Gibraltar during the Quaternary

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The record of highstand sea-level during the last interglacials (Isotope Stages 7, 5 and 1) in the Atlantic-Mediterranean linkage area

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INTRODUCTION: SEDIMENTARY ENVIRONMENTS AND GEOMETRIC-SPATIAL DISPOSITION OF THE MARINE MORPHOSEDIMENTARY UNITS CORRESPONDING WITH HIGHSTAND SEA-LEVELS.

There are two factors that can be considered as responsible for the different situations observed in the coastal zone: the tectonic factor and the distance throughout the coast of the source area of sediments (Zazo *et al.*, 1990; 1993). In zones with up-lift trend, and when the up-lift rate is around ≥7,5 cm/ka, the morphosedimentary units are staircased, the older being located higher than the rest. If the source area of sediments is located at a large distance, the units will be beaches represented as marine terraces whose scarp will be fossilized by small coluvions or dunes. Such is the case of the south coast of Almería.

When the up-lift rate is smaller, around 2 cm/ka, the morphosedimentary units are in offlap, the oldest being located higher than the others. If the source area of sediments is located very close, fan-deltas alternating with alluvial fans are developed. This would be the case of the Basin of Cope (Murcia).

In areas with subsidence trend, if the rate is 1-2 cm/ka, the different marine episodes are overlapped, the oldest remaining lower in relation to the most recent. The morphosedimentary units are represented by complexes of barrier island-lagoon, with beaches associated when the distance to source area of sediments is medium, as occurs in La Mata lagoon (Alicante). With equal subsiding rate, but greater distance to the source area of sediments, associated beaches would not exist, as is the case of the coastal sector between Rota and Puerto de Santa María (Cádiz).

When the subsiding rates are increased, ≥8 cm/ka, the morphosedimentary units are constituted by onlapping barrier island-lagoon systems with the most ancient units below the most recent ones. Furthermore these last penetrate more toward land, as in the Mar Menor and in the Gulf of Valencia.

From the cartographic and morphosedimentary analysis and from Th/U measures carried out in the peninsular coast in relation to the current situation of the palaeoshoreline ca.100 k, corresponding to the Last Interglacial, it is deduced that the zone that presents a greater up-lift trend corresponds to the area of the Strait of Gibraltar, with a rate of 0.11 mm/yr (Lario, 1996).

RECORD OF MARINE EPISODES FROM THE LAST 200 KA.

Faunal Migrations through the Strait of Gibraltar

Within the Spanish coasts, peninsular as well as insular, there is a record of highstand sea-level correlated with the global episodes and corresponding to the Isotopic Stages 7, 5 and 1.

The first two are characterized because their deposits contain warm or "Senegalese" fauna that, coming from Equatorial Africa, penetrated the Mediterranean through the Strait of Gibraltar. At this time the cold current of the Canary Islands followed a different path than at the present time (Fig. 1), being located more westwards, and the upwelling that currently is observed in the North African coast was not effective (Zazo *et al.*, 1989).

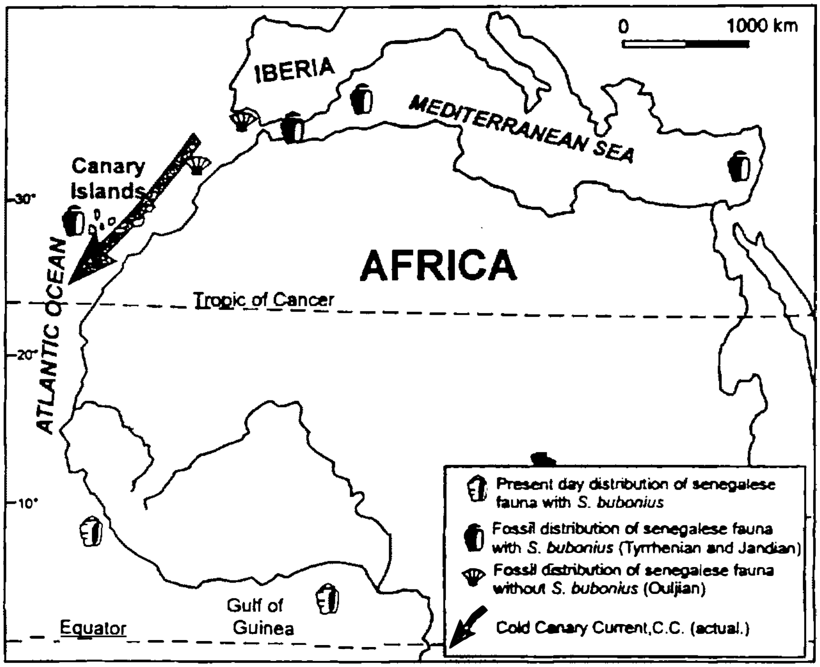

Fig. 1. Distribution of "senegalese fauna" during 7 and 5 Isotopic Stages, and present distribution (modified from Zazo *et al.*, 1994b).

This warm fauna is represented fundamentally by *Strombus bubonius*, that constitutes the most characteristic species, and accompanying species such as *Conus testudinarus*, *Arca noae*, *Cymathium dolarium* and *Cantharus viverratus*, all of them extinct from the Spanish Mediterranean and Atlantic coasts after the Last Glacial.

Marine levels corresponding to the Isotopic Stage 7: Penultimate Interglacial.

The record of marine deposits corresponding to the Penultimate Interglacial is well represented in the insular and peninsular coasts of our territory, marine episodes from this stage being found in the Mediterranean and in the Atlantic.

In the coast of Almería, Alicante and Murcia substage 7a dated near 180 ka, with scarce specimens of *S. bubonius*, known in this area as episode Tyrrhenian I, is very well represented (Goy *et al.*, 1986; Goy *et al.*, 1993). Part of the episodes designated as pre-Tyrrhenian should correspond to the first moments of this Stage, although there are no dates that confirm it .

In Gibraltar and in the coast of Málaga, in spite of the absence of warm fauna, the Th/U isotopic measures carried out confirm the presence of marine terraces corresponding to substages 7e and 7a (Goy *et al.*, 1994; Lario, 1996).

Marine levels corresponding to the Isotopic Stage 5: Last Interglacial.

This stage is well registered in the south and southeastern peninsular coast. From the palaeontological point of view a surge of the warm fauna (*S. bubonius*) is produced in the Mediterranean, while in the Atlantic peninsular coasts only part of the fauna associated with *S. bubonius* is recorded, due to palaeoceanographic conditions. In their step towards the Mediterranean the *S. bubonius* larvae did not develop into adult individuals and therefore, they are not found as fossils (Zazo *et al.*, 1994a).

For that reason the nomenclature of the marine episodes corresponding to the Last Interglacial is different according to the basins: Tyrrhenian in the Mediterranean, associated with the presence of *S. bubonius* and Ouljian in the Atlantic coasts of Huelva-Cádiz (by its similarity with the homonymous deposits of the Moroccan coast).

In the peninsular east these marine episodes are registered and dated. The one defined as Tyrrhenian II, associated with Isotopic substage 5e, has been dated between 143-125 ka; the corresponding to the T-III, associated with Isotopic substage 5c, has been dated in 95 ka; and finally, the corresponding to the T-IV, associated with Isotopic substage 5a, though it has not been possible to date because it is an open geochemical system, is assumed an age ≥70 ka (Goy *et al.*, 1993; Causse *et al.*, 1993).

In the Atlantic-Mediterranean linkage area (from the Gulf of Cádiz to the coast of Málaga) it is possible to find these episodes well represented and it has been observed that, as in the others records, each substage has behaved as a multiple episode with several positive pulsations (Goy *et al.*, 1994; Lario, 1996). Associated with substage 5e two episodes centred to ca.132 ka and ca.117-125 ka are observed, the first of them probably corresponding to the transition between the Stages 6/5 (Lario, 1996). In substage 5c, the most continuous unit observed throughout the peninsular coast, three pulsations are observed centred in 107 ka, 100 ka and 90 ka respectively. The episode associated with substage 5a and corresponding with the T-IV Mediterranean episode, that appears discontinuous throughout the coast, has been dated in this area at 80 ka.

Marine levels corresponding to the Isotopic Stage 1: Present Interglacial.

The global sea-level rise produced after the Last Glacial Maximum (ca.18 ka) reaches the current position, or slightly higher, in the Spanish coasts at about 6,450 yr bp (Zazo *et al.*, 1994b; Goy *et al.*, 1996).

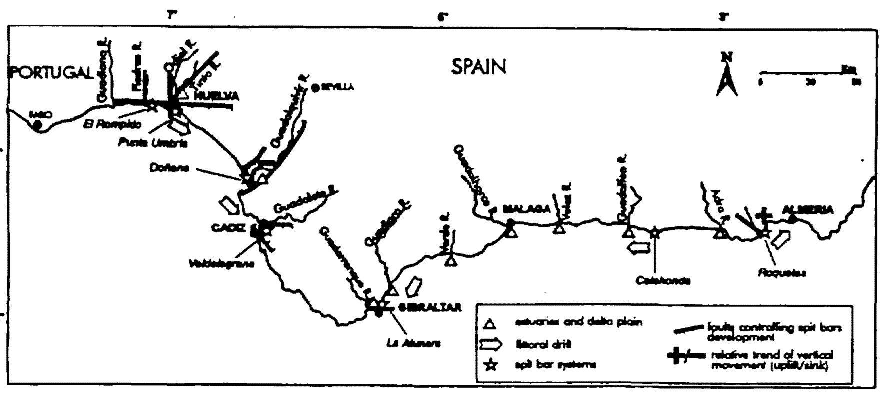

Fig. 2. Location map of the spit-bars systems and estuaries from the Atlantic and Mediterranean peninsular area. The samples and ^{14}C measurements are indicated on Table I.

Sample	Locality	Lab.Code	^{14}C-Age	+/-	d ^{13}C‰	material	unit	depth(m	Reference
PG-12	La Atunara	UQ-PG12	2675	110		shell	spit-bar		Lario et al., 1995
PG-13	La Atunara	UQ-PG13	3200	110		shell	spit-bar		Lario et al., 1995
PG-14	La Atunara	UQ-PG142	3140	120		shell	spit-bar		Lario et al., 1995
F-24	La Atunara	IRPA-1159 (1)	1210	35	1.83	shell	spit-bar		Goy et al., 1996
CH-1	Calahonda	LGQ-1025	1520	170		shell	spit-bar		Lario et al., 1995
CH-2	Calahonda	LGQ-1026	2720	180		shell	spit-bar		Lario et al., 1995
CH-3	Calahonda	LGQ-1027	800	190		shell	spit-bar		Lario et al., 1995
CH-4	Calahonda	LGQ-1028	720	190		shell	spit-bar		Lario et al., 1995
R-8	Roquetas	UQ-1133	6450	100	2.1	shell	spit-bar		Goy et al., 1986
R-7	Roquetas	UQ-1135	3600	100	2	shell	spit-bar		Goy et al., 1986
R-10	Roquetas	UQ-1140	2150	100		shell	spit-bar		Goy et al., 1986
R-2	Roquetas	R-2	1870	35	2.1	shell	spit-bar		Goy et al., 1986
H-2	El Rompido	R-2179	1460	50	-0.13	shell	spit-bar		Zazo et al., 1994
H-3	El Rompido	R-2180	1875	50	1.66	shell	spit-bar		Zazo et al., 1994
H-4	El Rompido	R-2207	1440	50		shell	spit-bar		Zazo et al., 1994
H-5	El Rompido	R-2203	2605	50		shell	spit-bar		Zazo et al., 1994
D-2	Doñana	R-2187	1790	50	1.62	shell	spit-bar		Zazo et al., 1994
D-7	Doñana	R-2205	2185	50		shell	spit-bar		Zazo et al., 1994
D-9	Doñana	R-2185	1860	50	1.53	shell	spit-bar		Zazo et al., 1994
D-11	Doñana	R-2210	2010	50		shell	spit-bar		Zazo et al., 1994
D-14	Doñana	R-2204	1490	50	1.62	shell	spit-bar		Zazo et al., 1994
D-15	Doñana	UtC-4191 (1)	3820	70	1.5	shell	spit-bar		Goy et al., 1996
D-16	Doñana	UtC-4188 (1)	1650	50	1.35	shell	spit-bar		Goy et al., 1996
D-17	Doñana	R-2188	1850	50	1.43	shell	spit-bar		Zazo et al., 1994
D-18	Doñana	UtC-4192 (1)	1370	60	1.46	shell	spit-bar		Goy et al., 1996
C-3	Valdelagrana	R-2182	2320	50	1.43	shell	spit-bar		Zazo et al., 1994
C-4	Valdelagrana	R-2208	3145	50		shell	spit-bar		Zazo et al., 1994
C-5	Valdelagrana	R-2181	2270	50	1.42	shell	spit-bar		Zazo et al., 1994
C-6	Valdelagrana	R-2186	2120	50	1.48	shell	spit-bar		Zazo et al., 1994
PU95-1	Punta Umbría	GX-20907	3315	70	1.5	shell	spit-bar		Goy et al., 1996
PU95-2	Punta Umbría	GX-20908	3555	75	1.8	shell	spit-bar		Goy et al., 1996
PU95-3	Punta Umbría	GX-20909	1900	70	1.8	shell	spit-bar		Goy et al., 1996
IC95-1	Ayamonte	GX-20899	835	65	0.2	shell	spit-bar		Goy et al., 1996
IC95-3	Ayamonte	GX-20900	3130	70	0.8	shell	spit-bar		Goy et al., 1996
P13-1	Guadalquivir	UtC-4028 (1)	2490	50		twigs	estuary	-7.3	Goy et al., 1996
P13-2	Guadalquivir	UtC-4031 (1)	2930	60	-2.9	shell	estuary	-7.3	Goy et al., 1996
PSM104/C0	Guadalete	GX-20913 (1)	3505	55	-25.5	organic matter	estuary	-4.8	Goy et al., 1996
PSM104/C3	Guadalete	GX-20914 (1)	5885	60	0.5	shell	estuary	-8.3	Goy et al., 1996
PSM104/C5	Guadalete	GX-20925 (1)	6420	45	1	shell	estuary	-11.5	Goy et al., 1996
PSM104/C9	Guadalete	GX-20916 (1)	7620	55	-0.3	shell	estuary	-15.2	Goy et al., 1996
PSM104/C11	Guadalete	GX-20917 (1)	7840	45	-0.1	shell	estuary	-20	Goy et al., 1996
PSM104/C15	Guadalete	GX-20918 (1)	8040	55	-0.1	shell	estuary	-21.5	Goy et al., 1996
PSM104/C20	Guadalete	GX-20919	8915	100	-28.4	peat	estuary	-24.77	Goy et al., 1996
PSM104/C21	Guadalete	GX-20920	9495	340	-27.8	peat	estuary	-24.95	Dabrio et al., 1996

Table I. ^{14}C Ages opf coastal deposits from south Spain

(1) AMS

Laboratories Code

UQ. Université du Québèb à Montreal, Canada.

R. Centro di Studio per la Geoch. Aplicata, Universitá La Sapienza, Roma, Italy.

LGQ. Lab Géologie du Quaternaire, CNRS, Luminy, France.

IRPA. Instit. Royal du Patrimoine Artistique, Bruxelles, Belgium.

UtC. Van de Graaf Lab., Utrecht, The Netherlands.

GX. Geohron Lab., Massachusets, USA.

From recent studies of the morphosedimentary units (Fig. 2) together with numerous ^{14}C dates (Table I), it has been possible to distinguish various phases that have influenced the evolution of these units and the evolution of the coastal morphology during the Holocene.

From the cartographic and sedimentological analysis together with that from the ^{14}C dates carried out in the spit-bar systems of Mediterranean and Atlantic coast (Zazo *et al.*, 1994b; Lario *et al.*, 1995; Goy *et al.*, 1996) it is possible to distinguish that from the Holocene maximum to the present time there are two phases of greater coastal progradation, one of them between ca.6,450 yr bp and 3,000 yr bp and the other between ca.2,750 yr bp and the present time. These two phases are separated by a gap between ca. 3,000-2,750 yr bp, that would represent a stage of greater erosion associated with a slight sea-level rise and climatic instability. Equally, different morphosedimentary units (from H_1 to H_4) have been recognized, corresponding to spit-bars and formed each one by a set of smaller units (*sets*) constituted by a group of ridges and runnels. The tectonic trend of the development areas of the spit-bar systems as well as their geographical situation, associated or not to large river outlets, are the reason that in the areas with uplift trend and not associated with rivers (e.g.: Roquetas) the spit-bar system is widely developed with presence of the units H_1 to H_4, while in areas associated with outlets of rivers and estuaries (Atlantic area) the spit-bar system begins to develop at ca.4,000 yr bp, appearing only the units H_2 to H_4 (Goy *et al.*, 1996; Lario, 1996).

From the study of the evolution data of the Holocene estuaries (Dabrio *et al.*, 1995; Goy *et al.*, 1996) it is observed that, associated with *tardiglacial* period (ca.14,000 yr bp), an encasement of the river systems is produced conditioning the palaeomorphology of the valleys on those on which the Holocene estuaries are situated. Equally it is observed that at ca.9,000 yr bp a deceleration in the sea-level rise takes place, represented by the deposition of peat previous to the estuary infill sequence. These authors also deduced that the maximum marine conditions are recorded between ca.8,000 yr bp and 7,000 yr bp, as well as the progressive restriction of the marine conditions in the estuaries is produced at ca.4,000 yr bp, associated with the wide development of spit-bar systems, that induced their colmatation during the second Progradation Phase. The total filling of the estuaries of the Atlantic area and the delta plain of the Mediterranean area take place during the last 500 years, associated with historic episodes of climatic instability as well as various anthropic performances (Lario *et al.*, 1995; Zazo *et al.*, 1996).

CONCLUSIONS

Along the Spanish coasts there is record of marine morphosedimentary units associated to highstand sea-level that can be correlated with the global episodes corresponding to the Isotopic Stages 7, 5 and 1. The first two are characterized by the apparition of warm fauna that coming from Equatorial Africa, penetrating into the Mediterranean through the Strait of Gibraltar. At this time the cold current of the Canary Islands followed a different path than at the present time, being located more westward, the upwelling that currently is registered in the North African coast not being effective. This warm fauna is not found in the Isotopic Stage 1 showing that the other two Isotopic Stages were warmer than the present one. Furthermore, climatic oscillations are recorded in the Present Interglacial as changes occurred in the littoral morphosedimentary units developed during this time.

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