The heterogenity of Holocene climatic and environmental history along the East Antarctic coastal regions

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Summary The reconstruction of the climatic and environmental history along the East Antarctic coastal regions is mainly based on investigations of geomorphological features and of biological proxies in lacustrine and marine sediment sequences. Although some consistencies in the onset and duration of warm and cold periods after deglaciation apparently exist, some records indicate significant differences from other records close by. These differences may partly be explained by dating uncertainties, overprinting of local factors, or possibly even misinterpretations of the proxies used. A comparison with the climate histories deduced from ice core records reveals, however, that the differences have at least partly to be caused by local effects and small-scale variations, which still need to be better understood and demonstrate the need of further research.

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Introduction

Approximately 98 % of Antarctica presently is covered by continental ice masses. The ice cover comprises about 91 % of the global ice volume, most of which (79 %) is stored in the East Antarctic Ice Sheet (EAIS). Changes in the extent and volume of the EAIS thus have a direct impact on global sea level (Denton and Hughes, 2002), and affect the global heat budget by influencing the albedo and the atmospheric and oceanic circulation patterns (Ingólfsson and Hjort, 1999). Predictions of the near-future EAIS evolution require a good understanding of modern climatic and environmental developments, but also (1) of the variability of the ice sheet and (2) of the reasons for its waxing and waning throughout this period.

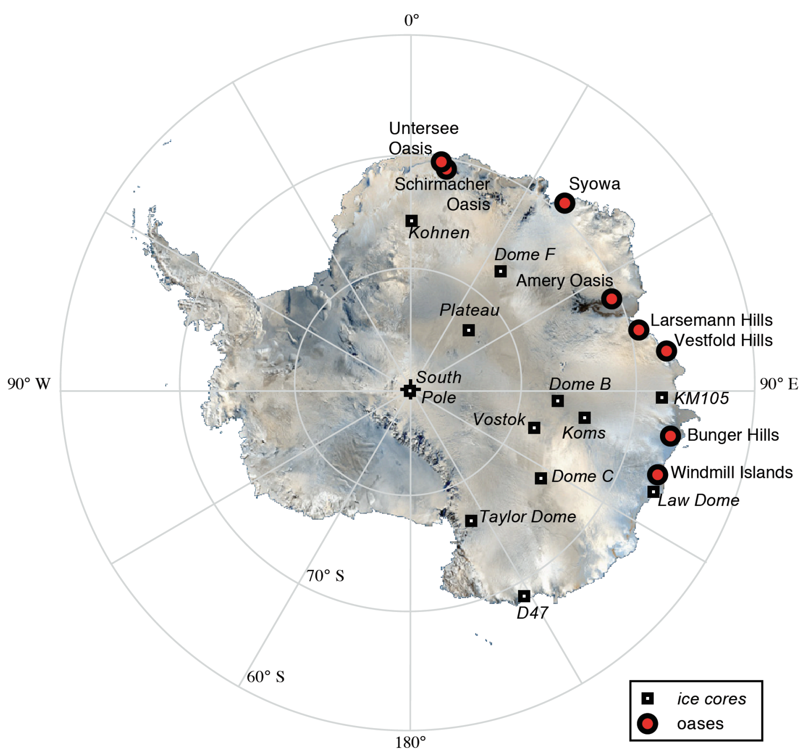

Figure 1. Map of Antarctica with locations mentioned in the text.

The extent and thickness of the EAIS during the early and middle Quaternary is very little known, and it remains poorly constrained even for the late Quaternary. The CLIMAP (1981) reconstruction assumed that the EAIS extended to the continental shelf edge at the Last Glacial Maximum (LGM) c. 21,000 yr BP. Deglaciation to the present coastline occurred sometime close to the start of the Holocene 10,000 yr BP (e.g., Huybrechts, 1990, Hughes, 1998). More recent reconstructions (e.g., Steig et al., 2001; Huybrechts, 2002) capture some of the variability seen in the field evidence, but still do not represent its full complexity. Today we know that deglaciation of the coastal areas of East Antarctica was highly diachronous. Deglaciation ranges from significantly less than 10,000 yr BP in Schirmacher Oasis (Schwab, 1998), 10,000 to 12,000 yr BP in, for example, Windmill Islands (Kirkup et al., 2002), in Untersee Oasis (Schwab, 1998), or Vestfold Hills (Fabel et al., 1997), c. 30,000 yr BP in Bunger Hills (Gore et al., 2001), to > 48,000 yr BP in Dry Valleys (Wagner et al., 2006) or Larsemann Hills (Hodgson et al., 2006) (Fig. 1). Furthermore, areas such as the Lützow-Holm Bay had been ice-free during the Marine Isotopic Stage 3 (Middle Weichselian) but exhibit the possibility of subsequent short-term ice overriding (Takada et al., 2003). These data show that the "local glacial maximum" can be rather different along the East Antarctic coastline from the global LGM. Also the Holocene reconstructions of ice movements are poorly constrained. For example, reports of ice advances between 7000 and 4000 yr BP (e.g., Domack et al., 1991; Colhoun and Adamson, 1992; Melles et al., 1997) are at odds with ice retreats reconstructed for the same period (e.g., Baroni and Orombelli, 1994).

In addition to the uncertainties in dating advance and retreat of the EAIS margin, and in reconstructing both the extent and the thickness of the ice sheet in certain times, still little is known about the reasons for these variations. This lack of understanding is most likely caused by the complexity of interactions between changes in the regional climate, relative sea level, and oceanic proper-ties. For instance, the regional climate via precipitation and temperature has a direct impact on the ice volume, the regional sea level affects calving rates at the ice margin, and the oceanic properties control the melting or marine ice formation beneath ice shelves and floating glaciers (e.g., Domack et al., 1991; Ingólfsson et al., 1992; Björck et al., 1996; Melles et al., 1997).

A significantly better understanding of the EAIS history and the reasons for the observed temporal and regional differences might be achieved by comprehensive reconstructions of the climatic and environmental histories along the East Antarctic coastal regions.

Comparison of reconstructed climate histories

Climate reconstructions along the East Antarctic coastal regions are mainly based on investigations of geomorphological features and of biological proxies in lacustrine and marine sediment sequences. Hodgson et al. (2004) proposed that a mid-Holocene hypsithermal is indicated in various records from Antarctica. However, a detailed comparison of records from coastal East Antarctica shows a more complicated and inconsistent picture (Fig. 2). These inconsistencies are probably caused by several uncertainties. Dating uncertainties may lead to erroneous ages, particularly when restricted amounts of organic and calcareous carbon and variable reservoir effects reduce the accuracy of the radiocarbon chronology. Additionally, the paleoclimate information can be masked by the glacial history in the regions, when irregular ice rafting and glacial melt-water supply alter the sedimentation. Furthermore, misinterpretation of the proxies investigated may also lead to erroneous results. These uncertainties may at least partly explain the differences in the occurrence of warm and cold periods during the past c. 13,000 cal yr BP along coastal East Antarctica.

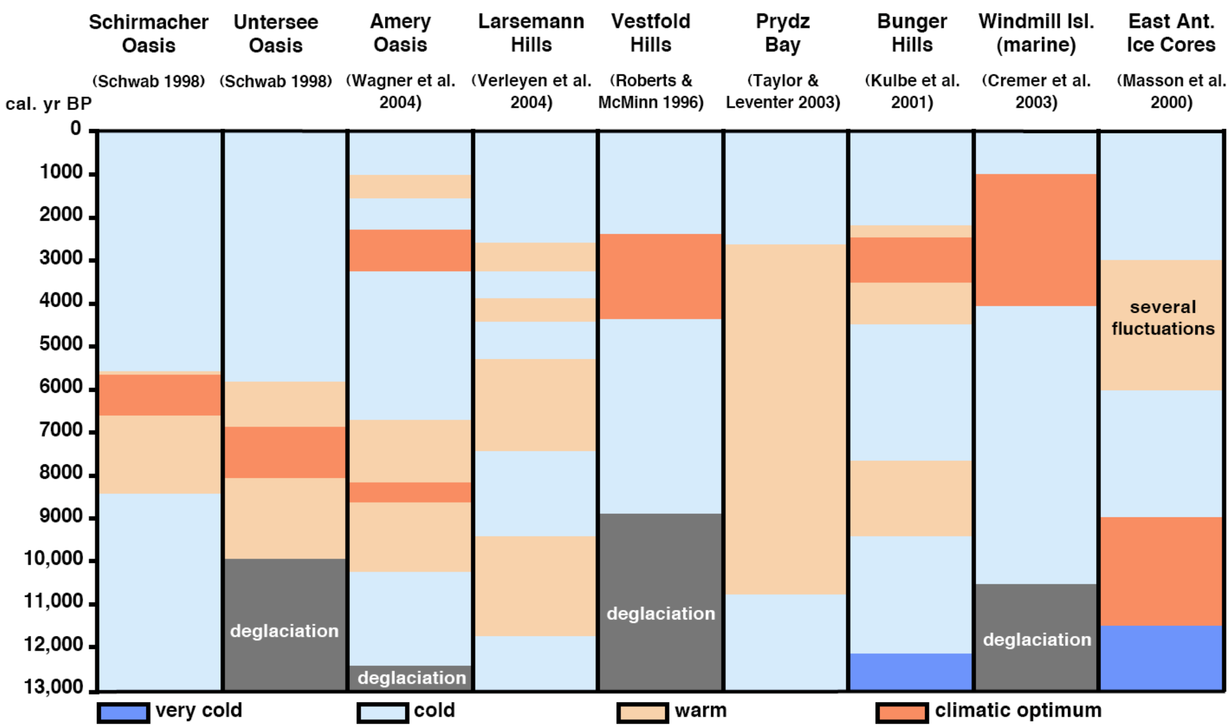

Figure 2. Comparison of paleoclimate information from several coastal regions in East Antarctica and from East Antarctic ice cores (for references see captions on top of columns).

From Schirmacher and Untersee oases, only sparse information is available. Schwab (1998) proposed that relatively warm temperatures prevailed in Schirmacher Oasis between ca. 8500 and 5500 cal. yr BP, with a maximum between c. 6500 and 5500 cal. yr BP. In Untersee Oasis, located only ca. 60 km to the southeast, the warming started already around 10000 cal. yr BP and led to a thermal maximum between 8000 and 7000 cal. yr BP. The climatic differences between both oases are surprising, but probably due to local affects, such as deglaciation and glacial melt-water supply (Schwab, 1998).

The climate reconstructions for the Prydz Bay region show even a more heterogenous picture. Whilst Pickard et al. (1984, 1986) proposed that in Vestfold Hills the Holocene climate was relatively stable, Zhang (1992) assumed a distinct climatic optimum to have occurred between c. 7000 and 4000 cal. yr BP. Roberts and McMinn (1996), on the other hand, found indications for a climatic optimum between c. 5000 and 2500 cal. yr BP (Fig. 2).

In the Larsemann Hills the climate history is more unequivocal, and different from the various climatic developments reconstructed for Vestfold Hills. In some coastal lakes from Larsemann Hills, biogenic sedimentation commenced shortly after deglaciation at c. 13,500 cal. yr BP, and remained unaffected by glacier advances since then (Verleyen et al., 2004). Changes particularly in the fossil diatom assemblages in these lakes provide strong indications for warm and humid periods from 11,500 to 9500 cal. yr BP, from 7500 to 5000 cal. yr BP, and from 3000 to 2000 cal. yr BP (Fig. 2).

In Amery Oasis, the only paleoclimatic information comes from variations in the biogeochemistry and diatom assemblages in a small lake that received biogenic sedimentation without glacial impact since c. 12,500 cal. yr BP (Wagner et al., 2004). These data suggest a different climate development, with warm periods in Amery Oasis from 8600 to 8200 cal. yr BP, from 3200 to 2300 cal. yr BP, and from 1500 to 1000 cal. yr BP (Fig. 2).

The obvious differences in the climate histories of the terrestrial regions around Prydz Bay are further complicated by the marine records from Prydz Bay, which also show an inconsistent picture of Holocene climate development. Taylor and Leventer (2003) inferred a warm and relatively stable early and mid Holocene climate (Fig. 2) from high abundances of diatoms and open-water taxa in several marine cores from the Prydz Channel. Sediment cores from beneath the Amery Ice shelf, in contrast, reveal that the ice shelf has retreated between c. 6500 and 1000 cal. yr BP, which was interpreted as being a consequence of warmer climate during this period (Hemer and Harris, 2003).

Further to the east, in Bunger Hills, thermal optima were reconstructed from the investigation of a sediment sequence from an epishelf lake for the early Holocene between 9400 and 7600 cal. yr BP and in the mid to late Holocene between 3500 and 2500 cal. yr BP (Kulbe et al., 2001).

Another 400 km to the east, in Windmill Islands, sediment sequences from partly separated marine basins do not indicate an early Holocene thermal maximum, but a late Holocene hypsithermal (Cremer et al., 2003; Fig. 2). Although this late Holocene hypsithermal probably corresponds with that observed in other oases; it is much longer and lasts from 4000 to 1000 cal. yr BP.

The discrepancies found in changes in the climate developments around the coast of East Antarctica cannot fully be explained by dating uncertainties or misinterpretations of the proxies used. This is also indicated by a comparison with the climate histories deduced from ice core records (Figs 1 and 2; Masson et al., 2000). Hence, the differences have at least partly to be caused by local effects and small-scale variations, for example in moisture supply, wind directions, or sea-ice cover, which still need to be better understood and demonstrate the need of further research.

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