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Northern Hemisphere Insolation Forcing of the 330,000 Year Sea-Level Highstand?

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The fundamental processes driving the growth and decay of the major Northern Hemisphere ice sheets remain speculative, but identifying these is the key to predicting future climate perturbations on glacial-interglacial timescales. Progression in this field is severely impeded by an absence of well-dated palaeoclimate records spanning several glacial cycles. Most of the existing records cannot be dated directly. Instead, many are assigned a chronology based on Milankovitch orbital forcing theory, assuming fluctuations in Pleistocene climate are driven by periodic changes in summer solar insolation at 60 or º65 N, caused by predictable variations in Earth's orbital parameters. However, the validity of the Milankovitch climate model remains uncertain. The question remains: Do factors other than just high latitude Northern Hemisphere insolation play an important role in forcing the growth and decay of the major Pleistocene ice sheets?

The precise timing of past sea-level highstands based on the mass spectrometric U-series dating of fossil reefs is a crucial and independent test of the validity of the Milankovitch model of climate change. Previous studies have focussed almost exclusively on the oxygen isotope stage 5e or Last Interglacial period, occurring at ~125 thousand years ago (ka) (e.g. Edwards et al., 1987; Bard et al., 1990; Chen et al., 1991; Szabo et al., 1994; Stirling et al., 1998). Beyond the last Interglacial, it is exceedingly difficult to obtain reliable chronological information due to large age-error terms and enhanced diagenetic effects. Even the relatively young stage 5e reefs give conflicting estimates for the timing and duration of the last Interglacial interval due to difficulties in assessing the reliability of a 230Th-age. There is also a severe lack of datable material for older interglacial sea levels because climate events beyond the last glacial-interglacial cycle are not often preserved in the geologic record. Few TIMS U-series observations exist for the stage 7 or Penultimate Interglacial reefs, dated at ~220 ka (Gallup et al., 1994). Even fewer mass spectrometric U-Th observations have been reported for earlier interglacials.

Using multiple collector ICP sector mass spectrometry (MC-ICPMS) and thermal ionisation mass spectrometry (TIMS), we present a unique suite of precise U-series ages for ancient reef terraces on Henderson Island, a coralline oceanic island in the Cook-Society region of the equatorial Pacific. Henderson Island is located in the extreme east of the Indo-Pacific sub-tropical province. As an "outpost" locality, it presents a hostile environment for coral reef development, and coral terraces may form only during very intense interglacial periods. Ironically, it is this hostile environment that has allowed, for the first time, a detailed study of coral terraces correlating with "older" interglacial periods. Offshore fringing reefs grew prolifically on Henderson Island during the ~330 ka stage 9 interglacial, but no coral terraces appear to have formed subsequently during the Penultimate, Last or Holocene interglacial periods, and these older terraces remain accessible today.

We report more than 30 precise 230Th-ages for the Henderson Island stage 9 reefs. These data provide, for the first time, a reliable and independent radiometric constraint on the global sea level curve at ~330 ka, for comparison with Milankovitch orbitally tuned chronologies. In 330 ka samples, 230Th-age uncertainties are typically better than ±2 ka at the 2s level, allowing the timing and duration of the Stage 9 interglacial to be well-resolved. Despite their extreme old age, the Henderson Island stage 9 reefs are exceptionally well preserved. Certainly, some diagenetic alteration has occurred in these ancient reefs, but the affect on the 238U-234U-230Th system appears predictable, allowing disturbed samples to be readily identified and discarded. The implications of this are two-fold. Firstly, important constraints can be placed on the behaviour of U and Th during diagenesis. Secondly, the U isotopic composition of seawater during the stage 9 interglacial can be reliably evaluated.

The stage 9 terraces are not the oldest reefs exposed on Henderson Island. In a fortuitous discovery, we also sampled reefs that grew during a major atoll construction phase occurring more than 600 thousand years ago. Our 2sM analytical uncertainties are at the sub-permil level for both U and Th measurement, allowing U-series chronology to be extended beyond the 500 ka upper limit usually reported for TIMS U-series techniques, and in 600 ka samples, the associated 2sM error in the age is better than ±35 ka. These, when combined with the younger stage 9 interglacial results, have important implications for understanding lithospheric flexure processes.

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