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Anomalous MIS 7 sea level recorded on Bermuda

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ABSTRACT

Three new U-series ages from coral fragments found in the Belmont Formation of Bermuda fall in a range of ~198 ka to ~196 ka. These late MIS 7 ages are consistent with those of ~201 ka and ~199 ka measured in a previous study. The disputed interpretation of the Belmont Formation as a unit that is allostratigraphically distinct from subsequent MIS 5e deposits, of the Rocky Bay Formation, is vindicated by a minimum age of 196 ± 3 ka for the total of 6 coral fragments it has yielded. Emergent marine deposits of the Belmont Formation include sedimentary lithofacies that are considered to be reliable relative sea level indicators. Prominent among these is a facies representing the "beach step": a feature that develops sub-tidally, directly at the base of the swash zone. From this facies, and others preserved along 6 km of Belmont Formation coastal exposure, it is concluded that MIS 7 relative mean sea level reached +4.5 m, and likely peaked at or above +6.0 m, relative to present sea level at Bermuda. Lower MIS 7 sea level positions that are evidenced and that have been quoted, in the past, are considered transitory positions, not maxima. The MIS 7 sea-level elevations on Bermuda, reconstructed in this study, are above the majority of those reported from elsewhere in the world. This challenges the long-standing notion of Bermuda as a vertically stable "tide-gauge", but is consistent with glacio-hydroisostatic models which predict land-mass subsidence at intermediate field sites, such as Bermuda, at the end of long interglacials. However, because of evidence of instability at Bermuda in the form of seismic activity and faulting, which require further investigation, judgement is reserved on the global implications of this palaeo-sea-level anomaly.

1. Introduction

1.1. Global palaeo-sea-levels at MIS 7

A compilation of early deep ocean oxygen isotope records by Porter (1989) (summarised from Shackleton and Pisias, 1985; Martinson et al., 1987), indicated that ice sheet volumes were substantially reduced three times between 250 and 180 ka, at Marine Isotope Stage 7 (MIS 7), but not to modern levels. By this interpretation, and other interpretations of continuous data such as that of Bintanja et al. (2005), there were three periods during MIS 7 when eustatic sea level approached the present level, but did not exceed it. Three peaks in global temperature during the time span of MIS 7 are, also, evident from the deuterium profile, measured in the Vostok ice core, which is considered a proxy for Antarctic temperature (Petit et al., 1999). A potential fourth MIS 7 positive sea level oscillation, at ~185 ka, was reported by Henderson et al. (2006) based on U-series dating of sedimentation events on the Bahamas Banks.

Evidence from spelaeothem growth-records from Argentarola Cave in Italy indicates that relative sea levels at sub-stages 7.5, 7.3 and 7.1 peaked above −18.5 m; with the lowest peak, at about −18 m at sub-stage 7.3 (Dutton et al., 2009). This general pattern was corroborated by oxygen isotope and other data, which are subject to bathymetric controls, from the Red Sea cores (Rohling et al., 2009). These indicate that sea level at MIS sub-stages 7.5 and 7.1 may have peaked as high as −10 m RSL (relative to present sea level) but that at MIS 7.3 fell well short. Muhs et al. (2002) provides a good summary of palaeo-sea-level data from emergent reef terraces at Barbados, New Guinea and Hawaii (far field sites). He notes that at least two MIS 7 mean sea level oscillations are inferred, which depending on the approach taken to correct for uplift, range from −20 m to a few metres above present sea level. Another comprehensive review of MIS 7 global sea level data from a variety

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of sources including reefs, speleothems and oxygen isotopes led Siddall et al. (2006) to conclude that after correction for uplift or subsidence, as appropriate at respective localities, eustatic relative sea level at each of the MIS 7 sub stages ranged between ~ −15 m and ~ −5 m.

Higher MIS 7 sea-levels are evidenced in the Mediterranean at Mallorca where "brackish" speleothems record a +4.9 m RSL at 230 ka (Vesica et al., 2000); while at Sardinia, marine deposits dated by the optically stimulated luminescence method (OSL) at 186 ka have been associated with a +2.5 m RSL palaeo-sea-level (Andreucci et al., 2009). Correspondingly, Murray-Wallace (2002) and Muhs et al. (2011) and Muhs et al. (2012) describe coastal deposits and coral reefs of MIS 7 age, respectively, in southern Australia, southern Florida and the Antilles (Caribbean), which witness relative palaeo-sea-level maxima in the range of +1 m to +4.5 m RSL.

The data quoted above are not from parts of the globe which are assumed to be in an equivalent tectonic setting to Bermuda. Nor was any consideration given as to whether they might have experienced comparable isostatic adjustment to Bermuda, attributable to its imputed position on the "peripheral bulge" of a major ice sheet complex (Raymo and Mitrovica, 2012). The data are intended to represent a cross-section of sources from which a wide range of MIS7 eustatic sea levels have been inferred, and with which the relative sea level record at Bermuda can be compared.

1.2. Bermuda palaeo-sea-levels at MIS 7

The carbonate archipelago of Bermuda, situated at 32.3° N, 64.8° W in the North Atlantic (Fig. 1), occupies the south-eastern edge of a 26 × 52 km submerged oval-shaped reef-rimmed platform, below which is the truncated Bermuda volcanic seamount. The islands are predominantly composed of lithified Quaternary aeolian bioclastic calcarenites, or "eolianites" (Sayles, 1931), which accumulated in shore-parallel, hillocky dune ridges. The six allostratigraphic geological formations identified by Vacher et al. (1989) are, from oldest to youngest: the Walsingham Formation, The Town Hill Formations (Upper and Lower), the Belmont Formation, the Rocky Bay Formation and the Southampton Formation. They are separated by geosols, characterised as "solutional unconformities" by Land et al. (1967). Emergent "marine" shoreface and foreshore deposits – the focus of this study – are volumetrically minor, being restricted to narrow coastal outcrops. They are considered effectively contemporaneous with eolianites which conformably overlie them. The association of episodic dune building with sea level highstands has thus been made (Bretz, 1960; Land et al., 1967; Vacher, 1972).

In the Quaternary calcarenites of Bermuda, Land et al. (1967) identified phreatic water table cementation and a depositional "strandline" in the Belmont Formation of the south shore (Fig. 1) at +2 m RSL. They believed that this recorded the penultimate interglaciation, i.e. MIS 7. Subsequently, a thorough all-encompassing study of Bermuda's palaeo-sea-level record was undertaken by Harmon et al. (1983); and on the basis of a marine layer within dated flowstone and four coral fragments from coastal deposits, they concurred that at MIS 7 eustatic sea level peaked at ~+2 m RSL at about 200 ka. They reported an older age of 262 + 35 −27 ka for an *Oculina* fragment found at Grape Bay, but they questioned the accuracy of any U-series ages greater 220 ka and did not associate the 262 ka age with the Belmont Formation or the penultimate interglacial. However, given the ~30 ka margin of error, this age could arguably be correlative with a marine transgression at a sub-stage of MIS 7. Subsequently, Muhs et al. (2002) reported late MIS 7 ages of 199 ± 2 and 201 ± 2 ka for two *Oculina* fragments collected from the Belmont Formation, also, at Grape Bay.

Geological mapping of the island which culminated with publication of the Geological Map of Bermuda (Vacher et al., 1989) identified dozens of previously undocumented exposures of emergent clastic marine deposits. These were concentrated within the Belmont and Rocky Bay Formations, which on the basis of allostratigraphic interpretation were considered representatives of highstands at the penultimate and Last Interglaciations, respectively. Among the new finds were "beach bubble" fenestrae in Belmont foreshore deposits at ~+7 m at Watch Hill Park (Fig. 1). Meischner et al. (1995) advanced a hypothesis of two Belmont marine transgressions peaking, respectively at + 1.5 m and +≥7.5 m RSL based on: 1) separation of two marine units by a vermetid-encrusted surface at Grape Bay; 2) measured elevations of sub-tidal bedding at Grape Bay; and 3) a "marine-eolian transition" at +7.5 m RSL at Watch Hill Park. Subsequently, Vollbrecht and Meischner (1996) presented evidence of meteoric phreatic diagenesis and coeval marine cement in the Belmont at Watch Hill Park ranging up to ≥+8 m RSL (at the "beach bubble" locality). They

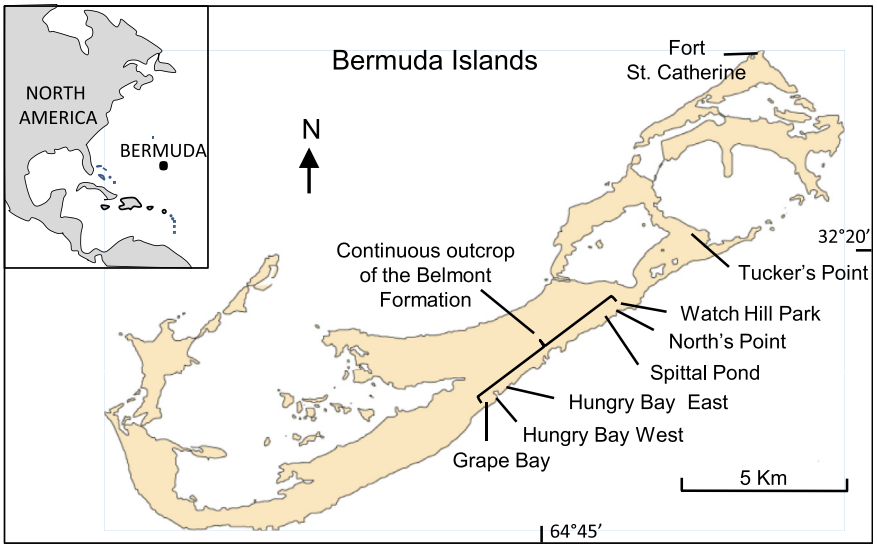

Fig. 1. Bermuda Islands locality map.