MIS 5 sea-level markers and regional uplifting in the Strait of Gibraltar (North of Morocco)

Indicadores del nivel del mar durante el MIS 5 y elevación tectónica en el Estrecho de Gibraltar (Norte de Marruecos)

M. Abad[1*], J. Rodríguez-Vidal[1], K. Aboumaria[2], M.N. Zaghloul[2], L.M. Cáceres[1], F. Ruiz[1], A. Martínez-Aguirre[3] and S. Chamorro[4]

1 Departamento de Geodinámica y Paleontología, Universidad de Huelva, Campus del Carmen, 21071-Huelva, España. manuel.abad@dgyp.uhu.es
2 Départment des Sciences de la Terre, Université AbdelMalek Essaâdi, Faculté des Sciences et Techniques, BP 416 Tánger, Marruecos.
3 Departamento de Física Aplicada I, EUITA, Universidad de Sevilla, Ctra. de Utrera Km 1, 41013-Sevilla, España.
4 Instituto de Estudios Ceutíes. Paseo del Revellín 30, 51080, Ceuta, España.

Abstract: This study investigates the morpho-sedimentary evidence of two highstands registered and dated during MIS 5 stage by U-series dating in the North of Morocco (Strait of Gibraltar). Bioerosive notch and mixed siliciclastic and carbonate deposits, high energy beaches with algal bioherms, were formed in coastal environments during MIS 5a. A sea-level altitude of +10 m asl was inferred for this substage. The record of MIS 5e-2 substage is less complete, consisting in upper foreshore and storm deposits located some meters above the sea-level (+13-15 m asl). A tectonic uplift rate of ~0.1 mm/yr has been estimated for the last 130 ky. This data is consistent with models of coastal uplifts elaborated for the Gibraltar Strait.

Key words: Marine terrace, notch, MIS 5, Strait of Gibraltar, Morocco**.**

Resumen: *Este trabajo analiza las evidencias morfosedimentarias de dos altas paradas del nivel marino datadas en el MIS 5 mediante series de U en el Norte de Marruecos. Durante el MIS 5a se formaron socaves bioerosivos (*notches*) y facies de playas de alta energía constituidas por depósitos mixtos siliciclástico-carbonatados. Una altura de 10 m snm ha sido estimada para esta etapa. El registro del MIS 5e-2 es menos completo, constituidos por depósitos de* foreshore *y de tormenta formados varios metros sobre el nivel del mar (+13-15 m snm). Se ha deducido una tasa de elevación tectónica de 0.1 mm/año para los últimos 130 ka. Estos datos son consistentes con los modelos previos de levantamiento tectónico elaborados para el Estrecho de Gibraltar.*

Palabras clave: *Terraza marina,* notch*, MIS 5, Estrecho de Gibraltar, Marruecos.*

INTRODUCTION

The Last Interglacial is considered the most recent geological period during which conditions were similar to the present interglacial (e.g. Tzedakis, 2003 and references therein). These circumstances make the Marine Isotope Stage (MIS) 5 a very adequate episode to infer rapid sea-level changes.

The western Mediterranean sea level was ~1−1.9 meters above modern sea level during MIS 5a and 1.5−3 m asl during MIS 5e, according to phreatic overgrowths studies on Majorca coastal caves (Tuccimei *et al*., 2006). On the whole, numerous papers were focused on MIS 5 deposits along the Spanish Mediterranean coasts, with the application of multidisplinary approaches (U-series measurements, geomorphological and morpho-sedimentary analyses, palaeontological assemblages) in order to define the number and timing of the Last Interglacial highstands. These studies are comparatively scarce in the North of Morocco.

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

REGIONAL SETTING

The Tanger peninsula constituted the southern margin of the Gibraltar Strait (Fig. 1) within the Gibraltar Arc−the Rif Range. Its tectonic structure and geological units are very similar to the Iberian Margin, with the Internal and External Zones of the Betic Range and “flysch nappes” cropping out.

The studied zone is located in the northwestern end of the range where well development staircased marine terraces are clearly observed in the landscape. These terraces are formed on the Mesozoic carbonate rocks of the Tariquide Units that make up the more important reliefs of this region. Well stratified claystones, limestones and sandstones of Flysch unit crop out both sides of Gebel Mousa (Bel Younech town) and in front of Perejil (Leila or Taura) island (Fig. 1).

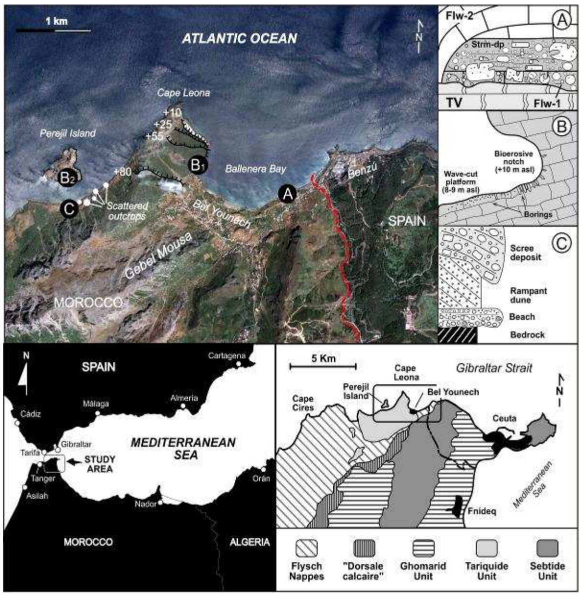

FIGURE 1. *Below, location of the studied area and geological setting of Northern Morocco. Above, location of the studied sections in Bel Younech beach (Section A), Cape Leona and Perejil island (Sections B) and scattered outcrops near of Perejil (Section C).*

METODOLOGY

Two stratigraphic sections (A and C, Fig. 1) were studied to identify the sedimentary facies and their environmental interpretation. Scattered specimens of macrofossils were examined at species level. Both speleothem and marine samples were dated by U-series analysis (alpha spectrometry) in the Laboratorio de Datación of the Dpto. de Física Aplicada of the Universidad de Sevilla.

Erosive littoral features (cliff, wave-cut platform, notch) were analyzed, measured and mapped in the field (Sections B1 and B2), with an additional analysis of aerial photographs. The topographic elevation of geomorphologic markers was measured by means of a high resolution altimeter.

RESULTS

Mixed carbonate-siliciclastic deposits crop out in two sections (Sections A and C) near the present coast. On the other hand, most of the limestone coast of Gebel Mousa presents a clear, pervasive and laterally continuous courtship of bioerosive marker at +10 m asl (Section B) (Fig. 1).

Section A

Bel Younech Beach (Section A) presents a staircased sequence of three travertine buildings. At its base, the lower one (TV in Fig. 1) contains scattered and sheltered coastal deposits, located between +13 and +15.5 m asl and preserved within large cavities. These deposits are constituted by cemented conglomerates of limited lateral continuity and 1–2.5 m thick (Fig. 2A). The calcareous flowstones that cement this deposit have been dated by U-series as MIS 5e-2 (Flw-1; 131.2±7.4 ka) and MIS 5a (Flw-2; 87.0±3.7 ka), respectively.

In the conglomerate facies, limestone and sandstone clasts are poorly sorted and show a heterometric distribution. Their rounding ranges from well-rounded to angular. In most cases, clast orientation is random and internal stratification is absent, although poorly defined subhorizontal bedding has been observed. Near the top of some deposits, low-angle parallel laminated sandstones are present. Fossils are uncommon and only some well-preserved specimens of the gastropod *Patella ferruginea* Gmelin, 1791 in life position have been collected. Boulders and cobbles are extensively bored by *Gastrochaenolites* traces.

Section B

The best preserved seal-level erosive markers are located in Cape Leona cliffs (Section B1) and Perejil island (Section B2), with well development marine notch (base of the floor at +10–11 m asl) and broad wave-cut platform at +8–9 m asl, both formed within Jurassic limestones. The amplitude of the marine notch is 210 cm and its depth is less than 25 cm (Fig. 1). These markers can be spatially correlated with nearshore deposits of MIS 5a described in the west side of Section C (Fig. 2C and D).

Two ichnogenera have been identified in these outcrops (*Gastrochaenolites* and *Entobia*), both corresponding to the boring activity of endobenthic bivalves and clionid sponges, respectively. Although they may appear scattered along the outcrops at variable height, the bigger boreholes (*Gastrochaenolites* isp.) are distributed mainly within a horizon of dispersed borings located between the base and the retreat point of the notch profile at +9 to +10 m asl. Small fossil traces consisting of a complex network of multiapertured and multichambered borings with a circular section and a variable diameter between 0.5 and 3 mm have been identified as *Entobia* isp. Although *Entobia* borings have been described to be very occasionally linked to *Gastrochaenolites* at the base of the notch (+9 m asl), its distribution pattern in outcrops is much more diffuse in many cases, appearing scattered next to red algae patches at variable heights along the western slope of Cape Leona.

Section C

On the steep coast facing Perejil island there is a regular slope with coarse conglomeratic, cemented scree deposits overlying a thick rampant coastal dune (Fig. 1). In this point, conglomerate and bioclastic sand deposits are located +10 m asl that grade to algal limestone and calcarenite facies at +8 m asl toward the north/northeast (Fig. 2B).

In higher outcrops, these deposits are constituted by a clast-supported polymodal conglomerate bedset, whose thickness ranges from <100 cm to 150 cm. Facies are highly bioclastic with a scarce in siliciclastic matrix. This bed overlies an erosive surface truncating the underlying units. These facies show normally graded bedding and very diffuse, gently parallel-inclined planar bedding, including some interbedded intervals (<10 m thick) of bioclastic sands with parallel lamination. Clasts are angular to rounded and range from granules to cobble in size. Borings of *Entobia* and *Gastrochaenolites* are very common in limestone clasts.

The palaeontological record includes fragmented gastropods (*Patella*, *Bittium*, *Conus*), bivalve pectinids, serpulids and very abundant skeletal elements of echinoids (plates and spicules). Debris of red algae (rhodoliths) are also especially frequent.

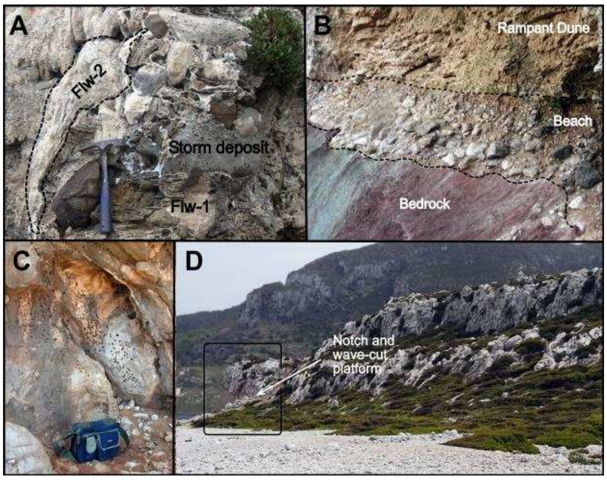

FIGURE 2. *A, Close up of bioeroded boulders deposited by storms during MIS-5e stage into travertine cavities. Two different growth phases of flowstone (Flw-1 and 2) cover these facies allowing to predate and postdate them. B, Beach facies in Section C where graded conglomerate overlies an erosive transgressive surface. C and D, Horizon of occurrence of* Gastrochaenolites *boreholes near the retreat point of the laterally continuous notch in Section B1*

Scattered outcrops toward the western locations can be lateratelly correlated with previous facies. In these outcrops carbonate facies are deposited on top of the erosional surface formed directly in Mesozoic limestone bedrock. They consist of massive packstone-limestone and are constituted by rhodoliths of calcareous algae (mainly *Lithophyllum* sp. and *Melobesia* sp.). The U-age of the calcareous algae corresponds to MIS 5a substage (84.4±3.3 ka). Patch-like growths are not directly observed due to poor outcrop conditions but, in some cases, red algae forming laminar structures have been preserved. Some specimens of the benthic foraminifera *Elphidium advenum* were collected from detrital matrices. Bivalves, serpulids, echinoderms and gastropods are very rare.

INTERPRETATION AND DISCUSSION

Facies analysis

The internal structure and palaeontological record of the coastal facies of Bel Younech (Section A) suggest foreshore and mainly backshore depositional environments during the substage MIS 5e-2, although the occurrence of the gastropod *Patella ferruginea* in life position (Hawkins *et al*., 2000) on boulders bioeroded by *Gastrochaenolites* (e.g. Bromley and Asgaard, 1993) indicate the proximity of a rocky shoreline exposed to high energy waves, probably adjacent to coastal cliffs.

Conglomerates and bioclastic sands in Section C have been interpreted as shoreface facies of microtidal, high-energy beaches deposited during the substage MIS 5a. In the coastal setting, polymodal, graded bedding, gently inclined stratified conglomerates with scarce matrix have been described in upper shoreface facies (Armitage *et al*., 2004). The fossil assemblage described in these outcrops is very similar to the “Lithophyllum incrustans and ursins” biofacies cited in present rocky substrate of the Gibraltar Strait (VV.AA., 2009). This assemblage lies on hard cliffs and large rocks in high-energy, wave-dominated coasts at depths that range from few centimeters to 7–8 m. Rhodolith-rich facies in laterally equivalent outcrops represent a more external and deeper shoreface environment (or even shallow marine zones), where (para)autochtonous patch growths of encrusting calcareous algae prevailed.

Sea-level erosional markers

The heights of the MIS 5a marine notch have been measured at +10 m asl in its middle-lower part, where the boreholes of bigger dimensions are concentrated. Borings belonging to the ichnogenus *Entobia* and, mainly, *Gastrochaenolites* have been found through the walls of the notch morphology, although also scattered at lower altitudes along Mesozoic limestones outcrops.

Gastrochaenolites boreholes correspond to the bioeroding work into calcareous substrate of the mytilid bivalve *Lithophaga lithophaga*. In the present study area, this is very common in the infralittoral zones of rocky shores exposed to the waves together with sponges, cirripids, bryozoans and coralline red algae. Some investigations carried out in other Mediterranean coasts have confirmed the value of high-density occurrence of *Gastrochaenolites* borings at the same topographic height linked to erosional markers elaborated during sea-level stillstands as a very useful tool to deduce water depths between 0 and 2 meters (Stiros *et al*., 1992). So, the indirectly dated bioerosive notch and wave-cut platform in Gebel Mousa coast (Sections B1 and B2) can be considered as good indicators of the sea-level for MIS 5a substage and a very useful tool to estimate vertical tectonic movements rates (e.g. Antonioli *et al*., 2007).

Recent tectonics and uplift rates

In the western Mediterranean, the tectonically stable coasts of Majorca Island display caves that provide an extraordinary setting for capturing past sea-level changes (Tuccimei *et al*., 2006). The altitudinal comparison of MIS 5e-2 Mallorca record with Gebel Mousa record allows inferring a maximum tectonic uplift rate to just below ~0.08 mm/yr for the last 130 ka in the study area. A very much certain altitude of the sea-level can be estimated for the MIS 5a highstand on the basis of the occurrence of bioeroded notch, resulting in a alike tectonic uplift rate of 0.11 mm/yr for the last 83 ka.

Numerous authors have described Last Interglacial marine terraces in southern Spanish coasts and northern Mediterranean and Atlantic littoral areas of Morocco. The spatial distribution of these terraces display a maximum coast uplift rate in the central part of Gibraltar Strait (0.2 mm/yr) that decreases toward the East and West (Zazo *et al*., 2003). This model fits well with the altitude and uplift rate deduced from the marine terraces described in Cape Leona.

Consequently, the tectonic uplift deduced indicates a prevailing role of eustasy over tectonics in the development of marine terraces of the North of Morocco (except for the central part of the Gibraltar Strait), although it is obvious that the importance of the latter must not be discarded. A comparison between the uplift rates deduced from the terraces of Cape Leona and the altitude distribution of MIS 5 marine terraces of western Mediterranean and Atlantic coasts of Africa with different degrees of tectonic activity allows us to classify the study area as a moderately active coast (0.08-0.11 mm/yr). In order to make this calculation, the different tectonic uplift rates have been recalculated taking as new references the highest sea-level data and the age for MIS 5e-2 and MIS 5a substages (135 and 83 ka, respectively) obtained from phreatic overgrowths on speleothems in Majorca (Tuccimei *et al*., 2006). This value of tectonic uplift is roughly close to that obtained in Murcia (Zazo *et al*., 2003) or Alhoceima regions (Gigout *et al*., 1974).

ACKNOWLEDGEMENTS

This research was supported by the Spanish–FEDER Projects CGL2010-15810/BTE and a postdoctoral fellow of the Spanish Government (Subprograma JDC-MICINN, Plan Nacional I+D+i 2008-2011). It is a contribution to the IGCP Project 911 (Decoding the Last Interglacial in Western Mediterranean).

REFERENCES

Antonioli, F., Anzidei, M., Lambeck, K. *et al*. (2007): Sea-level change during the Holocene in Sardinia and in the northeastern Adriatic (central Mediterranean Sea) from archaeological and geomorphological data. Quaternary Science Reviews, 26: 2463-2486.

Armitage, I.A., Pemberton S.G., Moslow T.F. (2004): Facies succession, stratigraphic occurrence, and paleogeographic context of conglomeratic shorelines within the Falher "C", Spirit River Formation, Deep Basin, West-Central Alberta. Bulletin of Canadian Petroleum Geology, 52: 39-56.

Bromley, R.G., Asgaard, U. (1993): Endolithic community replacement on a Pliocene rocky coast. Ichnos 2: 93-116.

Gigout, M., Cadet, J.P., Pierre, G. (1974): Sur le comportement de l´Arc de Gibraltar au Quaternaire recent d´apres les formations littorales. In: 2eme Reunion Annuelle des Sciences de la Terre.

Stiros, S.C., Arnold, M., Pirazzoli, P.A., Laborel, J. *et al*. (1992): Historical coseismic uplift on Euboea Island, Greece. Earth and Planetary Science Letters, 108(1-3): 109-117.

Tuccimei, P., Ginés, J., Delitala M.C., Ginés, A., Gracia, F., *et al*. (2006): Last Interglacial sea level changes in Mallorca island (Western Mediterranean). Zeitschrift für Geomorphologie, 50(1): 1-21.

Tzedakis, C. (2003): Timing and duration of Last Interglacial conditions in Europe: a chronicle of a changing chronology. Quaternary Science Reviews, 22: 763-768.

VV.AA. (2009): Bases ecológicas preliminares para la conservación de los tipos de hábitat de interés comunitario en España. Ministerio de Medio Ambiente, Medio Rural y Marino, Madrid. 142 pp.

Zazo, C., Goy, J.L., Dabrio, C.J., Bardají, T., Hillaire-Marcel, C. *et al*. (2003): Pleistocene raised marine terraces of the Spanish Mediterranean and Atlantic coasts. Marine Geology, 194: 103-133.