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Short Paper

No significant ice-sheet expansion beyond present ice margins during the past 4500 yr at Rauer Group, East Antarctica

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ABSTRACT

The history of glacial advances and retreats of the East Antarctic ice sheet during the Holocene is not well-known, due to limited field evidence in both the marine and terrestrial realm. A 257-cm-long sediment core was recovered from a marine inlet in the Rauer Group, East Antarctica, 1.8 km in front of the present ice-sheet margin. Radiocarbon dating and lithological characteristics reveal that the core comprises a complete marine record since 4500 yr. A significant ice-sheet expansion beyond present ice margins therefore did not occur during this period.

Introduction

The East Antarctic Ice Sheet (EAIS) currently holds ca. 79% of the global ice masses, which equals about 52 m of sea-level equivalent (Lythe et al., 2001). Mass-balance changes of the EAIS could thus have a significant impact on global sea level. However, mass-balance estimations for the EAIS indicate that only minor changes have occurred in recent decades (Mayewski et al., 2009), while the West Antarctic Ice Sheet (WIAS) is showing dynamic and large ice-volume fluctuations (Wingham et al., 2006), and the smaller ice areas on the Antarctic Peninsula (AP) are affected by the fast warming of the region (Vaughan et al., 2003).

The reconstruction of past glacial advances and retreats is difficult because of the complex reactions of glacial systems on changes in accumulation rates and temperature (Goodwin, 1998). Advances of East Antarctic alpine glaciers, ice-sheet margins and outlet glaciers during the mid and late Holocene have been reconstructed from glaciological and geomorphological field evidence (e.g. see review by Hall, 2009). Yet, the extent of such advances is difficult to assess because robust chronological constraints are often lacking. Records that allow precise dating and recognition of small-scale changes are needed to improve the understanding of past changes of the EAIS under different climate conditions, and to help measure the regional variability of these changes and to gain a holistic view of the whole ice sheet. This is a major precondition to substantially improving future predictions about the impact of the recent global warming on ice sheets.

The Prydz Bay region is a crucial site for reconstructing past developments of the EAIS, because it encompasses the largest drainage system in Antarctica (O'Brien et al., 2007). Field evidence for glacier and ice-sheet advances in the Prydz Bay region during the Holocene is sparse. A marine record from eastern Prydz Bay indicates a re-advance of floating glacial ice between ca. 7300 and 3800 ^{14}C yr BP (Domack et al., 1991). This observation is, however, not confirmed by another record from the same area (Taylor and McMinn, 2002). In the Vestfold Hills, eastern Prydz Bay, Holocene ice retreat was interrupted by the so-called Chelnock Glaciation since 2000 ^{14}C yr BP, when the northern margin of the Sørsdal outlet glacier expanded (Adamson and Pickard, 1983). A limited extent of Holocene glacial re-advances was proposed by Fitzsimons and Colhoun (1995), with ice advances of less than 500 m in the Vestfold Hills. A local glacier re-advance of unknown extent around ca. 2600 cal yr BP has been reconstructed from relative sea-level observations in nearby Larsemann Hills (Verleyen et al., 2005).

The Rauer Group, located between Larsemann Hills and Vestfold Hills, consists of several ice-free and low-lying islands (Fig. 1A) and is delimited by the EAIS to the east and bordered by outlet glaciers to the north and south. A rather stable ice-sheet margin, with maximum ice expansion of less than 500 m throughout the Holocene, is inferred from the degree of weathering of glacial deposits (White et al., 2009). However, precise dating of the deposition of the glacial erratics and moraines deposited on Rauer Group is difficult.

A sediment core was recovered from a 6.3-m-deep marine inlet located at Shcherbinina Island in the northern Rauer Group (Fig. 1A). The distance from the coring location to the present ice-sheet margin

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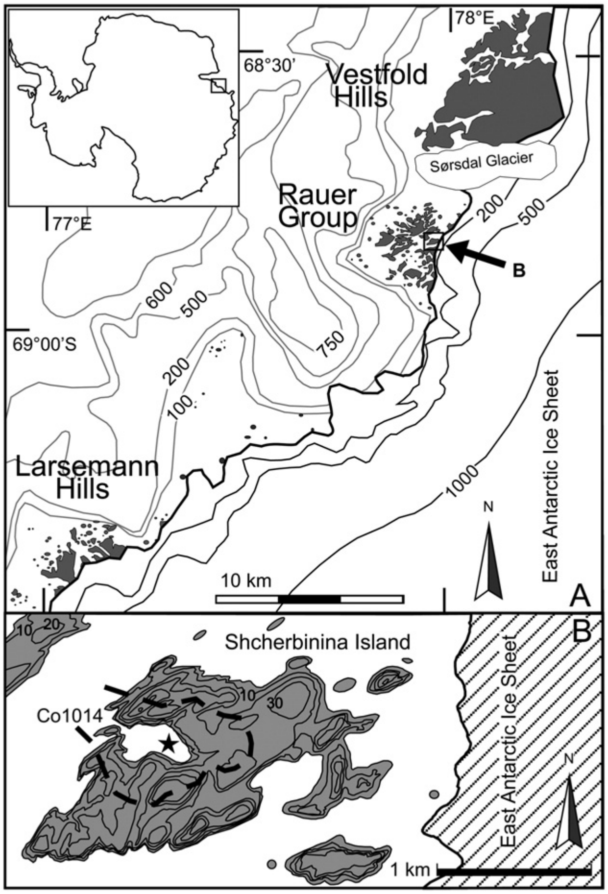

Figure 1. A) Eastern Prydz Bay, Antarctica, with presently ice-free coastal areas (dark grey). Rectangle in Rauer Group indicates the location of Shcherbinina Island and core Co1014. B) Topographic map of Shcherbinina Island with hydrological catchment of the cored inlet (dashed line) and coring location Co1014 (star).

measures ca. 1.8 km (Fig. 1B), and the hydrological catchment of the inlet comes as close as 1.3 km to the ice margin. The small distance of the core to the present ice-sheet margin in combination with relatively well-datable coastal marine sediments make the record an important contribution to understand the timing and extent of past ice-sheet movements better.

Results and discussion

The sediment core (Co1014) recovered from the marine inlet has a length of 257 cm. The sediments are of black colour and show faint lamination throughout. Low compaction is indicated by the high water content (Fig. 2). The high proportion of organic material is reflected by TOC (1.6–5.0%) and particularly by biogenic silica (BSi) (16–27%). Microscopic inspection of some samples showed that diatoms form the main source of BSi. The terrigenous fraction of the sediments is in general fine-grained, but some angular sand and gravel grains occur sporadically. Although the sand could originate from aeolian transport, the gravel clearly indicates ice-related transport, most likely due to drifting ice floes. The relatively uniform lithology of core Co1014 provides no evidence for a change in sedimentation processes.

The age–depth model of core Co1014 (Fig. 2) is based on four AMS radiocarbon ages. The ages were determined on the humic-acid-free (HAF) fraction of bulk organic carbon samples at the Leibniz Laboratory for Radiometric Dating and Isotope Research in Kiel, Germany (Table 1). A local reservoir effect of 1000 yr was estimated from the uppermost dated sample KIA 38366 (Table 1) and matches closely with that from two other marine inlets in the Rauer Group, where reservoir effects of 920 +/− 80 and 890 +/− 25 ^{14}C yr were measured (Berg et al., 2009 and *unpubl. data*). It is likely that changes in the reservoir effect over time occurred. However, since these changes cannot be determined, the modern reservoir effect is taken as constant. The radiocarbon ages were calibrated into calendar years (cal yr BP) using the Calib 5.1 rev programme (Stuiver et al., 2005) and the Marine04 data set (Hughen et al., 2004) with a deviation of

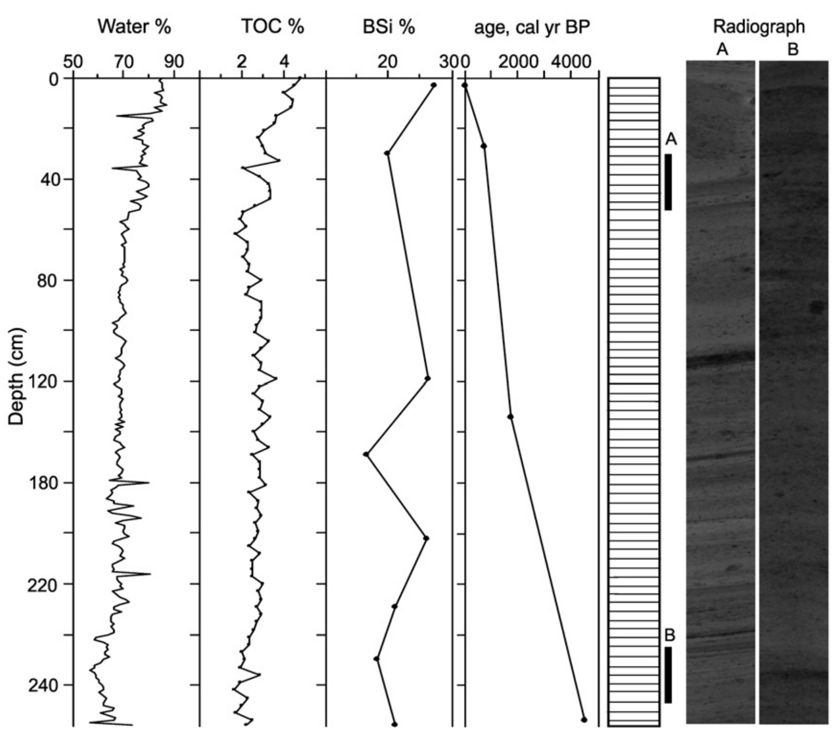

Figure 2. Water content, TOC (total organic carbon), BSi (biogenic silica), and calibrated radiocarbon ages of core Co1014. Lithological profile and radiographic images (2 cm in width) illustrate the laminated and monotonous appearance of core Co1014.3.

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Table 1
Radiocarbon ages of the humic-acid-free fraction (HAF) of bulk organic matter in core Co1014. For calibration an ΔR of 638 yr was applied to correct for local reservoir effect, calibrated ages are given as 2 σ range.

Lab. no.	Depth [cm]	^{14}C age [^{14}C yr BP]	Calendar age [cal yr BP]	Mean [cal yr BP]
KIA38366	3–4	1000 +/− 25	−3 to 66	31 +/− 34
KIA38367	27–28	1815 +/− 30	656–785	720 +/− 64
KIA38368	134–135	2785 +/− 30	1630–1828	1729 +/− 99
KIA38366	254–255	5000 +/− 35	4400–4615	4507 +/− 107

362 yr for the Southern Hemisphere (Stuiver and Braziunas, 1993) and a ΔR of 638 yr for the local reservoir effect. The radiocarbon ages of core Co1014 indicate a succession of increasing ages with increasing depths. The sample from the base of the core has an age of 4400–4615 cal yr BP (KIA38369; Table 1). Since major changes in sedimentation rates do not exist, core Co1014 likely contains a complete mid- to late-Holocene record.

Interpretation

The expanded ice sheet covered the Rauer Group region during the latter half of the last glacial cycle (White et al., 2009), and probably throughout the LGM. The onset of marine conditions after deglaciation was dated to the early Holocene in a marine basin located ca. 6 km off the present ice-sheet margin, 5 km to the northwest of coring location Co1014 (Berg et al., 2009). The basal age of core Co1014 from the inlet at Shcherbinina Island implies that the ice margin had reached a position comparable to the present prior to ca. 4500 cal yr BP and deglaciation of the islands was virtually complete. Moreover, the presumed continuous marine sedimentation preserved in the sediment record indicates that the coring location was not overriden by an advancing ice sheet during the past ca. 4500 yr. It is even unlikely that the ice margin reached the catchment of the inlet in Shcherbinina Island during the past ca. 4500 yr, since significant changes in the sediment composition are absent. Also, taken in concert with the weathering data presented by White et al. (2009) it can be argued that the ice sheet has not advanced more than 500 m beyond its present position during this time. Hence, mid- to late-Holocene advances of the ice-sheet margin must have been less than 1.8 km compared to the present ice-sheet margin, and likely did not exceed 0.5 km.

Furthermore, continuous marine sedimentation within the core during the past 4500 yr indicates that the site, and likely the shallow sill (2 m below sea level), have remained below sea level during this time, precluding the possibility of significant isostatic uplift during this period. Thus, it is unlikely that the regional or local ice load has altered significantly during this period, either by ice advance or retreat.

The well-dated record from Shcherbinina Island suggests relatively stable environmental conditions in the Rauer Group during the mid and late Holocene. This implies that the mid- to late-Holocene warm periods observed in the neighbouring ice-free regions (e.g. McMinn et al., 2001; Verleyen et al., 2004) either did not affect or only slightly affected the Rauer Group, or that the mid- to late-Holocene temperature did not exceed the present temperature regime. Also, the relative sea-level changes observed in Larsemann Hills are not necessarily replicated throughout the Prydz Bay region, or indeed throughout East Antarctica, providing further evidence that the East Antarctic Ice Sheet can behave quite heterogeneously, even on relatively small spatial scales. Thus, care must be taken to ensure that events recorded in high-resolution data from individual sites such as the relative sea-level curve at the Larsemann Hills are replicated across multiple sites before they are interpreted as representing the behaviour of large sectors of the continent, or of entire drainage basins such as the Lambert Glacier-Amery Ice Shelf System.

Lastly, our results confirm that the post-glacial rebound model (Ivins and James, 2005) from satellite remote-sensing data of ice elevations and ice motion are a reasonable approximation. Thus, the evidence of stability up until recent years is reasonable (e.g. Rignot et al., 2008). On the other hand, modelling suggests an increased ice loss since the year 2006 (Chen et al., 2009), which might be an indication that the recent temperature increase indeed exceeds the mid- to late-Holocene warm periods reconstructed for East Antarctica.

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