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A global compilation of coral sea-level benchmarks: Implications and new challenges

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ABSTRACT

I present a quality-controlled compilation of sea-level data from U–Th dated corals, encompassing 30 studies of 13 locations around the world. The compilation contains relative sea level (RSL) data from each location based on both conventional and open-system U–Th ages. I have applied a commonly used age quality control criterion based on the initial $^{234}U/^{238}U$ activity ratios of corals in order to select reliable ages and to reconstruct sea level histories for the last 150,000 yr. This analysis reveals scatter of RSL estimates among coeval coral benchmarks both within individual locations and between locations, particularly during Marine Isotope Stage (MIS) 5a and the glacial inception following the last interglacial. The character of data scatter during these time intervals imply that uncertainties still exist regarding tectonics, glacio-isostacy, U-series dating, and/or coral position. To elucidate robust underlying patterns, with confidence limits, I performed a Monte Carlo-style statistical analysis of the compiled coral data considering appropriate age and sea-level uncertainties. By its nature, such an analysis has the tendency to smooth/obscure millennial-scale (and finer) details that may be important in individual datasets, and favour the major underlying patterns that are supported by all datasets. This statistical analysis is thus functional to illustrate major trends that are statistically robust ('what we know'), trends that are suggested but still are supported by few data ('what we might know, subject to addition of more supporting data and improved corrections'), and which patterns/data are clear outliers ('unlikely to be realistic given the rest of the global data and possibly needing further adjustments'). Prior to the last glacial maximum and with the possible exception of the 130–120 ka period, available coral data generally have insufficient temporal resolution and unexplained scatter, which hinders identification of a well-defined pattern with usefully narrow confidence limits. This analysis thus provides a framework that objectively identifies critical targets for new data collection, improved corrections, and integration of coral data with independent, stratigraphically continuous methods of sea-level reconstruction.

1. Introduction

Dated fossil corals provide important benchmarks for understanding past sea-level history. Over the last three decades, during which period sophisticated dating has been possible, many coral relative sea level (RSL) benchmarks have been published (see full reference list in the section Methods). However, this wealth of data has not before been systematically compiled into a single, coherent and procedurally standardized dataset. I present a first such compilation for public dissemination and feedback. From the perspective of users of coral sea-level benchmarks, I then evaluate the first-order information contained within the compiled dataset and explore objective criteria for acceptance or rejection of individual data points from the dataset in order to obtain a systematic and coherent view of sea-level variability through time. This is achieved by organizing and selecting data according to two criteria: (1) the initial uranium ratios of coral samples, in order to assess dating quality, and (2) the location of the corals, in order to assess other factors that affect sea level estimates from corals (e.g. glacio-isostacy and tectonics). Finally, I perform a statistical assessment that takes into account age and sea-level uncertainties in the data, to recognize which trends are well supported by available data, which require more data support, and which data represent clear outliers. This assessment of statistical confidence in the main sea level changes identified from the full body of compiled coral data provides a transparent and objective starting point for identifying key targets for more detailed investigation of unaccounted-for uncertainties in tectonics, glacio-isostacy, coral position, age, and/or coral depth habitat. Ongoing work focuses on the magnitude (and uncertainty) of glacio-isostatic adjustments (GIA) that affect

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comparisons between sites, but such developments are beyond the scope of the present study, which focuses on establishing the level of internal consistency and clear outlier determination.

2. Methods

Compilation of RSL benchmarks from U-series dated corals comprises 30 published studies and 13 locations around the world ($n=897$ samples) (Fig. 1, Supplementary Table S1) (Dodge et al., 1983; Bard et al., 1990a, 1996; Chen et al., 1991; Stein et al., 1993; Zhu et al., 1993; Gallup et al., 1994; Szabo et al., 1994; Stirling et al., 1995, 1998, 2001; Chappell et al., 1996; Ludwig et al., 1996; Esat et al., 1999; Toscano and Lundberg, 1999; Yokoyama et al., 2001; Gallup et al., 2002; Muhs et al., 2002a, 2002b, 2006, 2011; Cutler et al., 2003; Speed and Cheng, 2004; Fairbanks et al., 2005; Thompson and Goldstein, 2005; Peltier and Fairbanks, 2006; Coyne et al., 2007; Thomas et al., 2009; Andersen et al., 2010; Bard et al., 2010). Most of the data compiled here were obtained directly from the original published

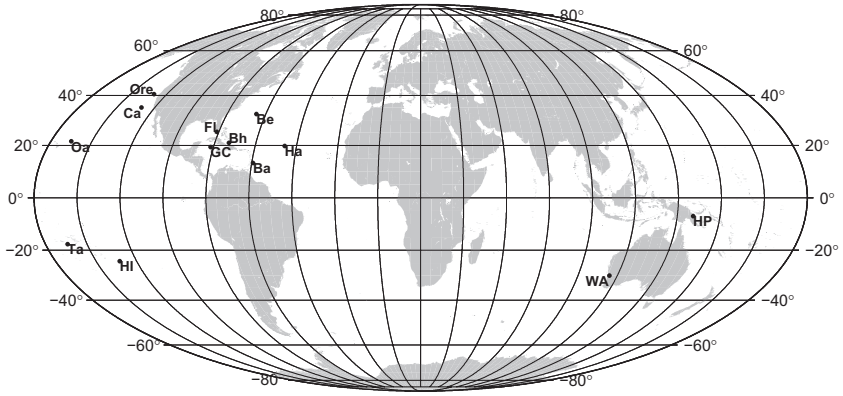

Fig. 1. Map with 13 coral locations included in the coral compilation: Oregon (Ore), California (Ca), Oahu (Oa), Tahiti (Ta), Henderson Island (HI), Florida (Fl), Bahamas (Bh), Gran Cayman (GC), Barbados (Ba), Bermuda (Be), Haiti (Ha), Huon Peninsula (HP), and Western Australia (WA).

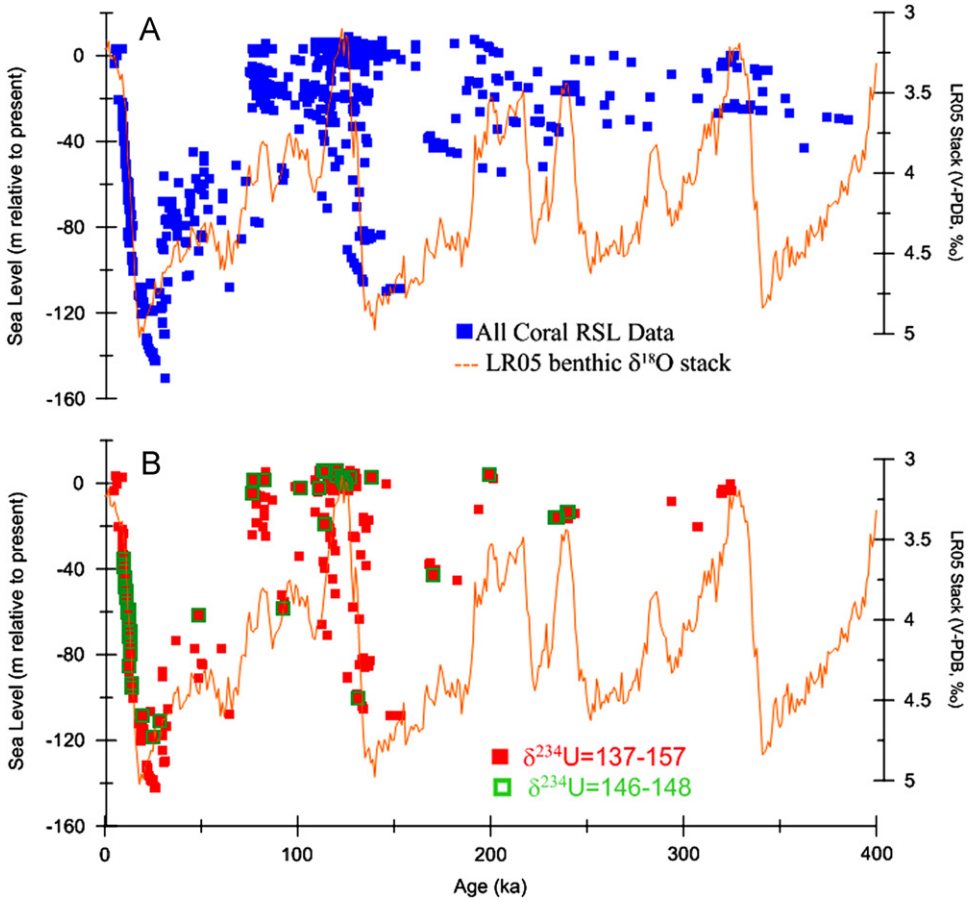

Fig. 2. Comparison between coral sea level benchmarks and the stratigraphically continuous benthic foraminiferal $\delta^{18}O$ stack (Lisiecki and Raymo, 2005) spanning the last 400 ka. Panel A contains all of the coral relative sea level (RSL) data in the compilation ($n=897$) (blue squares). Panel B contains selected coral RSL data based on $\delta^{234}U_i$ values within the 137–157‰ (red squares) and 146–148‰ (green squares) ranges. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)