The rise and fall of last interglacial sea-levels

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During the Last Interglacial (LI), global climate was similar to present-day and sea-levels were at or above modern heights. With the possibility that the Earth is about to enter into a new 'super-interglacial' phase due to Greenhouse warming, an understanding of past interglacial climates cycles is important as it provides a baseline against which future anthropogenic induced changes can be evaluated. The main driver of glacial-interglacial cycles is generally considered to be variations in the summer insolation received at the high latitudes in the northern Hemisphere (NH). With the advent of TIMS U-series dating of corals (Edwards *et al.*, 1986), it is now, in principle, possible to place a precise chronology on past sea-level changes and hence directly test the Milankovitch or orbital theory of climate change. Despite the improved precision of TIMS U-series dating, efforts to establish the duration of the LI have been hampered by the lack of unambiguous criteria to identify samples whose U-Th systematics have been undisturbed by carbonate diagenesis. Nevertheless, from stable, far-field sites, such as along the coast of Western Australia (Stirling *et al.*, 1995), there is a clear clustering of TIMS U-series ages in the interval from 118 ka to 128 ka that meet the criteria of having the same $\delta^{234}U$ value as modern seawater (ie $\delta^{234}U(t) = 150 \pm 10$). There are also a limited number of individual coral samples that also meet this criteria, but have ages as old as 135 ka (Stein *et al.*, 1993) and as young as 114 ka. Taken at face value, these latter ages imply a relatively extended period for the LI and are not consistent with the timing predicted from orbital forcing. One of the difficulties with the existing data sets is that nearly all the samples are from sites at or only slightly above existing sea-level, and hence it is difficult to identify stratigraphically inconsistent ages.

At Huon Peninsula in Papua New Guinea, the tectonic uplift rate is >2m/ka, and as a result the LI Reef VII complex is now exposed at a height of >200 m. In a serendipitous discovery, corals that grew during the penultimate deglaciation, have been found at a level of ~ −80 m below the LI. These corals are preserved in a cave (Aladdin's Cave) which provides a window into the penultimate deglaciation. Corals from Aladdin's Cave meeting the $\delta^{234}U$ criteria have U-Th ages of from 133 ka to 128 ka indicating that for the period from 133 ± 1ka to 129 ± 1 ka, sea-level was ~ −80 m lower than present-day. The interval maybe analogous to the Younger Dryas episode as cooler (−6°C) sea surface temperatures have been obtained from both oxygen isotopic and Sr/Ca analyses of a *Porites* coral in Aladdin's Cave. Two younger ages for corals have also been found in Aladdin's Cave, indicating that sea-level had fallen to ~ −50 m by 115 to 112 ka, consistent with the cessation of the LI at ~118 to 116 ka. In addition to these results Stein *et al.*, (1993) have reported ages of 135 ka for several coral samples from the reef VII complex at Huon Peninsula. Allowing for tectonic uplift, these results imply that sea-level was within −15 m to −20 m of LI heights at this time. Some support for these ages are found in a drill core from Western Australia where a coral at −7 m has been dated at 135 ka. While these results need to be confirmed, taken together with the Aladdin's Cave, they require an oscillation in sea-level during the early stage of the penultimate deglaciation (Fig. 1).

Using these independent sets of constraints it is now possible to derive a self consistent sea-level history for the LI. Deglaciation appears to have occurred in two major stages. Firstly, sometime prior to 135 ka sea-level began to rise from > −130 m to a height of −20 m by 135 ka. This first phase of rising sea-level thus occurred either during a period of decreasing NH insolation or at an insolation minimum and is therefore not consistent with the orbital theory. It is interpreted as reflecting instabilities in the relatively large ice sheets that were present during the penultimate deglaciation. From 135 to 133 ka sea-level fell rapidly from −20 to −80 m, to satisfy the Aladdin's Cave constraints. Such a rapid fall in sea-level is difficult to accommodate, as it is not easily attributable to growth of new glaciers, but may instead be due to regrounding of existing ice sheets during a cold period analogous to the Younger Dryas. Clearly, further data is required to substantiate this initial 'ice-sheet' induced oscillation in sea-level. From 133 to 129 ka the well constrained Aladdin's Cave data, show that there was a quiescent period of relatively slow sea-level rise at ~ −80 m which kept pace with the local

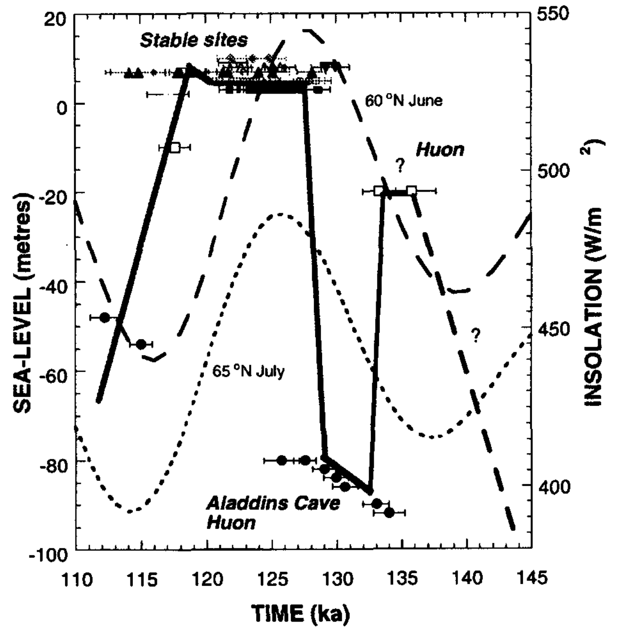

FIG. 1. TIMS U-Th ages for Last Interglacial corals.

tectonic uplift (~2m/ka). The second extremely rapid rise in sea-level of ~70 to 80 m, occurred from 129 ka to 128 ka. A rapid rise in sea-level is required to satisfy the overlapping (within the analytical error limits of ± 1 ka) age constraints from the Aladdin's Cave versus those from stable LI sites that have ages of up to 128 ka and implies a rate of sea-level rise of >30 m/ka extending for 1000–2000 years, compared to <300 years for the typical Heinrich event. This large meltwater pulse that initiated the main LI period may have resulted from a combination of both the higher summer insolation (490W/m^2 at 65°N July for the LI compared to ~470W/m^2 for the last deglaciation), as well as the rapid rate of increase in NH insolation during the LI. By 129 ka, the end of the LI 'Dryas' period, NH insolation was already greater than the Holocene maximum and was still rapidly increasing, thus providing a plausible trigger for a catastrophic sea-level rise event.

Within the limits of analytical uncertainty the 'main' LI high-stand thus appears to have occurred from ~128 $\pm$ 1 ka to ~117 $\pm$ 1 ka with observations from stable continental margins such as Western Australia, indicating that the relative height of the LI highstand was at least ~2 to 4 m above present-day levels (Stirling *et al.*, 1995). The question of whether this also translates to an increase in ocean volume relative to present-day, requires careful consideration. For an extremely rapid sea-level rise, glacio-hydro-isostatic effects will cause an overshoot in sea-level of ~2–4 m in far field 'stable' sites which is expected to gradually diminish over the next ~5 ka. This exponential decrease in sea-level is not observed in Western Australia suggesting either a 2–4 m rise in sea-level occurred towards the end of the LI, or a need for more refined isostatic models. What are the implications of these observations from the geologic record, for pulses of extremely rapid rise in sea-level? These catastrophic sea-level rise events are a factor of $\times$ 10 to $\times$ 20 faster than current estimates of sea-level rise due to global warming with business as usual scenarios. The possibility of an ~3 m increase in sea-level during the next century cannot therefore be discounted if the Earth again steps into a deglaciation mode. We are fortunate that for the past ~7 ka the Earth has been in an interglacial period, with constant eustatic sea-level, and summer insolation in the NH, the driver of glacial-interglacial changes, declining.

References

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