Geomorphology 203 (2013) 105–114

Contents lists available at ScienceDirect

Geomorphology

journal homepage: www.elsevier.com/locate/geomorph

Undrowning a lost world — The Marine Isotope Stage 3 landscape of Gibraltar

Joaquín Rodríguez-Vidal [a,*], Geraldine Finlayson [b], Clive Finlayson [b,c], Juan J. Negro [d], Luis M. Cáceres [a], Darren A. Fa [b], José S. Carrión [e]

[a] Departamento de Geodinámica y Paleontología, Campus del Carmen, Av. Tres de Marzo s/n, Universidad de Huelva, 21071 Huelva, Spain
[b] The Gibraltar Museum, 18–20 Bomb House Lane, P.O. Box 939, Gibraltar
[c] Department of Social Sciences, University of Toronto, Canada
[d] Departamento de Ecología Evolutiva, Estación Biológica de Doñana (CSIC), 41092 Sevilla, Spain
[e] Departamento de Biología Vegetal (Botánica), Facultad de Biología, Universidad de Murcia, 30100 Murcia, Spain

ARTICLE INFO

Article history:
Received 5 March 2012
Received in revised form 7 October 2012
Accepted 22 February 2013
Available online 1 March 2013

Keywords:
Geomorphology
Vegetation
MIS 3
Neanderthal
Gibraltar
Western Mediterranean

ABSTRACT

The Rock of Gibraltar, at the south-western extreme of the Iberian Peninsula and 21 km from the North African coast, is a 6-km long limestone peninsula which was inhabited by Neanderthals from MIS 5e until the end of MIS 3. A total of 8 sites, either with Neanderthal fossils or their Mousterian lithic technology, have been discovered on the Rock. Two, Gorham's and Vanguard Caves, are the subject of ongoing research. These caves are currently at sea level, but during MIS 3 faced an emerged coastal shelf with the shoreline as far as 5 km away at times. They hold a unique archive of fauna and flora, in the form of fossils, charcoal and pollen, helping environmental reconstruction of now-submerged shelf landscapes. In addition, geological and geomorphological features — a 300-metre dune complex, elevated aeolian deposits, raised beaches, scree, speleothems — complement the biotic picture.

The work is further complemented by a study of the ecology of the species recorded at the site, using present-day observations. The species composition in this fossil record closely matches the present day fauna and vegetation of the Doñana National Park, SW Spain: a mosaic of pine groves, coastal dunes, shrubland and seasonal wetlands and currently the richest reserve in terms of biodiversity in the Iberian Peninsula, located only 100 km to the northwest from Gibraltar.

All this information permits, for the first time, the quantification of the vegetation structure of the ancient coastal plain and the modelling of the spatio-temporal dynamics of the MIS 3 coastal shelf off Gibraltar.

1. Introduction

The Iberian Peninsula lies at the western end of the Mid Latitude Belt (MLB) (Finlayson, 2004), which runs from the Himalayas in the east to Portugal and Morocco in the west, and which was a biogeographical unit in terms of its topographical, faunal and vegetation features in the Tertiary and Early Quaternary (Finlayson, 2011). The distribution of Aurignacian-family industries closely matches the maximum geographical area occupied by the Neanderthals in Eurasia, which, in turn, matches the MLB (Finlayson and Carrión, 2007). It has been argued (Finlayson, 2009) that the Iberian Peninsula, and the South-west in particular, represent remnants of this ancient MLB. These landscapes have been dependent largely on the tectonic and eustatic-induced changes to the geomorphology, as well as on the edaphic substrate. Gibraltar lies at the extreme south west of the Iberian Peninsula. It represents a uniquely-preserved example that allows us to recreate a landscape that once typified large areas from Iberia to China. A multi-disciplinary approach to a high resolution reconstruction of the Gibraltar coastal area in MIS 3 is presented, as a prime example of an MLB relict landscape.

The Mediterranean vegetation and mixed forest has been observed to have persisted in a number of Iberian Mediterranean localities during Marine Isotope Stage 3 (MIS 3) (e.g. Carrión, 1992a,b; Burjachs and Julia, 1994; Carrión et al., 1995; Carrión and Munuera, 1997) despite it having been the coldest and most unstable of the entire Pleistocene (Finlayson, 2003; Martrat et al., 2004; Finlayson and Carrión, 2007).

The rapid climate changes that occurred during the last glacial cycle (~125–10 ka BP) meant that the coastal fringes, that are below sea level at present, were exposed for most of that time (Bailey and Milner, 2002/3; Moreno et al., 2005). In the south of the Iberian Peninsula, the exposed coastal plains would have become available to species as southern refugia, especially given coincidence of sea-level fall and shelf exposure with moments of relative cooling.

The importance of coastal environments and of the coastal shelf as a zone of geographic expansion by modern humans (Lahr and Foley, 1998; Quintana-Murci et al., 1999; Walter et al., 2000) and the exploitation of intertidal, marine and aquatic resources are increasingly being accepted as having been a widespread characteristic of early human palaeoeconomies and not just restricted to the Holocene (Klein, 1999;

* Corresponding author. Tel.: +34 959219862.
E-mail address: jrvidal@uhu.es (J. Rodríguez-Vidal).

0169-555X/$ – see front matter
http://dx.doi.org/10.1016/j.geomorph.2013.02.015

Erlandson, 2001; Mannino and Thomas, 2002; Klein et al., 2004; Finlayson, 2006; Fa, 2008; Brown et al., 2011; Cortés-Sánchez et al., 2011). More than 300 submarine sites having been noted by Werz and Flemming (2001), dating from between 5,000 to >45,000 ka BP off the coasts of Europe, North America, Australia and Japan. These coastal fringes could have provided corridors for the movements of species, including humans, as well as having provided refugia for their survival (Bailey et al., 2008). Thus, the landscape described here had a major influence on the survival and spread of fauna and flora, including humans. It is a landscape that is today restricted to pockets along the coastal fringes of SW Iberia. The best-preserved example is the Doñana National Park, located only 100 km away to the northwest of Gibraltar (Fig. 1). Here we argue that it is a hitherto unappreciated relic of a lost world.

2. Rock of Gibraltar — emerged geological landscape

The Gibraltar Strait area is located in the Western Mediterranean at the Africa-Eurasia convergent plate boundary. The Africa-Eurasia collision promoted a westwards displacement of the internal zones of the Betic cordillera, mainly during the Early Miocene, and the generation of the so-called Gibraltar Arc (Sanz de Galdeano, 1990).

This structural development took place in concert with an important regional rock uplift (Zazo et al., 1999; Rodríguez-Vidal et al., 2004). Major faults interacting with the coast have NE-SW and NW-SE orientations and they mainly work as strike-slip faults separating crustal blocks with different associated uplifting or subsiding character (Goy et al., 1995; Gracia et al., 2008). These largest lineations work as sinistral and dextral strike-slip faults, respectively, promoting consistent coastline displacements in the Gibraltar Strait. The tectonic blocks, defined by NE-SW and NW-SE faults, have had a differential uplift rate so forming a pseudo horst-graben system. In the Rock of Gibraltar the more active faults were NW-SE with relative downthrown staircased blocks to NE (Isthmus) and mainly to SW (Southern Plateau and Vladi's Reef), towards Gibraltar/Algeciras Canyon and the Strait.

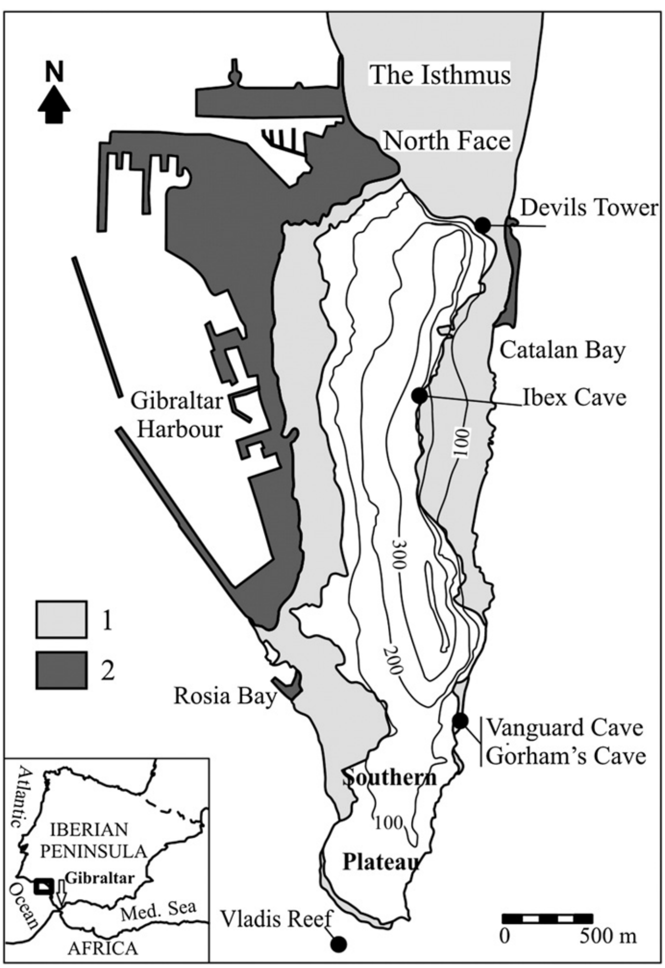

Fig. 1. Iberian Peninsula and the location of Gibraltar and Doñana area (rectangle). Simplified topographic map of the Gibraltar Peninsula. Contours at 100 m intervals. Legend: 1. Late Pleistocene morphosedimentary record. 2. Reclaimed land.

The Rock of Gibraltar is a small peninsula 5.2 km by 1.6 km having a total area of about 6 km^2 (Fig. 1). It has a north–south orientation, with highly eroded steep cliffs on the east while the west side consists of gentler slopes.

To the north of the peninsula, there is an isthmus consisting of Holocene sediments no higher than 3 m above sea level (a.s.l.) and linking it to the mainland. The Main Ridge of The Rock is composed of Early Jurassic limestone and dolomite rises up to three main peaks, two of which are above 400 m a.s.l. and form the central area. At the south end of the peninsula, the Southern Plateau is a staircased slope between 130 m and sea level (Rose and Rosenbaum, 1991), with a series of steep cliffs caused by Quaternary wave-cut erosion as a product of shoreline processes.

The tectonic structural movements that have determined the general shape and the surface erosional and depositional processes that have acted on the uplifted rocks have been identified by Rodríguez-Vidal and Gracia (1994, 2000) in the formation of this peninsula, and the complex geomorphological development and neotectonic uplift history has been described by Rodríguez-Vidal et al. (2004, 2007, 2010). These authors have provided a detailed analysis of the Rock's sedimentary record (uplifted marine terraces, windblown sands, scree breccias and karstic sediments) and its erosional landforms (cliffs, wave-cut platforms, staircased slopes and endokarstic systems) which show that the Rock's evolution has proceeded through a combination of tectonic uplift and eustatic sea-level change. Coastal cliffs that have been isolated from wave action when tectonic uplift has exceeded the rate of eustatic sea-level rise, or when the sea level has fallen, have been exposed to subaerial processes which have acted to degrade them further. Along the coast of Gibraltar the land has been uplifted at rates of 0.04 to 0.06 mm/yr in the last 100 ka (Goy et al., 1995).

Of the two prevailing winds in the Strait of Gibraltar, the easterly (Levante) and the westerly (Poniente), the former is by far the stronger. Rodríguez-Vidal et al. (2007) have described the effects on the build-up of dunes in the area of Gibraltar, particularly where large rampant type dunes accumulated against the steep slopes of the mountainous coast. The three main aeolian units identified on the Rock are the Monkey's Cave Sandstones, and the Alameda Sands and Catalan Sands on the west and east sides respectively (Rose and Hardman, 2000). From their geomorphological location and the dates of similar close sandy cave sediments (Rodríguez-Vidal et al., 2004, 2007) it can be inferred that these latter accumulations were generated during MIS 5 to 3, between 125 and 30 ka, originating from marine beaches, located between 6 m a.s.l. to 80 m b.s.l. (below sea level), before being blown inland to accumulate as topographic dunes.

For the better part of that last glacial cycle, the sea level remained on average 80 m below the present sea level, and at the Last Glacial Maximum fell to −120 m (Siddall et al., 2003). The landscape of Gibraltar was most affected on the east side of the Rock which is much shallower than to the west, and where a large coastal plain was exposed extending to up to 5 km from the present coastline (Fig. 2). There are a number of sites with archaeological evidence of human habitation along this side (Fig. 1), and we will attempt to provide insights into whether the shelf had emerged in MIS 3, and the biological species, water and lithic raw material resources that were present. The plain's substrate was windblown sands which accumulated against the limestone rock (Rodríguez-Vidal et al., 2007, 2010). Together, acidic sands and alkaline rocks created a geological ecotone which generated high ecological diversity.