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Speleothem evidence for MIS 5c and 5a sea level above modern level at Bermuda

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ABSTRACT

The history of sea level in regions impacted by glacio-isostasy provides constraints on past ice-sheet distribution and on the characteristics of deformation of the planet in response to loading. The Western North Atlantic–Caribbean region, and Bermuda in particular, is strongly affected by the glacial forebulge that forms as a result of the Laurentide ice-sheet present during glacial periods. The timing of growth of speleothems, at elevations close to sea level can provide records of minimum relative sea level (RSL). In this study we used U–Th dating to precisely date growth periods of speleothems from Bermuda which were found close to modern-day sea level. Results suggest that RSL at this location was above modern during MIS5e, MIS5c and MIS5a. These data support controversial previous indications that Bermudian RSL was significantly higher than RSL at other locations during MIS 5c and MIS 5a. We confirm that it is possible to explain a wide range of MIS5c-a relative sea levels observed across the Western North Atlantic–Caribbean in glacial isostatic adjustment models, but only with a limited range of mantle deformation constants. This study demonstrates the particular power of Bermuda as a gauge for response of the forebulge to glacial loading, and demonstrates the potential for highstands at this location to be significantly higher than in other regions, helping to explain the high sea levels observed for Bermuda from earlier highstands.

1. Introduction

Bermuda is situated on the forebulge resulting from ice loading on North America during glacial periods (Fig. 1). Relative sea level (RSL) at Bermuda therefore has potential to provide information about the deformation parameters of the Earth, and/or about the distribution of past Laurentide and Greenland ice sheets. Conditions appear favourable for reconstruction of such RSL: tectonic activity is limited, and conditions are appropriate for both coral development and speleothem growth, allowing the use of two of the most robust sea-level archives that can be directly dated during this time interval. Nevertheless, the sea-level history of Bermuda remains uncertain (e.g. Hearty, 2002; Rowe et al., 2014), with the amplitude of highstands during the last interglacial complex (e.g. Marine Isotope Stage 5; MIS 5) being particularly controversial.

It is now widely accepted that peak eustatic (i.e. global ocean mass equivalent) sea level of the Last Interglacial (e.g. MIS 5e), was above modern (e.g. Dutton and Lambeck, 2012; Dutton et al., 2015; Kopp et al., 2009). The amplitude of subsequent smaller highstands during MIS 5c (~106–93 ka) and 5a (85–74 ka) is, however, generally more controversial. For MIS 5a, which is the better documented of the two, a large range of RSL has been reported around the globe, ranging from −30 m at the Huon Peninsula, Papua New Guinea (Lambeck and Chappell, 2001) to +5 m on the Atlantic

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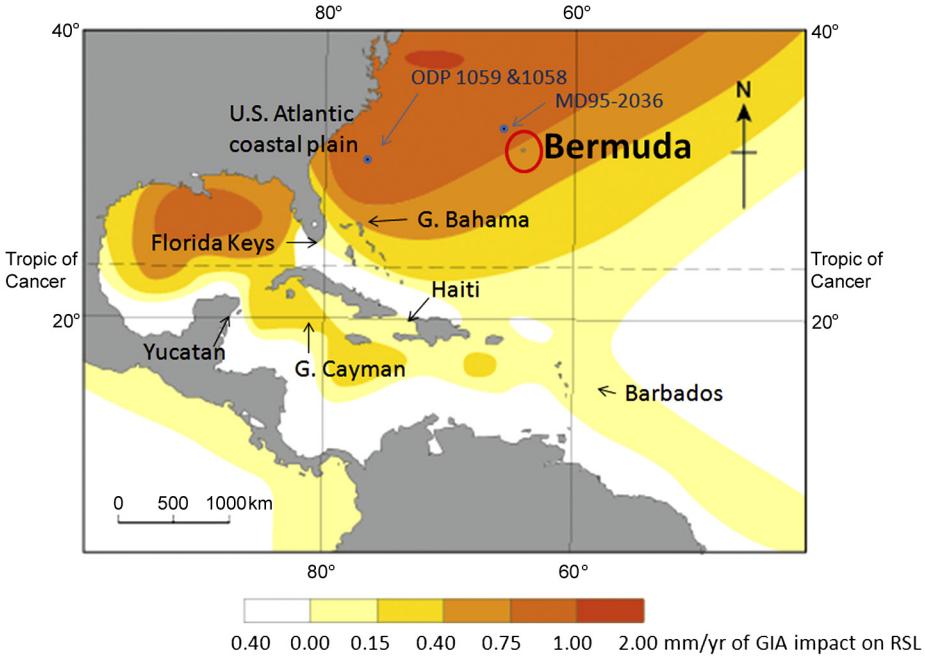

Fig. 1. Location map of Bermuda in the Western North–Atlantic Caribbean geodynamic context. The forebulge effect is visible through the colour shading representing the numerical prediction of the modern day impact of glacio-isostatic adjustment on relative sea level in mm/yr (adapted from Tamisiea and Mitrovica, 2011). Sites indicated in black are those for which RSL at MIS 5e, c, and a have been documented and are used in the discussion. Sites indicated in blue are those from which marine data is used for comparison. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

coast of the US (Wehmiller et al., 2004). Within the Western North Atlantic–Caribbean (WNAC) region, the MIS 5a highstand has been reported at elevations ranging from −22 to +5 m (e.g. Dodge et al., 1983; Dumas et al., 2006; Ludwig et al., 1996; Lundberg and Ford, 1994; Moseley et al., 2013; Muhs et al., 2002; Radtke and Schellmann, 2005; Richards et al., 1994; Toscano and Lundberg, 1999; Vacher and Hearty, 1989; Wehmiller et al., 2004). Such variability in WNAC RSL has been explained by glacio-isostatic adjustment (GIA) associated with the glacial forebulge (Potter and Lambeck, 2003). RSL in the North of the WNAC region is characterised particularly well by Bermuda, because it is a place where RSL records are available and is close to where GIA has the greater impact associated to the bulge (Fig. 1). This makes accurate knowledge of RSL at Bermuda particularly useful, not principally for the information it provides about eustatic sea level, but for the constraints it provides on Earth deformation and regional ice sheet histories.

In this study, we present new MIS5 RSL data for Bermuda, based on high-resolution U–Th dating of speleothems. Speleothems are generally protected from weathering and many forms of erosion by their location, and can provide powerful archives of past sea-level change. Speleothems are also generally sampled when in growth position, and can only accrete when above sea level, thus periods of growth robustly indicate RSL below their site of formation (Harmon et al., 1978; Moseley et al., 2013; Van Hengstum et al., 2015). Hiatuses in speleothem growth indicate possible periods when sea level was above that level, but are less robust indicators because other factors may lead to pauses in growth.

2. Background

2.1. MIS5 past sea-level reconstruction at Bermuda

The MIS5e highstand at Bermuda was higher than modern, as demonstrated by coral occurrences up to +6 m, and a marine aragonite overgrowth on a stalactite from Crystal Cave which developed during that period at +3 to +4 m (Harmon et al., 1981, 1983, 1978). There are also a number of well-documented marine conglomerates up to at least +9 m above modern sea level which, on the basis of U-series age data from numerous coral fragments within them, can be attributed to MIS5e (Harmon et al., 1983; Hearty and Kindler, 1995; Land et al., 1967; Meischner et al., 1995; Muhs et al., 2002). So although the elevation of MIS5e RSL at Bermuda is not precisely established, it was clearly above present-day level (Fig. 2).

On the contrary, the height of MIS 5c and 5a highstands at Bermuda is a contentious subject. Evidence for the height of the MIS5c RSL highstand includes (Fig. 2):

- RSL above −6 m based on synchronous termination of growth of two speleothems; coral fragments up to several meters above sea level dated ∼100 ka (Harmon et al., 1978);
- RSL below −15 m based on a speleothem growing continuously from 110 ka to the Holocene at −15 m, and on amino acid racemization ages on eolianites at ∼105 (Harmon et al., 1981);
- RSL above −15 m provided by rare corals in growth position dated from 105 to 97 ka (Vollbrecht, 1990);

Similar controversy exists for RSL during the MIS5a highstand (Fig. 2):

- RSL at 1–2 m based on a cluster of ages on coral fragments from 82 to 78 ka (Ludwig et al., 1996)
- RSL at a couple of meters above modern based on a cluster of ages on coral fragments from 84 to 78 ka (Muhs et al., 2002)
- RSL at 0–1 m based on amino-acid racemization data on land snails in a sub-aerial eolinite (Vacher and Hearty, 1989)

The strongest evidence suggesting RSL below modern for both MIS5c and 5a highstands is the continuous speleothem growth documented at −15 m from 110 ka to the Holocene (Harmon et al., 1981). The associated chronology for this sample is not completely robust due to the low precision and small number of α-counting U–Th ages. Potter and Lambeck (2003) suggested that