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Pleistocene variability of Antarctic Ice Sheet extent in the Ross Embayment

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ABSTRACT

Cores acquired by the ANDRILL McMurdo Ice Shelf Project (AND-1B) provide the basis for a new sedimentation model for glacimarine depositional sequences that reflect cyclic glacial–interglacial fluctuations of a marine-based ice sheet in the western Ross Embayment over the past 2.0 Ma. Notwithstanding periodic erosion during advances of the ice sheet, uncertainties inherent to the sedimentological interpretation, and a limited number of chronological datums, it is clear that subglacial to grounding-zone sedimentation was dominant at the AND-1B site during the Late Pleistocene with interglacials being represented only by thin intervals of ice-shelf sediment. Each sequence is characterised by subglacial, massive diamictite that pass upwards into glacimarine diamictites and mudstones. This provides the first direct evidence that the marine-based Antarctic Ice Sheet has oscillated between a grounded and floating state at least 7 times in the Ross Embayment over the last 780ka, implying a Milankovitch orbital influence. An unconformity in AND-1B, that spans most (~200 kyr) of the Mid-Pleistocene Transition is inferred to represent widespread expansion of a marine-based ice sheet in the Ross Embayment at 0.8 Ma. Prior to 1.0 Ma, interglacial periods are characterised by open-water conditions at the drill site with high abundances of volcanoclastic deposits and occasional diatomaceous sediments. These may have responded to precession (~20-kyr) or obliquity (~40-kyr) orbital control. The occurrence of 6.7 m of phonolitic glass reworked from Mt Erebus in interglacial deposits beneath Last Glacial Maximum till requires open ocean or ice shelf conditions in the western Ross Sea around the drill site within the past 250 ka and implies a Ross Ice Shelf similar to or less extensive than today during Marine Isotope Stage 7 or 5.

1. Introduction

The marine $\delta^{18}O$ isotope record provides arguably the most detailed proxy for past global ice volume and changes in oceanic temperature during the Pleistocene (Lisiecki and Raymo, 2005). However, uncertainties in the relative timing and extent of Northern Hemisphere versus Southern Hemisphere ice volume changes during this time, as well as the timing and magnitude of deep-water cooling makes the interpretation of the $\delta^{18}O$ isotope record equivocal (e.g., Shackleton, 2000; Miller et al., 2005). This highlights the need for proximal records of past fluctuations in Antarctic ice sheet extent from the continental margin. The marine sectors of the Antarctic ice sheets in particular are commonly cited as being potentially unstable in response to climate warming (Mercer, 1978; Joughin and Alley, 2011), yet little is known of the past dynamic behaviour and response of the marine-based Antarctic during Pleistocene warm intervals (Vaughan and Arthern, 2007).

The sediment record obtained from the ANDRILL AND-1B drill core (Fig. 1), collected from beneath the McMurdo Ice Shelf, provides an opportunity to correlate a direct record of marine-based ice sheet advance and retreat across the Ross Sea continental shelf directly to far-field geological proxies of associated oceanic and sea level change. Here, we use the AND-1B sediment record to document the processes occurring at the grounding-line in the ancestral Antarctic Ice Sheet in the Ross Embayment, focussing on the record younger than 2.0 Ma. While the ice flowing

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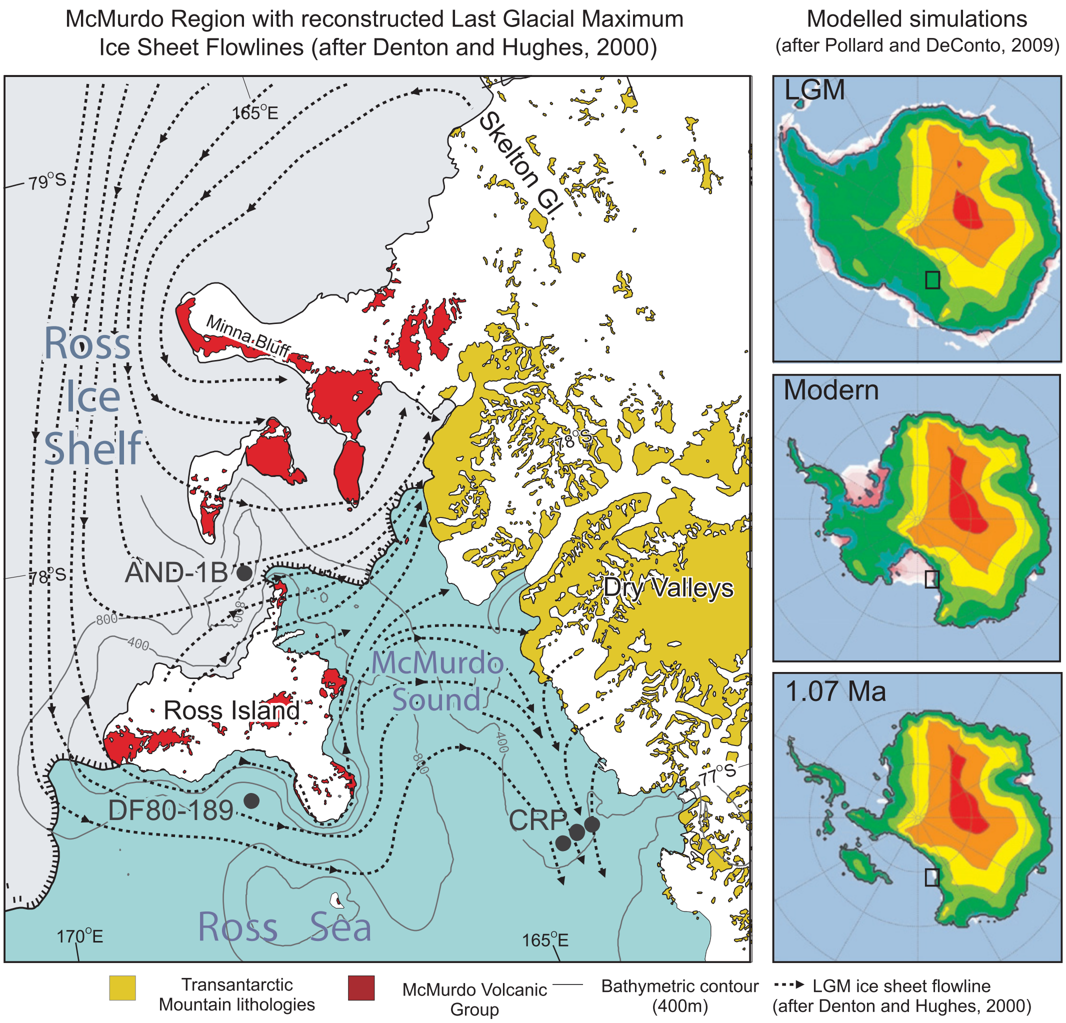

Fig. 1. Left) Map showing locations mentioned in text, the extent of Transantarctic Mountain and McMurdo Volcanic Group bedrock, and reconstruction glacial flowlines (dotted black line) for the grounded Last Glacial Maximum ice sheet in McMurdo Region (after Denton and Hughes, 2000); Right) Modelled reconstructions (after Pollard and DeConto, 2009) of Last Glacial Maximum, modern and Marine Isotope Stage 31 (1.07 Ma) suggest that the presence of grounded ice sheet, floating ice shelf, or open marine conditions at the AND-1B are a good indicator of the general state of the West Antarctic Ice Sheet as a whole. The green to red colour fills represent ice sheet elevations at 500 m contour intervals. McMurdo region is indicated by black box. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

over the AND-1B site during glacial periods originates from East Antarctica, previous studies have shown that the distal source of this East Antarctic ice, its reconstructed geometry and its thickness, grounded ~835 m below modern sea level at the AND-1B drill site in the Ross Embayment, requires a significant contribution of ice from West Antarctica relative to the present-day (Fig. 1; Naish et al., 2009; Pollard and DeConto, 2009).

Last Glacial Maximum retreat reconstructions (Conway et al., 1999; Domack et al., 1999; Ship et al., 1999; Licht et al., 2005; Mosola and Anderson, 2006; McKay et al., 2008), mass balance considerations (Pollard and DeConto, 2009), and the over-deepened/reverse slope nature of the Ross Sea continental shelf since the Late Neogene (Weertman, 1974; De Santis et al., 1995) indicate that the record of grounded ice sheet deposition at the AND-1B drill site is expected to be intimately related to the overall state of past marine-based ice sheets in the Ross Embayment. That is, an ice sheet that is fed by a contribution from both the East and West Antarctic Ice Sheets, but subject to the same marine influences on its mass balance as the wider West Antarctic Ice Sheet while the high-altitude regions of the East Antarctic Ice Sheet remain relatively stable. This is because air temperatures never become warm enough to cause significant surface melting on the East Antarctic Ice Sheet, whereas variations in ocean-induced melt and sea level affect the marine-based West Antarctic Ice Sheet much more than the East Antarctic Ice Sheet.

This implies that once retreat was initiated for past configurations of these marine-based ice sheets, it was likely to have occurred within the deep basins across the Ross Embayment in patterns similar to those hypothesized for the last glacial/interglacial cycle. (e.g. Conway et al., 1999; Denton and Hughes, 2000; Mosola and Anderson, 2006). The presence of open water deposits at the AND-1B drill site indicates the ice shelf calving-line was south of its present position, and therefore, the ice sheet was at least partially reduced in extent, but this is not evidence of complete collapse of the West Antarctic Ice Sheet. Nevertheless, well-dated periods of open water at the AND-1B drill site during the last 5 Ma (Naish et al., 2009) all correspond to times of partially to completely deglaciated West Antarctic Ice Sheet based on model simulations (Pollard and DeConto, 2009). Therefore, in the context of documenting past periods of partial or complete collapse of the West Antarctic Ice Sheet during the Pleistocene, open water conditions at the AND-1B drill site are required. In this paper, we identify such deposits in AND-1B and examine these in the context of the hypothesized collapses of the marine-based sectors of the West Antarctic Ice Sheet, as inferred by far-field sea level records.