The Antarctic contribution to Holocene global sea level rise

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The Holocene glacial and climatic development in Antarctica differed considerably from that in the Northern Hemisphere. Initial deglaciation of inner shelf and adjacent land areas in Antarctica dates back to between 10–8 Kya, when most Northern Hemisphere ice sheets had already disappeared or diminished considerably. The continued deglaciation of currently ice-free land in Antarctica occurred gradually between ca. 8–5 Kya. A large southern portion of the marine-based Ross Ice Sheet disintegrated during this late deglaciation phase. Some currently ice-free areas were deglaciated as late as 3 Kya. Between 8–5 Kya, global glacio-eustatically driven sea level rose by 10–17 m, with 4–8 m of this increase occurring after 7 Kya. Since the Northern Hemisphere ice sheets had practically disappeared by 8–7 Kya, we suggest that Antarctic deglaciation caused a considerable part of the global sea level rise between 8–7 Kya, and most of it between 7–5 Kya. The global mid-Holocene sea level high stand, broadly dated to between 8–4 Kya, and the Littorina-Tapes transgressions in Scandinavia and simultaneous transgressions recorded from sites e.g. in Svalbard and Greenland, dated to 7–5 Kya, probably reflect input of meltwater from the Antarctic deglaciation.

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Introduction

The modern Antarctic Ice Sheet (Fig. 1) covers an area of ca. 13.6×10^6 km^2, and consists of roughly 29×10^6 km^3 of grounded ice, with a total potential effect on sea level rise of about 66 m (Drewry et al. 1982; Denton et al. 1991). The role of Antarctic glacial ice as a meltwater source for global sea level rise since the Last Glacial Maximum (LGM) is controversial (Andrews 1992). Estimates range from as little as 0.5–2.5 m (Colhoun et al. 1992) to 37 m (Nakada & Lambeck 1988), depending on whether calculations are based on minimum or maximum reconstruction of LGM-ice volumes in Antarctica. A number of appraisals put the Antarctic contribution to global sea level rise since LGM on the order of 12–26 m (Hughes et al. 1981; Huybrechts 1990a, b; Tushingham & Peltier 1991; Peltier 1994; Clark et al. 1996). This is out of the total estimated global sea level rise of 120 ± 20 m since LGM (e.g. Chappell & Shackleton 1986; Fairbanks 1989; Peltier 1994).

The timing of LGM in Antarctica has not been precisely determined. It has been radiocarbon dated to 20–17 Kya (thousands of years before present) in the western Ross Sea area (Stuiver et al. 1981; Anderson et al. 1992; Kellogg et al. 1996; Licht et al. 1996), to 14 Kya in Taylor Valley, southern Victoria Land (Hall 1997), and to ≥ 17 and ≥ 14 Kya off East Antarctica and the Antarctic Peninsula, respectively (Banfield & Anderson 1995; Harris et al. in press). Most authors assume that LGM roughly coincides with the lowest global sea level stand at 20–18 Kya.

In order to make a fair estimate of the Antarctic contribution to global sea level rise since LGM, the overall ice volume at LGM needs to be established. However, existing appraisals are controversial. One category of estimates suggests that marginal domes of the Antarctic Ice Sheet were 500–1000 m thicker than at present and that ice extended to the shelf break around most of the continent (Clark & Lingle 1979; Denton 1979; Hughes et al. 1981; Zhang 1992). Hughes et al. (1981) calculated the volume of grounded ice in Antarctica at LGM to have been 37×10^6 km^3, compared to roughly 29×10^6 km^3 today, and suggested that the difference of 8×10^6 km^3 equalled about 24 m of global sea

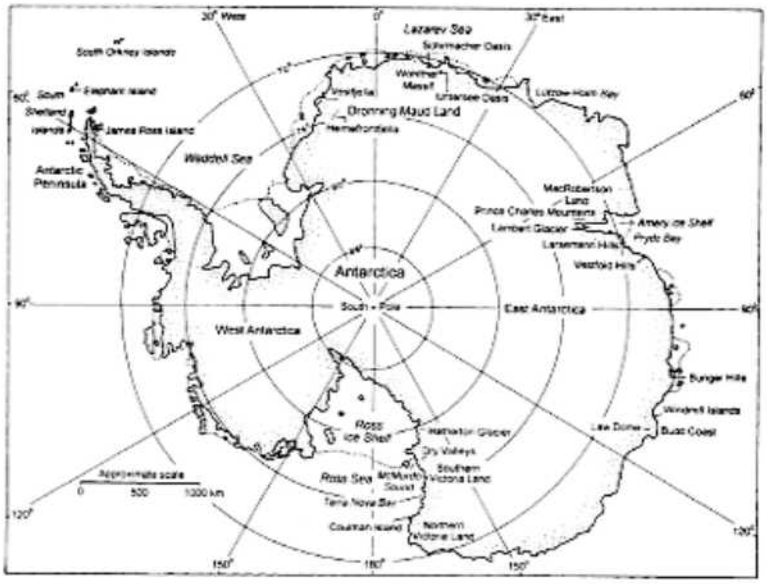

Fig. 1. Map of Antarctica.

level lowering at LGM. Their reconstruction was based on the assumptions that the East Antarctic Ice Sheet's peripheral domes thickened considerably and expanded towards the shelf break, and that the West Antarctic Ice Sheet was considerably expanded relative to its present configuration. Some other estimates advocate a considerably smaller ice extent at LGM, maybe only insignificantly larger than today's in some parts of Antarctica (Mayewski 1975; Colhoun & Adamson 1992; Colhoun et al. 1992; Goodwin 1993; Hayashi & Yoshida 1994). A recent review of Antarctic glacial history since the LGM (Ingólfsson, Hjort, Berkman et al. 1998) suggests that while ice extended well offshore around most of Antarctica at LGM, it did not extend all the way to the shelf break off East Antarctica and in the western Ross Sea, and that some East Antarctic coastal oases were probably ice-free. One interpretation of Antarctic ice-core data suggests that during LGM accumulation rates in interior Antarctica were 50–60% lower than mean Holocene rates (Raisbeck et al. 1987; Jouzel et al. 1989), and that LGM ice thickness in interior East Antarctica was less than during the Holocene (Raynaud & Lebel 1979; Martinerie et al. 1994).

Lacking good estimates of Antarctic ice volumes at LGM, an alternative way to examine the Antarctic contribution to post-LGM sea level rise is to look at the chronology of deglaciation and compare that with the Northern Hemisphere development. If the deglaciation history of Antarctica differs substantially from that in the north, the Antarctic contribution might show up as a water-volume input causing global sea level rise at a time when contribution from Northern Hemisphere ice sheets was unlikely. Thus a minimum estimate of the Antarctic contribution should be possible.

The Northern Hemisphere deglaciation

The Laurentide and Cordilleran ice sheets

The deglaciation of the North American ice sheets mainly took place between 16–8 Kya (Dyke & Prest 1987a; Fulton 1989; Lundqvist & Saarnisto 1995). The Cordilleran Ice Sheet retreated rapidly after 15 Kya, and disappeared between 10–8 Kya (Dawson 1992; Lundqvist & Saarnisto 1995). According to Dyke & Prest (1987a, b), the Laurentide Ice Sheet began retreating between 17–14 Kya. Between 13–11 Kya ice retreat and thinning accelerated. Huge proglacial lakes, the most important of which was Lake Agassiz, developed, and large volumes of meltwater were discharged into the Gulf of Mexico (Teller 1990). Between 11–10 Kya ice retreat caused the drainage of Lake Agassiz to change, so that its meltwater was discharged into the western North Atlantic. By ca. 8 Kya the Laurentide Ice Sheet disintegrated over Hudson Bay and the last documented major