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A Global Synthesis with implications
for management of future coastal change

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Quaternary coastal morphology and sea level changes

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Gracia F. J.[1], Rodríguez-Vidal J.[2], Belluomini G.[3], Cáceres L. M.[2], Benavente J.[1], Alonso C.[4]

Rapid coastal diapiric uplift in Cádiz Bay (SW Spain). Implications on OIS 3 sea level reconstruction.

[1]Dept. Ciencias de la Tierra, Facultad de Ciencias del Mar y Ambientales, Campus del río San Pedro, Universidad de Cádiz, 11510 Puerto Real, Cadiz, Spain, E-mail: javier.gracia@uca.es
[2]Dept. Geodinámica y Paleontología, Universidad de Huelva, 21071 Huelva, Spain.
[3]ITABC-CNR, Via Salaria, km 29,300, 00016 Monterotondo St., Roma, Italy.
[4]Instituto Andaluz del Patrimonio Histórico. Consejería de Cultura. Junta de Andalucía. Cádiz, Spain

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Abstract

The Bay of Cádiz, of about 30 km length and 15 km width, is located at the south-atlantic margin of the Iberian Peninsula, southwards of the Guadalquivir river mouth. Geologically it is located within the Subbetic Zone of the Betic Ranges. The origin of the Bay is related to vertical tectonic movements during a distensive phase in the upper Miocene - Pliocene (Benkhelil, 1976). This depression was occupied by a deltaic sedimentary system developed during the middle and upper Pliocene until the lower Pleistocene, giving rise to a stratigraphic unit with mixed fluvial and littoral characteristics.

In Quaternary times the spatial distribution of coastal environments was linked to several eustatic fluctuations, with the development of alluvial plains during lowstands and flooding phases during hisghstands.

Quaternary tectonic activity in the Bay is associated to the submeridian convergence between Africa and Eurasia, producing a maximum compressive horizontal stress direction at about NNW-SSE to N-S (Ribeiro et al., 1996). This stress field is represented in the Bay by two important strike-slip fault families, a sinistral NE-SW and a dextral NW-SE (Gracia et al., 1999). Similar recent tectonic lineations were identified by Zazo et al. (1999) in the nearby Gibraltar Strait.

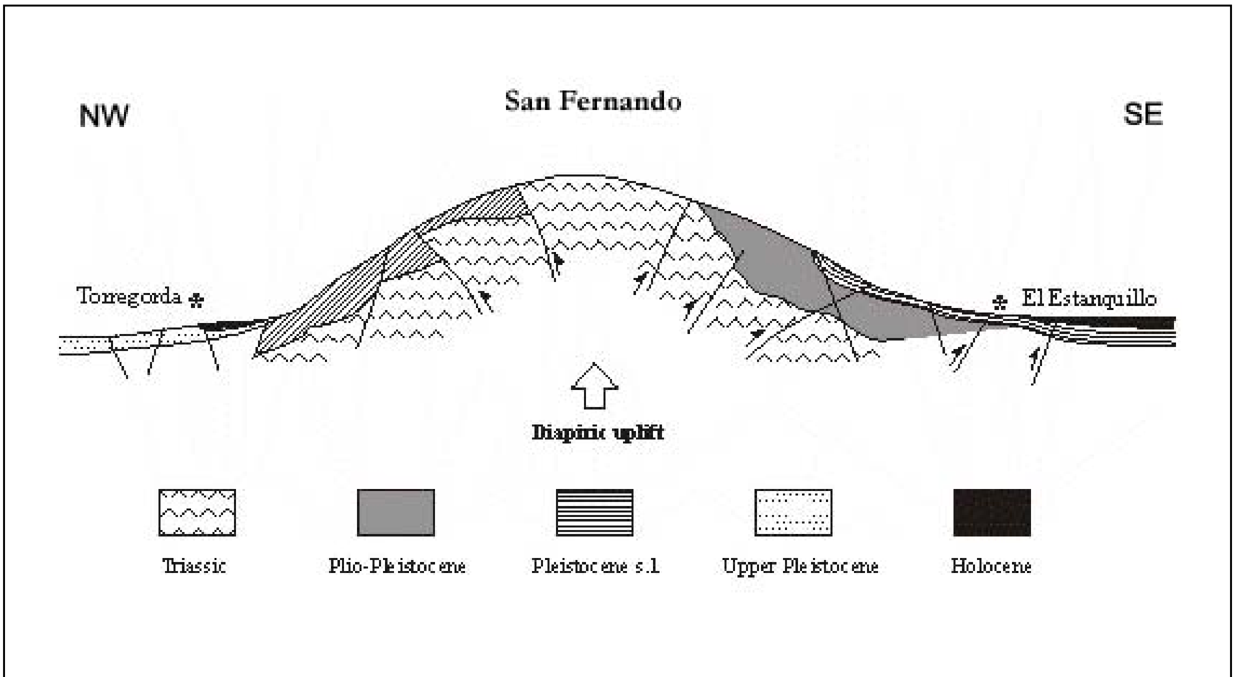

Figure 1. Traverse cross section of San Fernando diapiric anticline between Torregorda and El Estanquillo.

Diapiric structures are common in the region, and many of them affect Neogene and Quaternary units. They are usually conditioned by NE-SW fractures, suggesting some recent rearrangements in the basement accidents, that have probably induced this type of deformation (Rodríguez-Vidal et al., 1993).

San Fernando village, at the very centre of the Cádiz Bay, is located upon an elongated hill of up to 29 m above m.s.l., close to the coastline. Such a relief is formed by a diapiric anticline that affects the Plio-Pleistocene deltaic unit. The intrusive mass is formed by Triassic clays and gypsums. The fold limbs are faulted by normal accidents of NNE-SSW strike, controlling the hill orientation, and the whole structure can be considered as a tectonic horst formed during Quaternary times.

In the transverse cross section of Fig. 1 it can be seen how deformation affects an Upper Pleistocene unit at "El Estanquillo" zone. Two reverse faults dislocate an heterometric terrigenous deposit, of unknown age. The deposit is capped by a calcareous crust of 10-20 cm with clastic and laminated facies, including rests of microscopic marine organisms. Radiocarbon dating of the crust gives an age ranging between 22,860 ± 310 and > 44,500 yr BP. A thin level of aeolian sands and a slope deposit partly cover these units. The slope deposit is plenty of ceramic rests of an age at least younger than III century B.C.

In the Bay of Cádiz and surrounding areas several evidences exist about historical earthquakes that produced important damages in anthropic structures. This seismic activity dates back to the Classic Epoch. Some authors describe tectonic disturbances of seismic origin in the old Roman villages of Baelo Claudia (Gibraltar Strait) and Munigua (Sevilla), respectively south and north of the studied zone (Goy et al., 1994).

In more recent times other destructive earthquakes have affected the area, like the Lisbon earthquake of November 1755, which produced great damages and seismic sea waves (tsunami) in Cadiz town. In the surroundings of San Fernando, near "El Estanquillo" some archaeological evidences can be related as well to an antique historical seismicity. The floor level of a Roman salt fishery plant and other archaeological Bronze and Roman settlements, partly built upon the Plio-Pleistocene deltaic unit, show strong waviness. This deformation should have taken place after II century A.D., date by which these settlements were abandoned.In the western side of San Fernando anticline, a conglomeratic rocky shoal appears 3-4 km away from the coastline between Cádiz and San Fernando, with a very remarkable NNW-SSE linearity. This morphological lineament is separated from land by a straight submerged depression, parallel to the former. These features suggest the existence of at least two NNW-SSE faults that condition the orientation of the coastline and the nearby submerged topography. In the coastal area near San Fernando this unit outcrops forming a wide and very continuous shore platform that follows the coastline at 1 m above m.s.l., gently dipping southwards. The sedimentary characteristics of the deposit reveal a clear coastal beach origin, with alternating laminated sandstones and quartzitic conglomerate levels plenty of bivalve shells, laterally passing to continental alluvial fan facies towards the east. Radiocarbon dating of this coastal unit gave a calibrated age of 31,515 ± 773 yr BP. Other radiocarbon datings of shells included in the coastal sedimentary units of the zone gave ages ranging between 31,515 ± 773 and 20,990 ± 270 yr BP (Fig. 2), with five samples showing ages older than 40,000 yr BP.

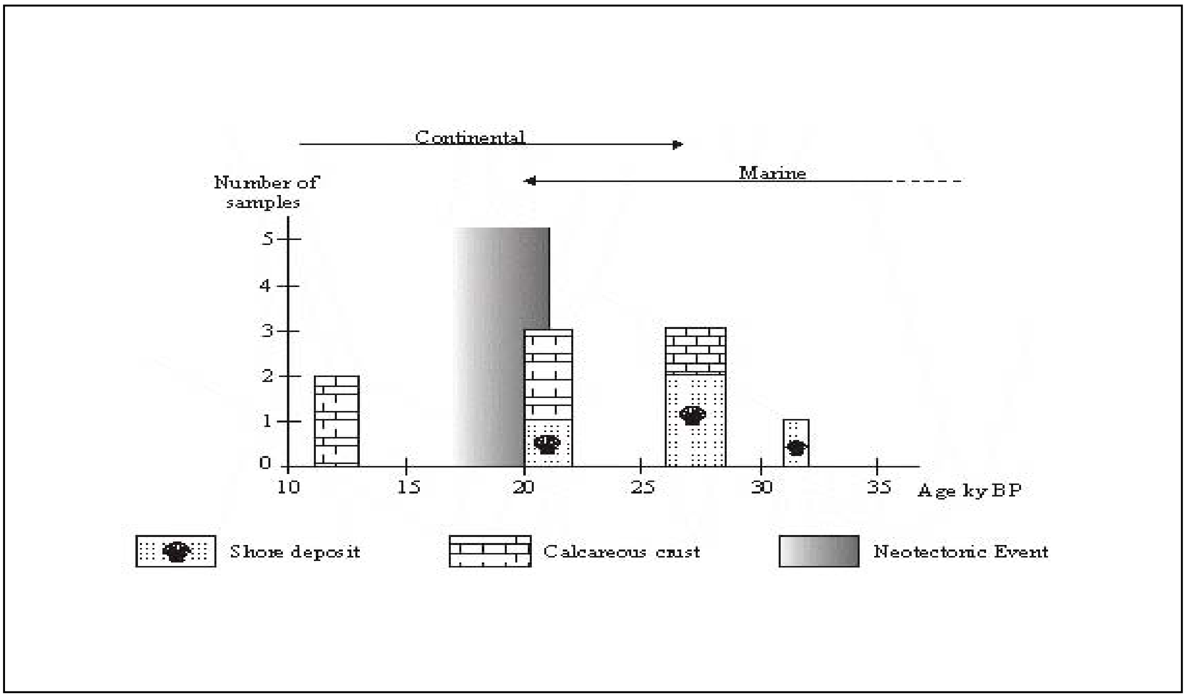

Figure 2. Late Pleistocene marine-continentel transition in San Fernando coastal area dedeced from radiocarbon dating. The progressive rising trend of this coastal zone was accelerated by the neotectonic event recorded at about 20 ka.

A very continuous laminated calcrete of continental origin overlies this deposit and extends into de intertidal zone. Radiocarbon dating of the calcrete gave values between 27,980 ± 382 and 11,080 ± 80 yr BP.

The coastal deposit is affected by many opened joints, partially filled by a white pulverulent calcrete deposit 30-40 cm wide. Radiocarbon dating of this crust filling gave an age of ca 21,760 ± 250 yr BP for a sample taken in the contact with the host-rock, and ca 19,703 ± 144 yr BP for the central part of the crust. The crust filling is affected by a second fracturing episode, characterized by open joints filled by thin reddish clastic deposits of unknown age. No slickenside indicators have been recognized and hence no relative movement can be deduced for the second fracturing system. All the joints present a very constant NNW-SSE direction, in accordance to the coastline orientation of the zone, to the regional NNW-SSE faulting family, and to the epicenter lineation of submarine earthquakes recorded near the coast.

Chronologically, the Late Pleistocene beach deposit is clearly included in the oxygen isotope stage 3. Coastal environments during this epoch have been traditionally supposed to be located at about 150 m below present sea level, according to data obtained from marine terrace sequences in the western Pacific (Aharon & Chappell, 1986).

However, actually very few real data exist about OIS 3 sea levels in southern Europe. Indeed, several authors have concluded that during OIS 3 sea level in the Mediterranean probably reached heights very near to the present level. Constraints on the position of relative sea-level from luminiscence data in southern Italy show that the sea-level rose from –29 m during substage 5a to –15 m during stage 3 (Mauz & Hassler, 2001).

Following these authors, disagreements in OIS 3 sea-levels between southern Italy and western Pacific highlight the lack of knowledge concerning Mediterranean thermohaline circulation and sea water exchanges between the Atlantic and Mediterranean seas during glacial cycles.

We do not know exactly the original position of the coastline during OIS 3. Nevertheless, existing data indicate that during OIS 3 several relative sea level rises took place. The position, morphology and amount of deformation of the Upper Pleistocene coastal deposits in San Fernando indicate a not very important tectonic uplift, from which it can be inferred a sea level located some tens of meters below present m.s.l., probably less than 30 m.

Regarding the rate of vertical tectonic movement in San Fernando anticline, although it probably took place along the Upper Pleistocene and Holocene, radiocarbon data indicate that the most important deformation took place between 31,000 and 21,000 yr BP.

The progressive rising trend of this coastal zone was accelerated by the neotectonic event recorded at about 20 ka (Fig. 2). A 30 m tectonic rise in a time span of 10,000 years would suposse an average rate of 3 mm/year. This is not a very important elevation rate for compressive margins (for example, in New Zealand values of + 4-8 mm/year are normal; Lajoie, 1986). However, the Gulf of Cadiz should be better considered as a convergent-transpressive margin, where most part of the recent deformation results in horizontal movements, rather than vertical. This prevailing horizontal tectonics can be seen affecting many morphological and sedimentary indicators in Cadiz Bay, like the recent strike-slip faults that offset Pleistocene fluvial deposits in the northern Bay margins (Gracia et al., 1999). Zazo et al. (1999) measured recent rates of tectonic uplift in the Gibraltar Strait from OIS 5 marine terraces, resulting in up to 1.51 mm/yr, quite slow if compared with present convergence rates (4 mm/yr). This argument could favour a reduced vertical rise of the OIS 3 coastal deposit, and then a palaeosea level slightly below the present one.

In San Fernando case study, the diapiric nature of the recent coastal uplift introduces some uncertainties about the causes and rates of the vertical movements, not totally related to the regional tectonic stress field. In this sense, some comparisons can be made with other similar recent diapires of the region. Existing data indicate that the maximum vertical uplift recorded during the Late Quaternary in nearby diapiric structures reaches up to 25 m (Rodríguez-Vidal et al., 1993). If we discount such a height from the present altitude of the San Fernando coastal deposit, we obtain an OIS 3 sea level at about 20 – 22 m below the present one, a value of the same order to the one recorded in southern Italy.

As a conclusion, data about recent tectonics in Cadiz Bay arise the problem of where to locate glacial sea levels in southern Europe. Comparisons with western Pacific Pleistocene sea levels have once more demonstrated to be inadequate. These almost antipode places belong to water masses where current circulation patterns, tectonic/isostatic trends and geoid behaviour have suffered very different evolution during the Late Quaternary. Although sea level fluctuations can behave more or less in the same sense at both places, all these factors strongly affect their amplitude, and then correlation of sea level heights becomes non-realistic.

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