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Very coarse-grained beaches as a response to generalized sea level drops in a complex active tectonic setting: Pleistocene marine terraces at the Cadiz coast, SW Spain

Laura González-Acebrón [a,*], Ramón Mas [a], José Arribas [b], Jose Manuel Gutiérrez-Mas [c], Carlos Pérez-Garrido [d]

[a] Dpto. Estratigrafía, Facultad de Ciencias Geológicas, UCM, IGEO-CSIC, C/Jose Antonio Novais 12, 28040 Madrid, Spain
[b] Dpto. Petrología y Geoquímica, Facultad de Ciencias Geológicas, UCM, IGEO-CSIC, C/Jose Antonio Novais 12, 28040 Madrid, Spain
[c] Dpto. Ciencias de la Tierra, Universidad de Cádiz, Polígono Río San Pedro s/n., 11510 Puerto Real, Cádiz, Spain
[d] Centro Nacional de Investigación sobre la Evolución Humana (CENIEH), Paseo Sierra de Atapuerca 3, 09002 Burgos, Spain

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ABSTRACT

The studied Pleistocene deposits at the Cadiz coast are located on the current intertidal zone or at cliffs parallel to the actual coast (6.50 m a.s.l.) from the localities of El Puerto de Santa María to Chiclana. Five sequences of very coarse-grained beaches have been recognized and dated. They unconformably overlie Pliocene units and are formed by clast-supported conglomerate and coarse-grained sandstone. Chronological ages ($^{87}Sr/^{86}Sr$ and AMS ^{14}C analysis) and stratigraphic correlation stand that the oldest marine terrace is the one placed topographically higher and towards the SE of Cadiz city, dated as Early Pleistocene (1.3 Ma). After it, the sea retreatment produces subaerial exposure of Sequence 1 and the development of several calcrete profiles and a paleokarst. Subsequent sea-level rises allow the sedimentation of Sequences 2, 3 and 4 during Early-Middle Pleistocene (1 to 0.8 Ma) in areas close to Cadiz city, with subaerial exposure recorded at the top of Sequences 3 and 4. During the very Upper Pleistocene, sedimentation of Sequence 5 occurs towards the SE of Cadiz city. Based on the spatial position of Sequence 5 we can conclude that this area constituted a downthrown block during the Latest Pleistocene, in relation to neotectonic processes and diapirism.

Sandstone framework (hybrid arenites) reveals that main source areas for these marine terraces include units from the Betic Orogene (Betic external zones -Triassic and Jurassic rocks-and the Gibraltar arc), the Guadalquivir basin passive margin (Iberian Massif), the Guadalquivir foreland basin (marine Miocene and Pliocene record) and local inputs of Pleistocene units. The siliciclastic supplies from sources were mainly constant during the sedimentation of all set of sequences, suggesting maturation processes as reworking and recycling of homogenized sediments during transport. Early diagenetic processes have been identified as carbonate cementation, neomorphism and dissolution, outlining the deduced sea-level fluctuations during deposition of Pleistocene sequences.

The marine terraces arrangement and its comparison with regionally adjacent areas allows to deduce that the southern and central Portuguese coast (Iberian Massif) and of the southern and southeastern Spanish coast (Betic Orogene) were predominantly tectonically raising during Pleistocene. However, the Cadiz Gulf coast (formerly Guadalquivir foreland basin) was mainly sinking during the same time interval.

1. Introduction

Holocene sedimentary record of the Gulf of Cadiz have been extendedly studied (i.e., Goy et al., 1996; Gutiérrez-Mas et al., 1996; Zazo et al., 1999; Dabrio et al., 2000; Gutiérrez-Mas et al., 2009a, 2009b; Monge Soares and Matos Martins, 2009, 2010). On the other hand, Pleistocene record has received less attention (Hernández-Molina et al., 2002; Gutiérrez-Mas and Mas, 2010; Gutiérrez-Mas and Mas, 2013). A series of very coarse-grained deposits (bioclastic conglomerate –usually between 2 and 60 mm- and sandstone) lying unconformably on Pliocene units and outcropping along the Cadiz coast have been dated as Pleistocene and interpreted as marine terrace levels of coarse-grained beaches (Gutiérrez-Mas and Mas, 2010; Gutiérrez-Mas and Mas, 2013). Outcrops of Pleistocene marine terraces are relatively frequent along the Mediterranean coast of S and SE Spain (Dabrio, 2000; Zazo et al.,

* Corresponding author.
E-mail addresses: lgcebron@geo.ucm.es (L. González-Acebrón), ramonmas@ucm.es (R. Mas), arribas@ucm.es (J. Arribas), josemanuel.gutierrez@uca.es (J.M. Gutiérrez-Mas), carlos.perez@cenieh.es (C. Pérez-Garrido).

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2003; Bardají et al., 2009; Dabrio et al., 2011). They correspond to levels of coarse-grained beaches being usually related to coarse-grained deltas (fan deltas).

The aims of this paper are: (1) to analyze the coarse sedimentary facies that characterize the Pleistocene deposits outcropping in diverse marine terraces at the coast of the Gulf of Cadiz and determine their sedimentary environments and the main factors that controls their deposition; (2) to place their recorded sedimentary sequences and lateral facies changes in a chronological chart based upon $^{87}Sr/^{86}Sr$ and AMS ^{14}C dating; (3) to examine their framework and interstitial components to establish the provenance and early diagenetic processes that affected these deposits; and (4) to integrate all these data in the context of the geological history of the area, focusing on sea-level variation and paleotectonics.

2. Location and geological setting

The studied area is located on the Atlantic coast of Andalusia in SW Spain (Fig. 1A and B), along the coast of the localities of El Puerto de Santa María, Cadiz, San Fernando and Chiclana de la Frontera (Fig. 1C). The studied Pleistocene deposits are located at the Gulf of Cadiz coast on the SW margin of the Guadalquivir Foreland Basin, and to the W of the Betic Mountain Range (Fig. 1B) and consist of a series of outcrops that are aligned NNW-SSE along the coast of Cadiz (La Caleta, Santa María del Mar, Cortadura, Torregorda, Sanctipetri Island and Torre Bermeja-La Barrosa; Fig. 1C). Five stratigraphic sequences and three vertically stacked marine terraces have been established in this work, based on the relative arrangement of the deposits and their chronological ages ($^{87}Sr/^{86}Sr$ and AMS ^{14}C analysis).

Two structural levels can be distinguished in the studied area (Fig. 1D): (a) a lower level consisting of pre-orogenic materials from the Betic Mountain Range (Early Permian to Miocene) and syn-orogenic deposits from the Guadalquivir Olistostrome Complex (Early–Middle Miocene), (b) a higher level of postorogenic materials (Late Miocene to Pleistocene) deposited after the Alpine Orogeny in marine and coastal environments within the Guadalquivir Basin (Berastegui et al., 1998; García-Castellanos et al., 2002), being the studied Pleistocene deposits part of the last stratigraphic record of this second level.

During the Lower Pliocene, the present Guadalquivir Basin was a gulf that opened southwards (Viguier, 1974; Aguirre, 1995), where bioclastic sandstone and bioclastic sandy grainstone and sandy-silty marls were deposited in shallow marine to coastal environments (Gutiérrez-Mas and Mas, 2012, 2013). Later, during the Pleistocene, bioclastic conglomerate and coarse sandstone were deposited in coastal environments (Gutiérrez-Mas and Mas, 2010, 2013).

Both Pliocene and Pleistocene sedimentary records evidence intense neotectonic activity, being affected by faulting and folding (Viguier, 1974; Benkhelil, 1976; Sanz de Galdeano and López Garrido, 1991; Rehault et al., 1985; Cloetingh et al., 1992; Gutiérrez-Mas et al., 2004; Gracia et al., 1999, 2008). The seismicity is related to the Azores-Gibraltar fault, which represents the Africa-Eurasia plate boundary, which movement has caused intense earthquakes. Several boulder-bearing layers in both the Pliocene and the Pleistocene sedimentary records and have been interpreted as caused by tsunamis (Gutiérrez-Mas and Mas, 2010, 2012, 2013).

3. Materials and methods

Several fieldwork campaigns were conducted focusing on: detailed geological mapping, logging and sampling four detailed stratigraphic sections, together with sedimentological observations in other complementary outcrops. The pebble size, shape and composition are considered for lithofacies and provenance analysis, as well as paleocurrents, which have been measured in imbricated pebbles and in trough and planar bedded sandstones.

Double-polished thin sections were prepared from a total of 27 samples of Pleistocene conglomerates and sandstones for petrographic analysis. Cold cathodoluminescence and microprobe tests were performed on the diagenetic products. K-ferrocyanide and Alizarine-red (Lindholm and Finkelman, 1972) solution was used to partially stain thin sections for a better differentiation of carbonate minerals.

Quantitative petrographic analysis was performed on 18 selected sandstone samples for provenance analysis, choosing medium grained

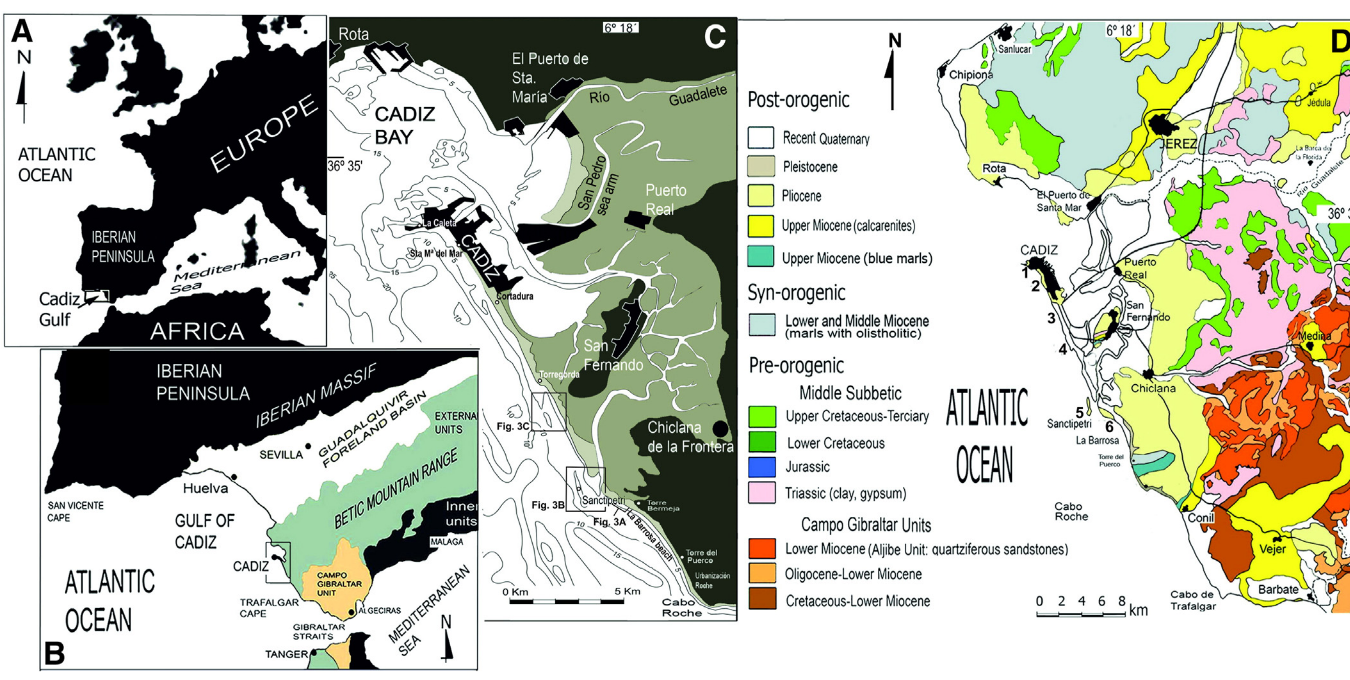

Fig. 1. Geographical and geological setting of the studied area: A. General geographical setting of the Gulf of Cadiz; B. General geological setting of the Gulf of Cadiz; C. Detailed location of the studied area indicating the situation of Fig. 3A, B and C; D. Geology of the studied area. Studied sections and outcrops: 1. La Caleta; 2. Santa María del Mar; 3. Cortadura; 4. Torregorda; 5. Sanctipetri Island; 6. Torre Bermeja-La Barrosa. Modified from Gutiérrez-Mas and Mas (2013).