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Evidence of MIS 5 sea-level highstands in Gebel Mousa coast (Strait of Gibraltar, North of Africa)

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ABSTRACT

The Last Interglacial is considered the most suitable episode from which to infer patterns of rapid sea-level change since its climatic conditions were similar to those of the present interglacial. However, specifying the true position of its sea level with high accuracy is very troublesome in the absence of sedimentological, erosional or even palaeontological markers. This study investigates the morphosedimentary evidence (beach deposits, cliff, notch and shore platform) of two highstands registered and dated during MIS 5 stage by U-series dating in the North of Morocco (Strait of Gibraltar). Bioerosive notches and mixed siliciclastic and carbonate deposits, high energy beaches with algal bioherms, were formed in coastal environments during MIS 5a. A sea-level height of +10 m asl can be inferred for this substage. The record of MIS 5e substage is less defined in the geomorphological record, consisting of backshore/foreshore deposits located at +13 to +15 m asl. A tectonic uplift rate of ~0.1 mm/yr has been estimated for the last 130 kyr. These data are consistent with models of coastal uplifting calculated for the Strait of Gibraltar.

1. Introduction

Evidence from a variety of sources in the field is required to accurately interpret sea-level changes in the geological record. In the last decades, depositional (Dumas et al., 2006; Bardají et al., 2009a; Muhs et al., 2011), geomorphological (Antonioli et al., 2006a; Hearty et al., 2007) and even archaeological markers (Auriemma and Solinas, 2009; Anzidei et al., 2011) have been used as indicators of sea-level rise during the Late Quaternary. For a correct interpretation of this evidence using a multidisciplinary approach to the study of sea-level history, independent confirmation of the age of the deposits through chronometric methods such us uranium-series or amino-acid racemization (AAR) geochronology is required (Hearty et al., 2007), whilst coastal and marine deposits linked to shoreline fluctuations can determine the hydrodynamic conditions and, indirectly, the eustatic changes. Conversely, a precise measure of the palaeo-sea level is very difficult to estimate in the absence of appropriate sedimentary structures (e.g. foreshore plunge-step; Dabrio et al., 1985) or specific sedimentary environments, such as tidal flats (Mauz and Bungenstock, 2007) or reflective and microtidal beaches (Dabrio et al., 2011). It is only in certain settings (e.g. wave dominated, small tidal range and carbonate coastal cliffs) where the integrated analyses of morphosedimentary complexes are useful tools for the precise reconstructions of the relative sea-level position during Quaternary highstands (Ferranti et al., 2006; Antonioli et al., 2007), and in this respect, bioerosional and tidal notches are precise indicators (+/− centimeters) of short-term sea-level positions (Stiros et al., 1992; Laborel et al., 1994; Antonioli et al., 2006a, 2006b; Ferranti et al., 2006; Hearty et al., 2007).

The Marine Isotope Stage (MIS) 5, and in particular the MIS 5e (or Last Interglacial), is considered the most suitable recent geological period for comparison with the present interglacial (e.g. see Tzedakis, 2003 and references therein; Rohling et al., 2008). Its duration was around 17–18 kyr, between ~133 and 116 ka, during which global sea level rose around 6 (±3) m above present sea level (e.g., Hearty and Kindler, 1995; Shackleton et al., 2002; Siddall et al., 2003; Lambeck et al., 2004). During MIS 5e, sea-level changes are characterized by intervals of transition and stability marked by abrupt shifts (Hearty et al., 2007). These circumstances make this stage a reliable episode from which to infer rapid sea-level change patterns even though its climatic conditions and global ice volumes were not

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exactly similar to the present ones, with a surface temperature around 2 °C warmer and the Greenland ice sheet more reduced than at present (Rohling et al., 2008). The number of highstands during MIS 5, and especially during MIS 5e, is still an issue and there is agreement on the number, timing and heights reached by the sea (e.g., Antonioli et al., 2004; Dorale et al., 2004; Hearty et al., 2007; Bardají et al., 2009a, among others).

Numerous papers have focused on MIS 5 deposits along the Spanish Mediterranean coasts using multidisplinary approaches (U-series dating, geomorphological and morphosedimentary analyses, palaeontological assemblages) in order to resolve this problematical issue, and focusing their interest on MIS 5e rather than MIS 5c and MIS 5a. MIS 5 presents four or five sea-level highstands along the Spanish coastline (Zazo et al., 2003). According to phreatic overgrowths studies in coastal caves located in Mallorca in the western Mediterranean, sea-level was ~1.5–3 m above present sea level (m asl) during MIS 5e and ~1–1.9 m asl during MIS 5a (Fornós et al., 2002; Tuccimei et al., 2006; Dorale et al., 2010). For the Rock of Gibraltar, Rodríguez-Vidal et al. (2007a, 2007b) described several marine terraces and coastal sedimentary deposits at heights between 1,5 and 5 m asl. More recently, Dabrio et al. (2011) described small-scale, short-lived fluctuations and rapid sea-level changes recorded during the second MIS 5e highstand in the southeastern coast of the Iberian Peninsula.

Similar studies are comparatively scarce for the north of Morocco, with the main ones dating to the 1970's, covering a brief description and chronological setting of marine terraces, with additional geomorphological and neotectonic interpretations (El Gharbaoui, 1977, 1978). Further to the southwest, the Quaternary littoral deposits are better studied, including the Ouljian regional stratotype which can be partially correlated with MIS 5 stage (Biberson, 1961; Texier et al., 2002; Rhodes et al., 2006). More recently, several studies describe the palaeoenvironmental evolution of this area during the Last Interglacial (Aboumaria et al., 2005; 2009), and try to correlate the age and altitude of marine terraces with adjacent travertines forming during warm and wet interglacial periods (El Kadiri et al., 2010). These last authors suggest an eustatic factor to explain the origin of the marine terraces, although they infer a significant tectonic influence on this region.

The main aim of this paper is to describe and date a hitherto undescribed bioerosive notch in northern Morocco, and other sedimentological sea-level markers, corresponding to Late Pleistocene highstands developed during the Last Interglacial in Cape Leona and the coast of Gebel Mousa (Northern Morocco) (Fig. 1). Secondly, we compare the data obtained with the pattern of tectonic uplift established for the western Mediterranean coast on the basis of marine terrace altitude.

2. Regional setting

The study area is located in the Tangier peninsula in the North Coast of Morocco. The coast is steep with a wave-dominated hydrodynamic regime. The Atlantic tidal wave enters the Mediterranean with an eastward progressive propagation. The average tidal range in this area is 50 cm and its range varies from a few centimeters during neap tides to 1 m during spring tides (Benavente et al., 2007).

The Tangier peninsula constitutes the southern margin of the Strait of Gibraltar (Fig. 1) within the Gibraltar Arc–Rif Range. The Betic-Rif mountains belt is the most westerly of the alpine mountain chains of Southern Europe and Northern Africa. The Rift Belt of North Africa is generally divided into three: the Internal Zone, an Intermediate Flysch Zones, informally known as the Flysch Nappes, and the External Zone (Wildi, 1983) (Fig. 1).

From the geological point of view, the study area is located in the northwestern end of this range where well developed staircased marine terraces are clearly observed in the landscape (Rodríguez-Vidal and Cáceres, 2005) (Fig. 2). These terraces are formed over the Mesozoic rocks of the Riffian Internal Zones that crop out extensively in this region: mainly carbonate rocks of the Tariquide Units that make up the more important reliefs of the region. The Flysch Unit is constituted by well stratified claystones, limestones and sandstones, which crop out in both sides of Gebel Mousa (Bel Younech town) and in front of Perejil Island (also known as *Leila* or *Taura Island*) (Figs. 1 and 2).

3. Material and methods

3.1. Sedimentology and palaeontology

Standard field techniques were employed in the investigation and sampling of the outcrops. Two stratigraphic sections were measured, logged and photographed to identify the main sedimentary structures and facies for palaeoenvironmental interpretations (Fig. 2). Furthermore, some petrographic samples of representative facies were collected and analyzed under transmitted, polarized light after preparation of polished cylinder and thin sections in order to determine textural components, microfossils and diagenetic

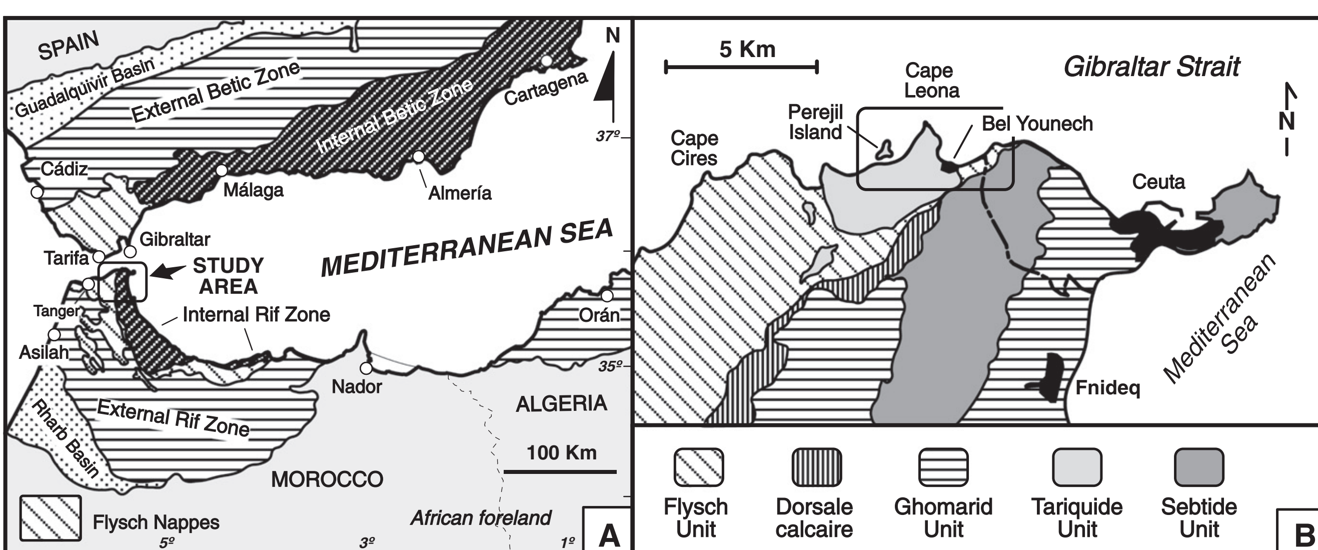

Fig. 1. A, location and geological sketch of Southern Spain and Northern Morocco. B, geological setting of the studied area.