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Reappraisal of sea-level lowstand during the Last Glacial Maximum observed in the Bonaparte Gulf sediments, northwestern Australia

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ABSTRACT

During the Last Glacial Maximum (LGM), ice volume reached a relative maximum and global temperature was lower than today. Understanding continental ice volume change requires accurate reconstruction of relative sea level, but tectonic uplift and isostatic adjustment effects complicate many records. Using marine sediment cores from the Bonaparte Gulf in northwestern Australia, a so-called "far field" tectonically stable site, Yokoyama et al. (2000) reported that the LGM terminated abruptly at 19 ka with a rapid sea-level rise (19 ka event). Their sea-level reconstruction determined the age of the LGM termination, but the timing of its inception remained less well constrained, partly because the number of radiocarbon analyses was insufficient to clarify LGM duration. Here we return to the Bonaparte Gulf and present a new relative sea level that better constrains LGM duration with high-resolution radiocarbon dating of a recently recovered marine sediment core (water depth: 120 m, length: 583 cm). Radiocarbon dating of 23 molluscs and 26 bulk organic-matter samples, together with total organic carbon, total nitrogen, and stable carbon isotopes, provide a record of paleoenvironmental variability in response to sea level change. Our results indicate that the LGM sea-level minimum occurred at 20.8 cal ka BP and the LGM duration was shorter than previously reported.

1. Introduction

Ice volume change has had a major impact on the global climate system during the Quaternary Period. Both ice sheet growth and subsequent decay (e.g. meltwater) influence the atmospheric and oceanic circulation (e.g. Manabe and Broccoli, 1985; Deschamps et al., 2012). Study of the Last Glacial Maximum (LGM) at ~20 ka, during which ice sheet extent reached a relative maximum with a global decrease in sea level up to −135 m (Yokoyama et al., 2000a, 2001), can help better constrain the relationship between climate and ice volume change. The LGM is particularly well suited for study due to the applicability of radiocarbon dating. Older glacial maxima recorded in marine sediments cannot be as accurately or precisely dated.

Far-field sites that are remote from regions of extensive ice cover and therefore relatively unaffected by glaicio-isostatic adjustment are desirable to reconstruct ice volume due to the small difference between global eustatic and local relative sea level. The Bonaparte Gulf is a far-field site located in a tectonically stable region with a shallow and well-developed shelf (Fig. 1) that was mostly exposed

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and connected to the Timor Sea by the 10-km wide, tide-influenced Maltia Valley during the LGM (van Andel et al., 1967; Bourget et al., 2013). Yokoyama et al. (2000a, 2001) reconstructed paleo-water depths of the Bonaparte Gulf using ostracod assemblages and reported an LGM lowstand of -125 ± 4 m that began sometime prior to 22 cal ka BP and terminated abruptly at 19 cal ka BP with a rapid sea-level rise (19 ka event). While this result was later reproduced using finer resolution (De Deckker and Yokoyama, 2009), the age of LGM initiation was not well constrained. To address this issue, we present a relative sea-level record from the LGM obtained by detailed radiocarbon measurements and paleoenvironmental reconstruction using a newly recovered core (KH11-1GC06) from the same location in the Bonaparte Gulf.

2. Methods

2.1. Materials and physical properties

Sediment gravity core KH11-1GC06 was recovered in 120 m water depth aboard the *R/V Hakuho Maru* at the same location in the Bonaparte Gulf as RS176/GC5, which was used by Yokoyama et al. (2000a, 2001) and De Deckker and Yokoyama (2009). KH11-1GC06 is 583 cm in length. Well-preserved molluscan fossils of the species, *Paphia undulata*, *Turritella terebra*, *Spisula* sp. and *Anadara* sp. (Table 1 and Fig. 2), are indicative of paleoenvironment and were picked to reconstruct the relative sea level (e.g. Nicholas et al., 2014). Color reflectance was measured at a 2 cm interval immediately after splitting the core using a Minolta CM-2002 photospectrometer. Split-core scanning X-ray fluorescence (XRF) was later conducted at a 1 cm interval using a TATSCAN-F2 located at the Kochi Core Center (KCC).

2.2. Geochemical analysis

KH11-1GC06 was subsampled at a 2.5 cm interval using 7-ml cubes for geochemical analysis. The low gradient of the ~600 km-wide Bonaparte shelf resulted in a considerable change in distance from shore during the LGM. To detect changing contributions of marine and terrestrial organic matter, total organic carbon (TOC), Carbon/Nitrogen (C/N) ratios and $\delta^{13}C$, were measured.

2.3. Radiocarbon dating

Radiocarbon dating was performed on 23 molluscs and 26 bulk organic-matter samples. Molluscs were etched by 10 M HCl (Yokoyama et al., 2000b). Analyses of bulk sediments were performed on subsamples from 7-ml plastic cubes pretreated twice in 3 M HCl for 12 h to digest calcium carbonate.

Graphitization was performed following the method of Yokoyama et al. (2007). The analyses were performed at the University of Tokyo using a Tandem Accelerator at the Micro Analysis Laboratory and a Single Stage AMS at the Atmosphere and Ocean Research Institute.

Radiocarbon ages were calibrated to calendar ages using Oxcal 4.2 (Ramsey and Lee, 2013). The Marine13 curve was used for molluscan fossils and Intcal13 for bulk organic matter samples (Reimer et al., 2013). The local reservoir correction is not known for the Bonaparte Gulf and is likely very small (e.g. O'Connor et al., 2010). Therefore we did not specify a local reservoir correction.

3. Results

3.1. Lithologic description

KH11-1GC06 (Fig. 2) mainly consists of light to dark silty clay, with sandy siliciclastic sediment primarily limited to the interval from the coretop to 10 cm below seafloor (cmbsf). Yellowish silty clay is present from 10 to 60 cmbsf. Nannofossils and small planktic foraminifers are present to ~60 cmbsf. Greenish clay to silty clay comprises the interval from 60 to 470 cmbsf. Silty clay primarily comprises the interval from 470 cmbsf to the bottom of the core (583 cmbsf), and shell fragments are common from 430 to 510 cmbsf (Figs. 2 and 3).

3.2. Relative sea level indicators

3.2.1. Geochemical analysis

KH11-1GC06 is divided into three geochemical units (Fig. 4). Unit 1 extends from the core top to 60 cm, Unit 2 from 60 to 450 cm, and Unit 3 is from 450 cm to the core bottom (Fig. 4). Unit 1 is characterized by down-core trends in TOC, C/N ratios, and $\delta^{13}C$,

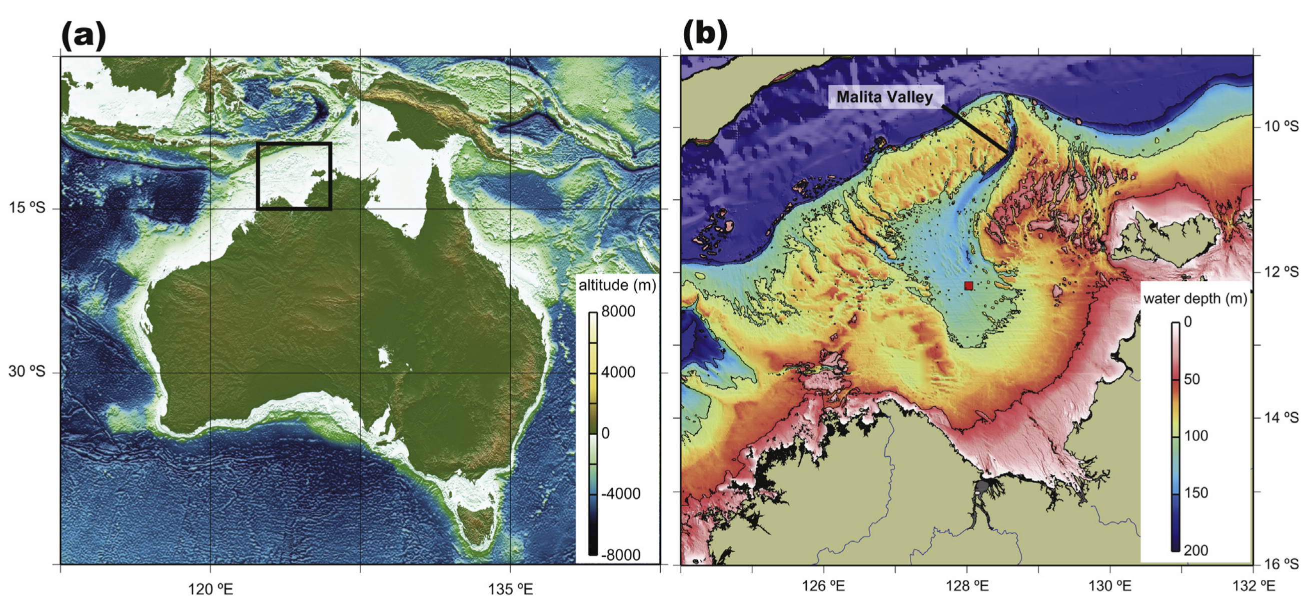

Fig. 1. (a) General view of Australia. The black square shows the Bonaparte Gulf region. (b) Bathymetric map of the Bonaparte Gulf. The contour interval is 50 m. The red square shows the KH11-1GC06 and RS176/GC5 coring site. Data source is Australia Bathymetry and Topography Grid from Geoscience Australia.