m/z range below 25,000. The design and development of a mass analyzer better suited for this method of ion generation is an important area for future work.

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11. The charge reduction process could in principle involve reactions of the bipolar neutralizing gas with either the electrospray-generated droplets or the electrospray-generated ions. This important mechanistic distinction is closely related to a controversy in the literature as to the mechanism of ion generation in ESI [M. Dole *et al.*, *J. Chem. Phys.* **49**, 2240 (1968); J. V. Iribarne and B. A. Thomson, *ibid.* **64**, 2287 (1976); B. A. Thomson and J. V. Iribarne, *ibid.* **71**, 4451 (1979); F. W. Röllgen, E. Bramer-Wegen, L. Bütfering, *J. Phys. (Paris)* **48**, C6-253 (1987); G. Schmelzeisen-Redeker, L. Bütfering, F. W. Röllgen, *Int. J. Mass Spectrom. Ion Processes* **90**, 139 (1989)], and in the present work it also relates to the question of where in the system the droplets are transformed into ions. The experiments reported here do not permit discrimination between these two mechanisms.
12. The ESI ion source consists of a 38-cm-long fused-silica capillary (150-μm outer diameter, 25-μm inner diameter) with the spray end conically ground to a cone angle (angle between the capillary axis and cone surface) of 35° (#2001145, Polymicro Technologies, Phoenix, AZ). The inlet of the capillary is immersed in analyte solution, and a positive pressure of 10 psi (70 kpa) is applied to the sample container to produce a typical flow rate of 0.13 μl/min. The solution is maintained at a potential of +3500 V (proteins in positive ion mode) or −2950 V (DNA in negative ion mode) relative to the inlet of the ionization chamber by means of a platinum electrode immersed in the sample. The spray is stabilized against corona discharge [J. Zeleny, *Proc. Cambridge Philos. Soc.* **18**, 71 (1915); M. G. Ikonomou, A. T. Blades, P. Kebarle, *J. Am. Soc. Mass Spectrom.* **2**, 497 (1991)] with a sheath gas of CO_2 (1 liter/min) fed through a stainless steel tube (1.5-mm inner diameter) concentric with the silica capillary. The ^{210}Po α particle source was obtained from NRD Incorporated, Grand Island, NY (#P-2042).
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18. The work described here has benefited from the efforts of other members of our laboratory and the University of Wisconsin Department of Chemistry over several years. We particularly acknowledge the helpful contributions of S. Mouradian, C. Hop, M. Vestling, and R. Clausen in this regard. Supported by Department of Energy grant DE-FG02-91ER61130, NIH grants R01HG00321 and R01HG001808, and NIH-GMS 5T32GMO8349 training grant (M.S.).

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Rapid Fluctuations in Sea Level Recorded at Huon Peninsula During the Penultimate Deglaciation

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About 140,000 years ago, the breakup of large continental ice sheets initiated the Last Interglacial period. Sea level rose and peaked around 135,000 years ago about 14 meters below present levels. A record of Last Interglacial sea levels between 116,000 years to 136,000 years ago is preserved at reef VII of the uplifted coral terraces of Huon Peninsula in Papua New Guinea. However, corals from a cave situated about 90 meters below the crest of reef VII are 130,000 ± 2000 years old and appear to have grown in conditions that were 6°C cooler than those at present. These observations imply a drop in sea level of 60 to 80 meters. After 130,000 years, sea level began rising again in response to the major insolation maximum at 126,000 to 128,000 years ago. The early (about 140,000 years ago) start of the penultimate deglaciation, well before the peak in insolation, is consistent with the Devils Hole chronology.

The coral reef terraces at Huon Peninsula in Papua New Guinea extend more than 80 km along the coast and have been uplifted at a rate that varies from 0.5 m per 1000 years (ky) in the northwest to nearly 4 m/ky to the southeast. The high uplift rates have exposed a record of late Quaternary interglacial and interstadial sea-level high stands (*1–4*). Prominent among these stands is reef structure VII, which formed when the sea level rose during the penultimate deglaciation, a period that may have lasted for more than 10,000 years at ~125,000 years before present (yr B.P.), when the climate was similar to or possibly warmer than the present climate and sea levels were 3 to 5 m higher. At Kwambu, a present-day analog of terrace VII exists with a barrier reef, a lagoon, and a fringing reef; here, the fossil terrace VII is at a height of 225 m (Fig. 1).

During an international expedition to the Huon terraces in July through August 1992, we located a large ancient sea cave in the riser of terrace VIb [isotope stage 5b-5c, with a nominal age of 90 to 100 kiloannum (ka)] (Fig. 1, Kwangam section). It is situated ~400 m west of Kwangam River, at ~90 m below the crest of reef VII. The cave presumably formed when a younger reef grew over earlier corals that were buried in rubble. An unusually large (>1 m in diameter) *Porites* coral was found just inside the entrance, and other corals were found on the floor and walls. To highlight the discovery of such a well-preserved specimen, we named the location "Aladdin's Cave." Here, we present U-series ages of corals from Aladdin's Cave and terrace VI that, combined with stratigraphic relations to other dated samples from reef tract VII, provide information on rapid sea-level changes during the course of the penultimate deglaciation and its relation to solar insolation.

The timing and duration of the Last Inter-

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glacial is questionable; some records of coral growth suggest a long duration of at least 17 ky from 131 to 114 ka (*5, 6*). The Devils Hole calcite chronology places the start of the shift from a glacial to an interglacial climate even further back in time to ~140 ka (*7*); this age precedes the major orbital insolation peak that was responsible for the warming and directly contradicts predictions of the astronomical theory (*8*). In contrast, data from fossil coral platforms of Western Australia indicate prolific reef growth only over a brief interval from 128 to 122 ka (*9*), which is in agreement with the timing of orbital insolation cycles.

Reef tract VII is a large structure with a barrier reef, a lagoon, and an inner fringing reef at its crest (Fig. 1). The main body of reef tract VII overlies the upper Tertiary limestone of the north Huon Peninsula (the Cromwell Limestone) (*1–3*) and, toward the rear, overlies reef tract VIII. Beds of boulders, gravel, and mafic sand are sandwiched between the Cromwell Limestone and reef tract VII at many localities, including the Kwangam River gorge (*10*). These beds are considered to be fan delta deposits and, informally, are named the Bobongara beds. We refer to the entire structure as reef tract VII and use the terms "VIIa" (the fringing reef at the rear), "VIIb" (the barrier reef), and "VIIc" (a prominent bench below and seaward of the barrier) to designate the terraces (Fig. 1).

Terraces VIb, VIa (above VIb), and V (below VIb) are platforms of younger raised fringing reefs that offlap the front of reef tract VII. Aladdin's Cave, which cuts through the riser of terrace VIb, is ~90 m lower in height than the crest of reef VII. Reefs VIa, VIb, and V each offlap reef VII at many localities, including the Kwangam and Kwambu sections (Fig. 1), so that the lower parts of reef tract VII are exposed at places in each riser. Fringing reef VIb is a thin wedge that is only 2 to 5 m thick; the rear of terrace VIb cuts into reef tract VII, and its riser is an ancient sea cliff that cuts reef VIa and a portion of reef tract VII (Fig. 1). Aladdin's Cave acts as a window to the lower structure of reef tract VII. Uplift rates that were estimated from the elevation of reef VII at Kwangam and Kwambu are ~1.6 and ~1.9 m/ky, respectively (*1, 2*).

The corals exposed within Aladdin's Cave include heads of *Porites* and various Faviidae. Corals are abundant and large (up to 1 m in diameter) and have annual growth bands with widths of ~1.0 cm, which are typical of corals that live in water depths of less than ~12 m (*11*). The matrix includes the cemented rubble of broken branching and of other corals. No traces were found of any taxa or structures, such as rhodoliths or the giant foraminifera *Cycloclypeus*, that are characteristically found in sediments deposited below a depth of ~50 m and are readily found in deeper forereef deposits at the front of reef tract VII. The position of the site (~90 m below the crest on the front of reef tract VII) suggests that it might belong to the lower forereef of VII, but the coral association indicates an upper forereef deposit. Shallow-water coral deposits within reef VII, which are found at many tens of meters below its crest, have been recognized elsewhere in the region, including sites at the Sazum River and Bobongara (*1, 2*), which are ~14 km west and ~30 km southeast of Kwangam, respectively.

The occurrence of shallow-water facies deep within the front of reef tract VII suggests that it developed as a keep-up reef, which is a reef that formed by keeping pace with the rising sea level. This model has long been adopted for the major reef tracts at Huon Peninsula, including reef tracts I (formed during the Holocene) and VII (*1–3*); the model is supported for reef tract I by drilling, facies analysis, and dating, which show that the reef grew more than 50 m vertically as a shallow-water keep-up system during the postglacial sea-level rise (*1*).

Aladdin's Cave extends for more than 10 m into reef tract VII (immediately beneath reef VIb), and its entrance is over 18 m wide. Close to the entrance, the roof structure is supported by a pillar of cemented coral rubble. Corals in growth position protrude from the sloping floor and are visible in the walls. The entrance is dominated by the *Porites* coral. Coral samples were recovered from the floor and walls of Aladdin's Cave and several other caves in the vicinity for dating (*9, 12*) (Table W1, available on the Web at www.sciencemag.org/feature/data/984437.shl). However, samples from the other caves were mostly recrystallized. Additional corals from reef VIa were collected from the Kwambu section (Fig. 1).

The state of preservation of corals from Huon Peninsula that have been dated to the Last Interglacial age is relatively poor; only about a third of the analyses of reef VII corals resulted in reliable ages that were within acceptable criteria (*4*). Subtle diagenetic alterations may introduce systematic errors that

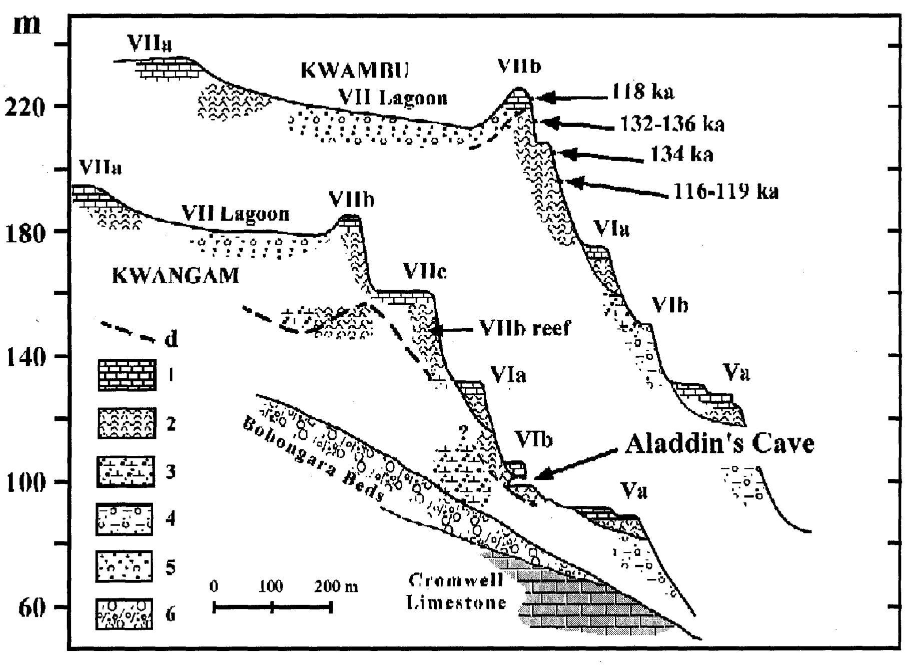


Fig. 1. A profile of coral terraces V to VII, including Aladdin's Cave at the base of reef VIb at west Kwangam and the equivalent reefs at Kwambu that were dated previously (*4*). The horizontal scale for both sections is 1:15,000, which was calculated from air photographs; the vertical scale for Kwambu was calculated from a theodolite survey, and the vertical scale for Kwangam was calculated from calibrated digital altimeter. Disconformity (d) within reef tract VII, observed on the eastern side of Kwangam gorge (*1, 2, 10*) is transferred to the west Kwangam section as shown and is considered to separate two transgressive complexes within reef tract VII (reefs VIIa and VIIb). The full extent of this disconformity has not been recognized. The Kwangam section flanks the Kwangam River and includes fluvial sand and gravel in the paleolagoon between terraces VIIa and VIIb; the proximity of the section to the river may have affected the development of reefs VIIa and VIIb, which appear to have different relationships at Kwangam and Kwambu. Terrace VIIc is dominantly an erosion platform cut into reef VII and is comparable with a 110-m-wide cut platform, 600 m east of the present Kwangam River mouth. The facies are as follows: 1, coral biolithite of reef crest and platform; 2, coral framestone and bafflestone of forereef and reef crest; 3, bioclastic limestone and grainstone, which are inferred to be forereef and slope; 4, rhodolith limestone; 5, lagoon sediments, which are dominantly bioclastic grainstone; and 6, the Bobongara beds, which are composed of conglomerates, tuffs, and wackes. Reefs VIa, VIb, and V each offlap terrace VII. Lower parts of reef VII are exposed at places in each riser and, in particular, at Aladdin's Cave. The Kwambu section shows the location and age range of the corals that were dated by Stein *et al.* (*4*).

are difficult to detect, even within the strictest compliance criteria. For this reason, we have chosen a relatively broad range in the calculated initial $^{234}U/^{238}U$ ratio of ±8 per mil as acceptable. The $^{234}U/^{238}U$ ratio in living corals is 149 ± 1 per mil, and the ±8 per mil range (141 to 157 per mil, within errors) is equivalent to a time interval of about ±2000 years (*12*). A narrower acceptable range would not substantially alter the conclusions derived from the data.

Coral samples from terrace VII at Sialum have been previously dated by Stein *et al.* (*4*). Their acceptable ages formed two distinct clusters of corals at 118 to119 ka and at 132 to 136 ka (Fig. 1, Kwambu section). In these two age clusters, barrier reef VIIb has corals that are separated vertically by 7 m. Thus, the sea level at 136 ka could have been 43 m lower than at 118 ka, given the 1.9 m/ky uplift rate (*4*). In addition, corals situated ~30 m below VIIb have an age range from 116 to 119 ka (Fig. 1, Kwambu section). In contrast, at tectonically stable sites (such as those found in Western Australia), a major uninterrupted period of coral growth occurred between 122 and 128 ka (*9*); there are only a few reliable coral ages at 116 ka at elevations of ~5 m below the corals at 122 to 128 ka (*9*).

The ages of the corals from Aladdin's Cave are predominantly clustered between the oldest dates from Western Australia and those from near the crest of reef VII at Kwambu (Fig. 2). The mean age of corals from the crest of reef VII is 134 ± 1 ka, and the mean age of the cave corals of this time interval is 130 ± 2 ka. Most of the acceptable ages of corals from Aladdin's Cave are within the range of 126 to 134 ka. The large *Porites* coral at the cave entrance was dated independently by thermal ionization mass spectrometry (TIMS) and by alpha spectrometry; the two sets of measurements are in excellent agreement on the same sample (sample AC-U11) (Table W1 and Fig. 2). The mean age of the sample is 127 ± 2 ka. A sample from the top of the *Porites* has an age of ~126 ka, whereas samples from the base have an age of ~128 ka; these samples had only marginally acceptable $^{234}U/^{238}U$ ratios, but *Porites* has an open lattice structure that fluids can easily penetrate, and dating of ~100,000-year-old *Porites* is likely to produce less reliable results than the dating of favid coral types with solid wall structures. Oxygen isotope and Sr/Ca ratios for the *Porites* from Aladdin's Cave show that the sea surface temperature at the cave was ~6°C lower than the temperature during the formation of the VIIa fringing reef, which appears to have grown in a climate that is similar to the present climate (*13*). The 6°C difference in sea surface temperatures indicates that the cave corals grew during a glacial period. This difference also precludes the possibility of subsidence and relocation of the *Porites* coral (and by inference, other corals in Aladdin's Cave) at ~80 m downslope from reef VII. The distance between Aladdin's Cave and the sample site at Kwambu reef VII is ~5 km; there is no evidence for major subsidence over such a distance, where most of the major reef structures are laterally continuous and can be readily traced.

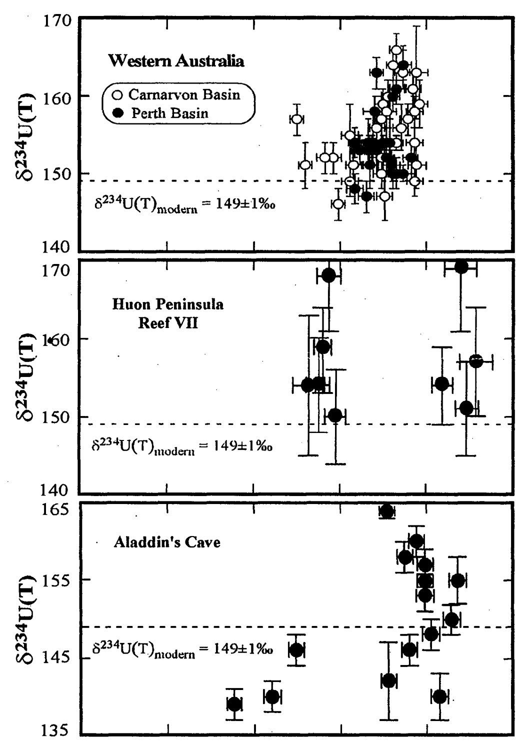


Fig. 2. Uranium isotopic composition, $^{234}U/^{238}U$, at the time of coral growth T versus the ^{230}Th age of corals from Aladdin's Cave contrasted with similar data from the Last Interglacial terrace VII at the Huon Peninsula (*4*) and from the Last Interglacial coral platforms along the coast of Western Australia (*9*). Modern coral U isotopic composition is indicated by the dashed line at $\delta^{234}U$=149 ± 1 per mil (‰). The data from Western Australia and Huon Peninsula were obtained with charge collection TIMS (*9, 12*) and are superior in analytical precision. However, diagenetic alteration is a significant problem for corals from the Huon Peninsula, and we consider an age spread of ±2000 years to better reflect the overall reliability of the data. Corals with U isotopic composition within 149 ± 8 per mil have an age uncertainty of ±2000 and are considered to have acceptable ages. At reef VII, the lack of corals from 122 to 128 ka may be due to incomplete sampling. At Huon Peninsula, radiocarbon ages from the surface and cliffs of the raised Holocene reef tract range from 7 to 9.5 ka and represent the last stages of postglacial sea-level rise. Specimens that are younger than 7 ka have only been recovered from small regressive terraces that cut into the main Holocene structure (*25*). Such features are not preserved on reef tract VII. It appears that major reef building at Huon Peninsula occurred only when rates of sea-level rise kept up with or exceeded tectonic uplift. The 118-ka corals of reefs VIIa and VIIb may have also been deposited during an episode of sea-level rise at the end of the Last Interglacial. The mean age of older corals is 134 ± 2 ka at VII (10 m below VIIb) (Fig. 1, Kwambu section) and 130 ± 2 ka at Aladdin's Cave. The corals at the cave appear to have grown ~4000 years later than those that are found 10 m below VIIb or ~80 m above the cave. The age-height distribution indicates a substantial oscillation in sea level during the penultimate deglaciation, preceding the Last Interglacial era as defined by the age distribution of corals at Western Australia between 122 and 128 ka. Uncertainty in the age is largely due to errors in the decay constants, which contribute ~950 years to $2\sigma_M$ at 125 ka.

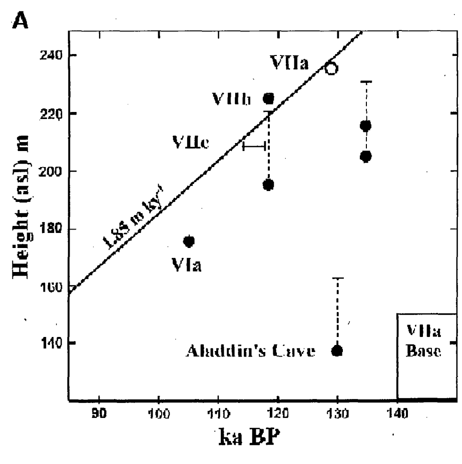
Three coral samples from Aladdin's Cave have ages between 108 and 115 ka (Table W1), and two corals from terrace VIb, which is near the cave, have ages of 130 ka. This is not surprising because the surface of the terrace VIb cliff is dotted with hollows, which presumably provide access to coral deposits that predate reef VIb. Corals from Kwambu, Kanzarua, and Nanda (Table W1) also appear to record two events: one associated with ~135 ka (reef VII at Aladdin's Cave) and one associated with ~115 ka (sample AC-U12 at Aladdin's Cave). Samples Kwam-U4 and Kanz-1 are older (137 to 140 ka) and could represent an early stage of the penultimate deglaciation. The mean age of reef VIa is 105 ka (Table W1), but at Kwambu, there is a considerable range in ages between 99 and 113 ka. It has been difficult to obtain a reliable age for reef VIb because of the poor quality of corals from the sampled localities; however, one acceptable measurement gave an age of 89.5 ka.

There appears to be a conflict between samples from Aladdin's Cave [100 m above sea level (asl) and ~130 ka] and from reef VII (up to 220 m asl and ~134 ka) (Fig. 3A). Various interpretations are possible. The age measurements might be wrong. However, all samples summarized in Table W1 passed accepted cross-check criteria, and the two laboratories [Australia National University (ANU) (Table W1) and California Institute of Technology (*4*)] have reproduced each other's measurements of cross-check samples and standards (Table W1, sample HP 23) [reef VIIb was dated previously at 132 to 135 ka (*4*)]. On the other hand, corals that grew at Aladdin's Cave could have grown in water that was 60 m deeper than that at the 134-ka Kwambu sites. The absence of deep-water facies and the width of annual growth bands provide evidence against this possibility. The 6°C lower temperature is also difficult to reconcile with a high sea level.

Because of tectonic uplift, age-height data from reef VII sites at Kwambu and Kwangam are not sufficient to construct an absolute sea-level curve for the penultimate deglaciation and the Last Interglacial. The data only constrain relative sea-level changes (Fig. 3A) but can be reduced to local eustatic sea levels by using a datum established from stable sites. Uplift rates for the Huon Peninsula have been estimated from terrace VIIb, which has been dated at 118 to 120 ka with an assumed paleo–sea level at 0 to 5 m (*1, 2*). However, there is some uncertainty with this estimate. More than 70 mass spectrometric U-series ages from Western Australia (*9*) provide constraints for a sea level of 3 to 5 m during the Last Interglacial from 122 to 128 ka (*9*). High-precision dates from many other localities (*9*), when critically assessed, are in agreement with the narrow range in ages from Western Australia. Drill core data from the coast of Western Australia (*9*) and offshore from Abrolhos Island reefs (*5, 6*) indicate that the eustatic sea level at ~135 ka (after being adjusted for hydroisostasy) was ~14 m below the present sea level (*9*). The apparent end (~116 ka) of the Last Interglacial at Western Australia has been observed at Mangrove Bay, where the local sea level may have been as much as 6 m below the maximum Last Interglacial levels. Between 122 and 118 ka, the sea level was not constrained; however, indirect evidence points to sea-level instability after 122 ka (*9*).

Sea-level data from stable sites require isostatic corrections before they can be compared with Huon Peninsula paleo–sea levels (*9*). Recently, corals collected at Florida and Bermuda from elevations close to the present sea level were found to have a mean age of 80 ka (*14*). These locations are considered to be intermediate field sites, which are in proximity to Northern Hemisphere ice sheets, and eustatic sea levels may have been as much as 10 m below the present sea level (*9*). In other words, corals that grew 10 m below the present sea level at 80 ka may now be situated at the intertidal zone because of postglacial rebound. However, Last Interglacial corals at Bahamas (intermediate field) occur at similar elevations as those at Western Australia (far field). Consequently, estimates of glacio-isostatic effects may not be as robust at this level of detail. We adopted the calculated value of –10 m and assumed that, at ~80 ka, sea levels were 10 m below the present levels during the formation of reef Va. In most records, isotope stages 5a (80 ka) and 5c (105 ka) are assigned to similar sea-level elevations. We followed this analogy and assumed that reef crest VIa was formed at 105 ka at 10 m below the present sea level. These markers provide an absolute trajectory for Aladdin's Cave (Fig. 3B), given that the cave is located ~38 m below reef VIa and ~4 m above reef Va (Fig. 1). It was located at –48 m at 105 ka and at –6 m at 80 ka. These elevations correspond to an uplift rate of ~1.6 m/ky, which is consistent with the elevation and age of reef VIIb at Kwangam (185 m and 118 ky). The second trajectory is parallel to the first, but 90 m higher, and represents the trajectory of reef VIIb in time. As shown, the data from Aladdin's Cave indicate that the sea level fell by 60 to 80 m after the initial rise at the termination of the penultimate glacial. The uncertainty of +20 m relates to the likely range of depths that corals in the cave could have grown in. Stable sea levels during the Last Interglacial, from 122 to 128 ka, were 3 to 5 m above present levels. There may have been a brief pause in the sea-level decline at 116 to 117 ka at a few meters below the present levels, as indicated by the Mangrove Bay data from Western Australia and the ages from 116- to 119-ka that were found at ~30 m below VIIb at Kwambu. Ages for the VIIb crest (118 ka) and those ~30 m below (116 to 119 ka) overlap; nevertheless, the two sets of corals could have grown up to 2000 years apart within analytical errors.

Features of the penultimate deglaciation can be contrasted with events that occurred during the last postglacial sea-level rise. The Younger Dryas (YD), dated at ~12,000 yr B.P., was a prominent event during the last deglaciation (Termination I), when, for about 1300 years, near-glacial conditions prevailed before a return to rapid warming and a rise in the sea level (*15*). Coral dates from Barbados, Huon Peninsula, and Tahiti (*16*) provide evidence for a pause in



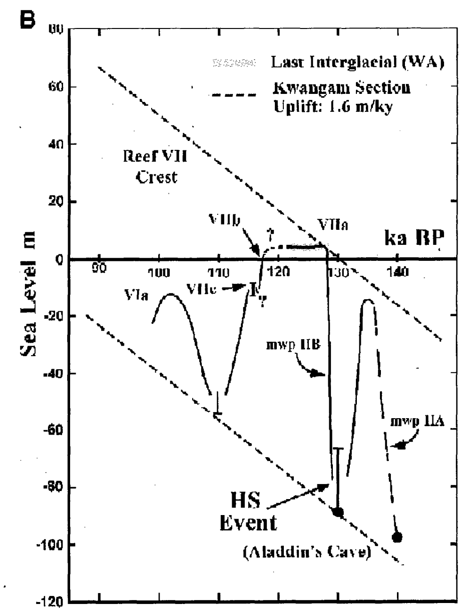


Fig. 3. (**A**) The age-height relation for dated terraces at Kwambu that was constructed by assuming that the top of terrace VIIa at 118 to 120 ka was 0 to 5 m above the present sea level. The dates and heights that were assigned for various terraces have been derived from Fig. 1 and (*4*). The point from Aladdin's Cave has been adjusted for the difference in uplift rate. The dashed vertical lines indicate the possible range of water depth (0 to 20 m) in which corals grew. The top of terrace VIIa is shown at ~129 ka as representing the culmination of the sea-level rise in the penultimate deglaciation as analogous to the Holocene reef and terrace I at Kwambu (*1, 2*). The age of terrace VIIa is not known; a single dated sample (*4*) gave an age of 118.7 ka with marginally acceptable U isotopic composition ($\delta^{234}U = 168 \pm 7$ per mil). The exact location of this sample from the top of terrace VIIa is uncertain (open circle). The presence of corals from 118 ka at the top of terrace VIIa would imply a +10-m sea-level high stand above the Last Interglacial sea levels (*26*). Diagonal line, rate of 1.85 m/ky. Error bar indicates the range of ages at reefs VIIb and VIIc. (**B**) Eustatic sea-level curve for the penultimate deglacial period and the Last Interglacial constructed from reliable literature data (*9*), including the results from our work. The smooth sea-level curve glosses over coseismic uplift events at Huon Peninsula, which are discrete and meter scale and would not be discernible at this scale. The diagonal dashed lines represent the uplift with time for the crest of reef VII and Aladdin's Cave. To be consistent with the labeling of the two meltwater pulses at Termination I, which were separated by the YD event, we labeled the penultimate (Termination II) deglacial meltwater pulses as "mwp-IIA" and "mwp-IIB." The intervening pause in deglaciation and the precipitous sea-level fall in the Huon Peninsula is labeled the "HS Event," after the nearby village of Sialum. The first pulse, mwp-IIA, reaches an elevation of ~14 m below the present sea level before a pause and a regression of ~80 m. The exact magnitude of the sea-level fall depends on the depth that corals grew at Aladdin's Cave and may be uncertain by up to +20 m (~70 to 90 m). If sea levels during the penultimate glacial maximum were as low as those during the Last Glacial Maximum (~125 m), the total rise during mwp-IIA would be ~110 m, which is comparable to the estimated 50-m rise for the YD mwp-IA. The second pulse, mwp-IIB, covers ~85 m. This scenario is in contrast to events that occurred during the last deglaciation, in the YD episode, where only a pause (rather than a drop in sea level) has been observed. Sea-level lows at the base of the reef VII structure and between stages 5e (VIIb) and 5c (VIa) are estimated from work by Chappell and Shackleton (*1*). WA, Western Australia; question marks and dashed curves, uncertainty in sea level. Error bars indicate the range in elevation of corals of similar age.

deglaciation bracketed by meltwater pulses of rapid sea level rise, possibly at rates in excess of 40 m/ky (*15*), which require a nonuniform and episodic collapse of major ice sheets (*17*). The penultimate glacial period (~150 ka) was more severe, and North Atlantic and North Pacific subarctic fronts were up to 5° farther south in latitude (*18*) than during the Last Glacial Maximum (~20 ka). The present data (Fig. 3B) suggest that the penultimate deglaciation may have included an exaggerated YD-type event. Similar oscillations were discerned from oxygen isotope records from deep-sea cores; Sarnthein and Tiedemann documented YD-type occurrences at the start of the last six glacial terminations from the Ocean Drilling Program site 658, off the northwest coast of Africa (*19*). A reversal of deglacial warming, during the penultimate deglaciation, was sharper and more pronounced than during the YD episode (*19*). A comparative study of magnetic parameters, grain size, and $\delta^{18}O$ from a piston core off the southwest coast of Greenland, corresponding to Terminations I and II, revealed major differences between the last two deglaciations (*20*). Synchronous magnetic and oxygen isotope signals at Termination II indicate an early and rapid deglaciation of Greenland (in contrast to the relatively late deglaciation during Termination I), and a well-defined light $\delta^{18}O$ peak (corresponding to an influx of meltwater) was followed by a return to glacial-type $\delta^{18}O$ levels before attaining full interglacial values. Marine, lacustrine, and terrestrial records from 24 globally distributed sites (*21*) also indicate a YD-type oscillation during the penultimate deglaciation. This event was named the "Zeifen-Kattegat climate oscillation" after the location where the warming was first documented in southern Germany at Zeifen and the subsequent cold snap, known as the Kattegat stadial, that was documented in the Anholt II borehole in Denmark (*21*).

The question of external or Milankovitch forcing, as opposed to internal ice-sheet dynamics, which precipitated the breakup of major ice sheets, is subject to debate (*22*). The early start to the Last Interglacial in the Devils Hole chronology (*7*) and the early deglaciation at Huon Peninsula are consistent with ice-sheet dynamics. The sea-level high at 135 ka is only ~14 m below present levels (Fig. 3B). The warming at Devils Hole by 140 ka thus appears to be a global phenomenon and, in records without sufficient resolution, can be mistaken for the start of the Last Interglacial. However, the sea level high at 135 ka was not sustained, and there was, evidently, a return to glacial conditions before further warming and sea-level rise, which were presumably forced by the high-latitude insolation maximum between 126 and 128 ka (*23*).

An important problem with the present sea-level curve is that cumulative precipitation may not be sufficient to regrow the ice sheets within 5000 years to about half the volume that they attained at the glacial maximum. One possible solution is that the higher sea levels, following the initial meltwater surge, would allow sea ice to migrate farther inland along continental shelves. A return to cold conditions is likely to ground some of this ice, initiating a sea-level fall. The full Laurentide ice sheet is believed to depress the crust by up to 400 m (*24*). A removal of the load would result in a rapid uplift that would also help to ground icebergs. In this way, sea levels could be lowered rapidly without the need for gradual ice buildup through precipitation.

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