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Uranium-series ages of corals, sea level history, and palaeozoogeography, Canary Islands, Spain: An exploratory study for two Quaternary interglacial periods

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ABSTRACT

We present the first U-series ages of corals from emergent marine deposits on the Canary Islands. Deposits at +20 m are 481 ± 39 ka, possibly correlative to marine isotope stage (or MIS) 11, while those at +12 and +8 m are 120.5 ± 0.8 ka and 130.2 ± 0.8 ka, respectively, correlative to MIS 5.5. The age, elevations, and uplift rates derived from MIS 5.5 deposits on the Canary Islands allow calculations of hypothetical palaeo-sea levels during the MIS 11 high sea stand. Estimates indicate that the MIS 11 high sea stand likely was at least +9 m (relative to present sea level) and could have been as high as +24 m. The most conservative estimates of palaeo-sea level during MIS 11 would require an ice mass loss equivalent to all of the modern Greenland and West Antarctic ice sheets; the more extreme estimates would require additional ice mass loss from the East Antarctic ice sheet. Extralimital southern species of mollusks, found in both MIS 11 and MIS 5.5 deposits on the Canary Islands, imply warmer-than-modern sea surface temperatures during at least a part of MIS 11 and much warmer sea surface temperatures during at least a part of MIS 5.5. Both MIS 11 and MIS 5.5 marine deposits on the Canary Islands contain extralimital northern species of mollusks as well, indicating cooler-than-present waters at times during these interglacial periods. We hypothesize that the co-occurrence of extralimital southern and northern species of marine invertebrates in the fossil record of the Canary Islands reflects its geographic location with respect to major synoptic-scale controls on climate and ocean currents. Previous interglacials may have been characterized by early, insolation-forced warming, along with northward migration of the intertropical convergence zone (ITCZ), accompanied by weakened trade winds and diminished upwelling. This allowed the arrival of extralimital southern taxa from the tropical Senegalese faunal province. During later parts of the MIS 11 and 5.5 interglacials, decreased insolation may have resulted in southward migration of the ITCZ, strengthened trade winds, and re-establishment of upwelling. Such conditions may have brought about not only local extinction of the Senegalese fauna, but allowed southward migration of the cooler-water Mediterranean fauna to the Canary Islands in the later parts of interglacials, a complex palaeoclimate record that is mirrored in the deep-sea core record.

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1. Introduction

Past warm periods in the geologic record are of considerable interest today because of the prospects of a warmer future Earth. One such period that has received much attention is the last interglacial period (LIG), also known as marine isotope stage (MIS) 5 (of which MIS 5.5 is the peak) in the oxygen isotope record of foraminifera from deep-sea cores (Imbrie et al., 1984; Martinson et al., 1987). During MIS 5.5, ~130–115 ka, global ice volume was significantly lower than today, based on numerous sea level studies from tectonically stable regions (Kopp et al., 2009; Muhs et al., 2011; Dutton and Lambeck, 2012). Interestingly, sea surface temperatures (SSTs) during this time, reconstructed from deep-sea core data (foraminifera, radiolaria, diatoms, coccoliths, and alkenones) show that globally the LIG was only slightly warmer than present (Turney and Jones, 2010; McKay et al., 2011). Nevertheless, these same reconstructions show that there were significant regional differences from the global average. For example, in mid-to-high latitudes (30°N to 70°N) of both the Atlantic Ocean and Pacific Ocean, LIG SSTs may have been significantly warmer than present, by up to ~4 °C. Because these apparent regional anomalies are based only on the deep-sea core records, it is important to confirm that these geologic proxies of past warming are reliable.

Another time period of interest, but one which has received far less attention, is an interglacial that occurred ~420–360 ka, known as MIS 11 in the deep-sea core record (Imbrie et al., 1984). There has been an increasing interest in MIS 11 because the Earth's orbital configuration at that time was similar to that of today's (Berger and Loutre, 1991,

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2002). Indeed, Berger and Loutre (2002) speculate that MIS 11 could have been an exceptionally long and warm interglacial period and a suitable analog for a future climate on Earth. Studies of the magnitude of the MIS 11 high sea stand at ~400 ka have generated highly divergent estimates, from ~22 m above present (Hearty et al., 1999; Lundberg and McFarlane, 2002; McFarlane and Lundberg, 2002) to a high sea stand near present (Bowen, 2010). Muhs et al. (2012a), studying the coral reef terrace record on Curaçao, provided a range of estimates of palaeo-sea level during MIS 11, from about +8 m to about +20 m. In addition to uncertainties about palaeo-sea level during MIS 11, there are very few studies of SST during this interglacial period (Martrat et al., 2007; Kandiano et al., 2012).

Emergent marine deposits, whether expressed as erosional, wave-cut benches or constructional coral reefs, are one of the most powerful tools for reconstructing sea level history. These markers of former shorelines can be dated by U-series methods, if corals are present. If such shorelines are found on tectonically stable coasts, their elevations can yield palaeo-sea level estimates. In addition, such deposits often contain fossil shallow-water marine invertebrates, commonly mollusks. Fossil molluscan assemblages in marine terrace deposits can be used for estimating past SSTs, because many mollusks are highly sensitive to water temperature. Indeed, global biogeographic units (also referred to traditionally as faunal provinces) for marine invertebrates have been developed by a number of investigators over many decades, and are based to a great degree on this temperature sensitivity. Two of the best-known global faunal province schemes are those of Valentine (1973) and Spalding et al. (2007). The Valentine (1973) scheme is based largely on shared species and species diversity whereas the Spalding et al. (2007) scheme is based, for the most part, on patterns of endemism. Belanger et al. (2012) showed that biogeographic units for both these schemes can be predicted with 89–100% accuracy by a very limited number of variables, principally temperature, salinity, and productivity. Indeed, temperature alone correctly predicts 53–99% of the biogeographic structure along coastlines globally. Modern faunal provinces of the eastern Atlantic Ocean, using the Valentine (1973) scheme, show a clear correspondence with mean annual SSTs (Fig. 1a, b).

Reconstruction of both sea level history and SSTs from emergent marine deposits requires accurate chronology. One problem that has plagued studies of Quaternary marine deposits throughout the Mediterranean and on European and African coastlines of the eastern Atlantic Ocean is a lack of reliable ages. Here, we present new U-series ages of corals from emergent marine deposits on Gran Canaria and Lanzarote (Canary Islands), Spain (Figs. 1, 2). Previous work on the Canary Islands suggests that the deposits we studied on Gran Canaria and Lanzarote could date to MIS 11 and MIS 5.5 (Meco et al., 2002, 2006, 2008). In addition, we evaluate the fossil record (primarily mollusks) from these deposits for their palaeozoogeographic significance, using updated information about modern zoogeography.

2. Study area

The Canary Islands are a chain of volcanic edifices that formed over a hot spot as the African plate has migrated eastward from the Mid-Atlantic Ridge spreading center (Carracedo, 1999; Carracedo and Day, 2002; Carracedo et al., 2002). Lanzarote and Fuerteventura, the easternmost islands, have volcanic rocks that date as far back as 20–15 Ma, whereas the oldest rocks on El Hierro and La Palma, the westernmost islands,

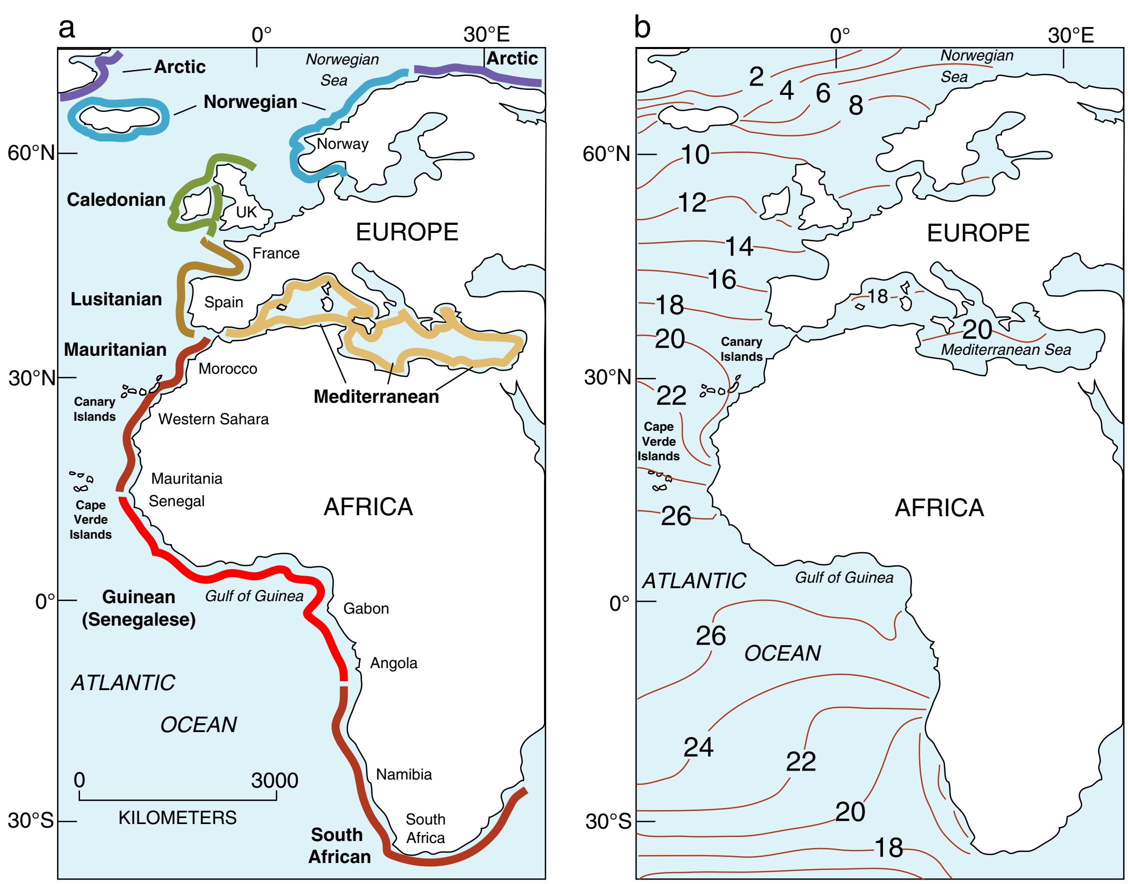

Fig. 1. (a) Location of the Canary Islands off the west coast of Africa and marine invertebrate faunal provinces of the eastern Atlantic Ocean. (b) Mean annual sea surface temperatures over the same region as in (a).
Panel a is redrawn from Valentine (1973). Panel b is taken from Conkright and Boyer (2002).