Database of ^{14}C samples and results in the Cabo de Gata spit barrier system.

CLIMATE AND SEA LEVEL CHANGES

Transference of data at the millennium scale for evaluating at the same time the evolution of climate and sea level trends is really difficult, but forecasting is even more uncertain. The maximum Holocene flooding (i.e. the maximum of the Flandrian transgression) in this area has been dated ca. 6500 ^{14}C yr BP (Zazo *et al.*, 1994, Zazo *et al.*, 1996a, Dabrio *et al.*, *in press*, Goy et al., *1996*).

Holocene marine deposits

Onshore deposits

They consist essentially of spit barrier units accumulated around the Gata Cape (Cabo de Gata) lagoon. Preserved deposits of these units form the present eastern coastline of the Almeria Bay. We assume that longshore drift to the NW favoured the growth of the oldest spit barrier units H_1 and H_2 (Figs. 1 and 2) closing in the process a large lagoon that extended inland as compared to the present lagoon. These units have not been dated in Gata Cape, but correlation with similar outcrops dated some 23 km away to the W indicate ages ranging between ca. 6500 and 2550 yr BP. These two units correspond to the first phase of coastal progradation that began after the maximum flooding of the Flandrian transgression.

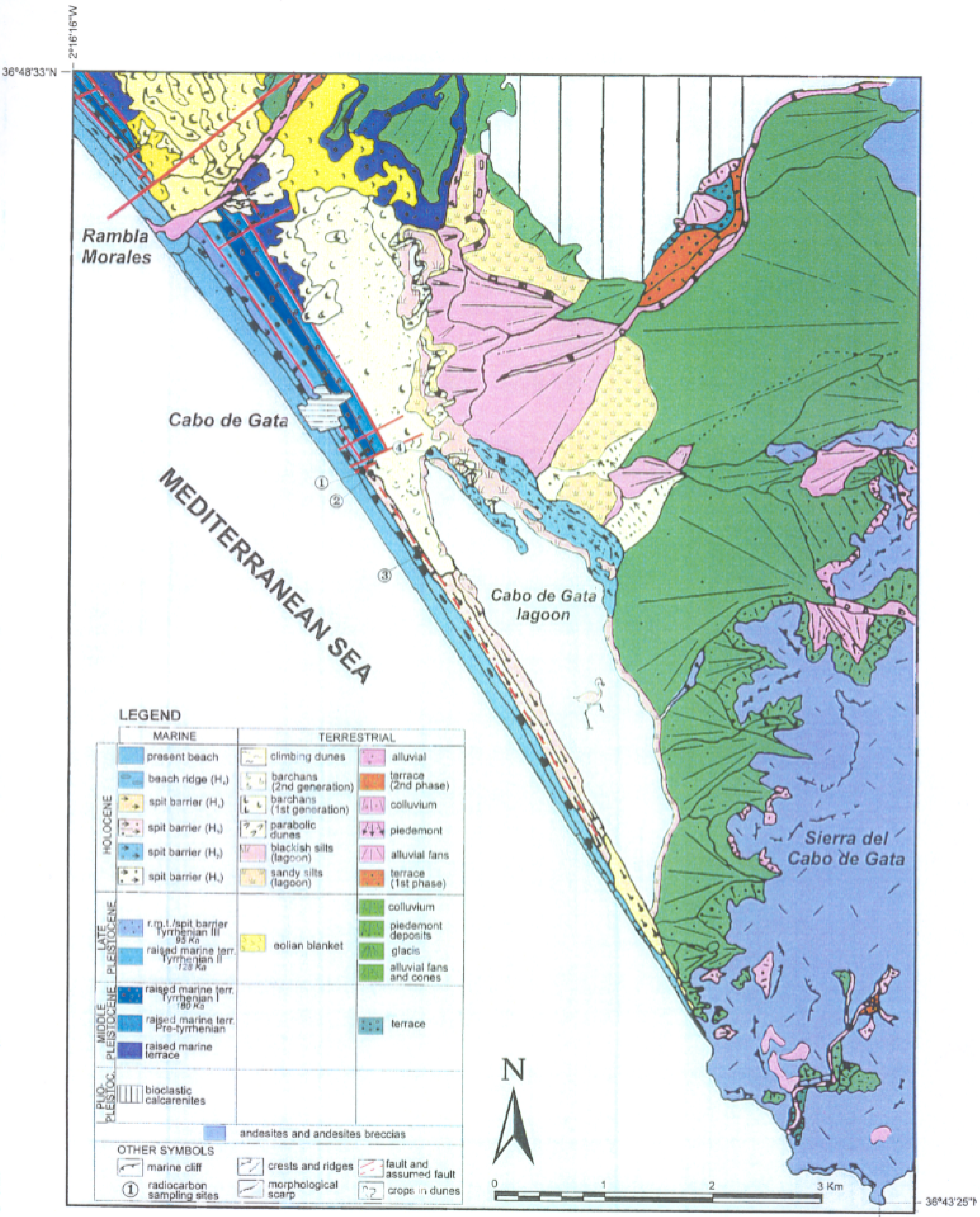

Figure 1. Quaternary Geomorphological Map of Cabo de Gata (Almería, SE Spain). Radiocarbon samples:① CG96-3; CG96-4; CG-2; CG-3. ② CG96-1. ③ CG96-5. ④ CG-5

The younger spit barrier units H_3 and H_4 closing the present lagoon accumulated under a prominent longshore drift toward the SE, favoured by a combination of the prevailing south-westerly winds and the general trend of the coastline. The uplifted block of a N40-45° trending fault system crossing the village of Gata Cape acted as the root area of units H_3 and H_4 which accumulated on the downthrown fault block, partly resting on deposits dated as H_3 and Tyrrhenian in age. These two units correspond to the second phase of coastal progradation taking place in the last 2300 yr BP.

Offshore deposits

High resolution seismic stratigraphy analysis allowed Hernández-Molina *et al.* (1995) to interpret the internal structure of the littoral wedge off Gata Cape. They distinguished four seismic units. The most recent records coastal progradation during the last highstand inside the general trend of sea level during the last 6500 yr BP. Two subunits inside this unit (Fig. 2) are interpreted to correspond to two regressive phases during two relative sea-level falls.

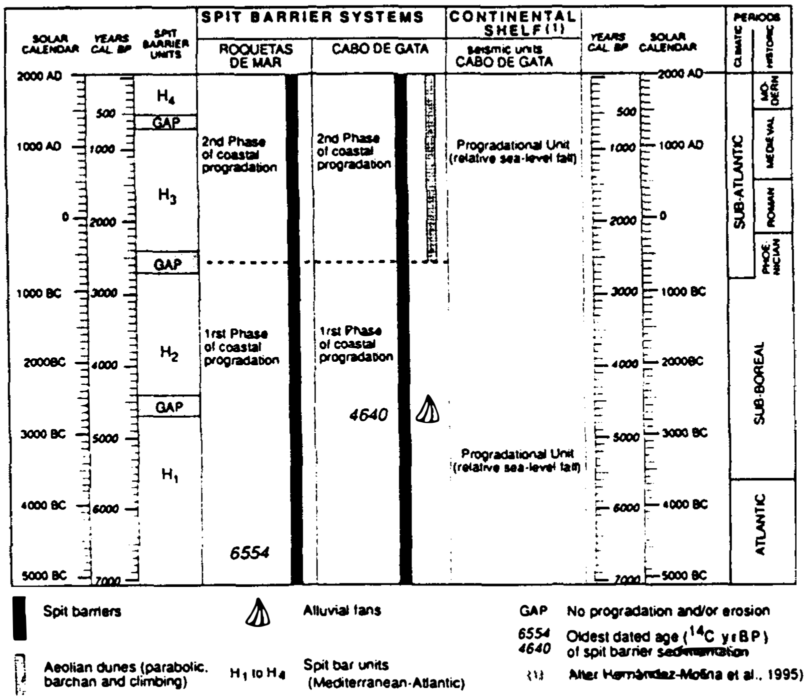

Figure 2.- Chronostratigraphy of spit barrier units and aeolian phases in the Cabo de Gata area. Note that italic typing indicate calibrated ages (Cal BP).

Aeolian dune deposits.

We have recognised four stages of dune development including several types of dunes which were mapped (Fig. 1). The oldest aeolian dunes consist of an aeolian sheet of probable Late Pleistocene age, which extends more inland than the younger ones.

The remaining systems are composed of parabolic dunes, barchans and climbing dunes that accumulated under prevailing south-westerly winds. These systems began to accumulate close to the beginning of second phase of coastal progradation (Fig. 2) ca. 2700 cal. BP. This is supported by their close relations with the spit barrier units (H) mapped in the area.

Borja *et al.* (1999) recognised three phases of aeolian-dune sedimentation in the south Atlantic coast of Spain after the maximum Flandrian flooding. Radiocarbon measurements, archaeological and historical data prove that aeolian sedimentation began ca. 2700 cal. BP. The last two phases accumulated after 14^{th} century AD (ca. 600 cal BP) indicate more arid conditions and evident anthropic influence. The almost complete absence of aeolian deposits between ca. 7000 and ca. 2700 cal BP may be related to a somewhat more-humid period.

Alluvial fans

Two large alluvial-fan systems occur related to the lagoon of Gata Cape. The larger, and older system, spreads at the toe of Sierra de Gata. Correlation with marine Tyrrhenian deposits (180-95 Ka) confirms that they were laid down during the Last Glacial. According to this, we infer a Late Pleistocene age. The younger system is of Holocene age, at least post. Spit barrier unit H_1. We suggest that it may represent a more humid period ca. 4000 yr BP.

Radiocarbon data

New radiocarbon measurements (Table I) are given in this paper. These are complementary to the published by Goy *et al.*, (1986), who first dated the spit barrier units (H) near Roquetas that form the most complete set in the south Spain. Also useful are those of drill-cores used to date pollen analysis (Yll *et al.*, 1994, Pantaleón-Cano *et al.*, 1996, see below).

A common difficulty is that faunal remains are often recycled to younger spit units. For this reason, careful mapping of morpho-sedimentary units and analysis of sedimentary structures is essential prior to any sampling. This is illustrated by the occurrence of the oldest samples (CG-3) in the H_3 Unit (Figs. 1 and 2, Table I). Dating of sample CG-5 is problematic since it was collected near the surface due to local constraints.

Other three samples studied (CG-2, CG96-3 and CG96-5) are of H_2 age. However this unit is not mapped in this particular place (Fig. 1)because, in general, it is covered by H_3. In any case H2 and H3 are easily distinguished from each other because H_2 includes beach rocks.

Pollen data

In Almeria, in a zone with a semi-arid present-day climate, the pollen diagrams from three cores drilled in coastal areas (Roquetas de Mar, San Rafael, and Antas) show higher values of the scrubby communities that expand them over this area during the Atlantic period (Pantaleón-Cano *et al.*, 1996). The most complete record corresponds to San Rafael (36° 47'N, 2° 25'W), located west of Gata Cape at the municipality of Roquetas de Mar. Data from this site suggests widespread vegetal cover and high water availability between ca. 9000 and 4500 yr BP (Atlantic period). These climatic conditions are characteristic of the 'Holocene climatic optimum' (6000 to 5000 cal BP). In contrast, steppe conditions (less temperature and humidity) existed between the end of the Atlantic and the middle part of the Sub-Atlantic periods. Pollen diagrams by Follieri *et al.* (1977) show a period with specially warm and xeric conditions between 1700 and 1600 yr BP. Clear signs of human impact on the landscape are detectable around 3000-2000 yr BP, when the effect of agriculture are unequivocal.

According to pollen data, the climatic trend in SE Iberian Peninsula after the climatic optimum is cyclic increase of aridity (Burjachs *et al.*, 1997).

DISCUSSION OF RESULTS — CONCLUSIONS

The origin of the Cabo de Gata lagoon is related to joint action of two factors. First, the neotectonic behaviour of the area, located to the south of the large N40-50°E, left-lateral strike-slip fault of Rambla de Morales, a prolongation of the Carboneras fault (Fig. 1). Second, the effects of the Holocene glacio-eustatic transgression that brought the sea level from −120 m to an elevation slightly above the present. The fault also moved vertically causing differences in elevations that increase toward the north as revealed by the raised marine terraces deposited during the Interglacials associated with the Isotopic Stages 7 and 5. These deposits yield a warm fauna including *Strombus bubonius* (Tyrrhenian: T I, T II, and T III) dated (Fig. 1) using Th/U (Hillaire-Marcel *et al.*, 1986b, Zazo *et al.*, 1993).

Joint action of the system of faults parallel to the one at Rambla de Morales and the N140°E controlling the present direction of the shoreline caused a topographic low that was occupied by lagoons at least during the holocene transgression. Those areas were eventually isolated from the open sea by spit barriers.

During the maximum of the Flandrian transgression (ca. 6500 yr BP) the sea invaded a large area some 2 km inland of the present coastline. We assume that sea level at that time should be ~1.5 m higher than the present. A later trend to gentle sea level fall produced coastal progradation and left behind stranded beach ridges corresponding to the former spit barrier units (H) that enclosed the lagoons. We have distinguished two main episodes of lagoon generation (Fig. 1). An older episode dated as 7000 and 2700 cal BP is located inland, and separated from the sea by spit units H_1 and H_2 which grew under littoral drift directed toward the NW, forced by south-easterly winds.

The present lagoon was formed after the growth of spit units H_3 and H_4 between 2400 cal BP and Present. Main littoral drift was to the SE under prevailing winds from the SW.

The systems of aeolian dunes associated to these spit barrier deposits accumulated since ca. 2700 cal BP. Wind directions measured in all cases correspond to south-westerly winds.

In relation to climate, pollen data (Pantaleón-Cano *et al.*, 1996) indicate higher humidity between 9000 and 4500 yr BP (i.e. covering at least the time of deposition of H_1 spit barrier unit) and more steppary conditions since 4500 yr BP to ca. 1300 yr BP. According to these findings the idea that the two phases of coastal progradation occurred during more arid periods, as proposed by Zazo *et al.* (1994, 1996a, b), Goy *et al.* (1996), is questionable. However, the Gap between 4400 and 4200 yr BP coincided with the deposition of Holocene alluvial-fan systems (Fig. 1), and evidences a more humid phase.

According to geomorphological data, the maximum aridity occurred since ca. 2500 yr BP, when the coastal dunes began to accumulate.

Although anthropic action in the area is clear between 3000 and 2000 yr BP (Folliery *et al.*, 1997), there is evidence of natural changes of the climatic parameters (wind and littoral drift directions, et cetera) ca. 2500 yr BP (Zazo *et al.*, 1996 a, b, Goy *et al.*, 1996). These changes coincided with the Gap separating the two previously cited phases of coastal progradation distinguished both in the southern Mediterranean coast and continental shelf of Iberia.

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