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Asynchronous behavior of the Antarctic Ice Sheet and local glaciers during and since Termination 1, Salmon Valley, Antarctica

Margaret S. Jackson*, Brenda L. Hall, George H. Denton

School of Earth and Climate Sciences and The Climate Change Institute, University of Maine, Orono, ME, 04469, United States

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ABSTRACT

The stability of the Antarctic Ice Sheet under future warming remains an open question with broad implications for sea-level prediction and adaptation. In particular, knowledge of whether the ice sheet has the capacity for rapid drawdown or collapse, or whether it can remain stable during periods of warming, is essential for predicting its future behavior. Here we use 55 radiocarbon dates, coupled with geomorphologic mapping, to reconstruct the timing of changes in ice extent and elevation during the last ice-age termination in Salmon Valley, adjacent to McMurdo Sound in the western Ross Sea Embayment. Results indicate that a grounded ice sheet in the Ross Sea Embayment achieved its maximum elevation and extent along the headlands of Salmon Valley at ∼18,000 yr BP, during a period of increasing temperatures and accumulation over the Antarctic continent. This ice remained at or near its maximum on the headlands near the valley mouth until after ∼14,000 yr BP. Removal of grounded Ross Sea ice from Salmon Valley was complete shortly after ∼7900 yr BP, indicating that the grounding line had retreated through southern McMurdo Sound by that time. We suggest the primary driver of Ross Sea ice removal from McMurdo Sound was marine-based, either through basal melting or calving due to sea-level rise. When combined with regional data, the Salmon Valley record suggests that this sector of the Antarctic Ice Sheet did not contribute in a significant way to deglacial meltwater pulses, such as meltwater pulse 1a. In contrast to the Ross Sea ice, our work also shows that local, independent alpine glaciers in Salmon Valley have advanced through the Holocene. Land-terminating glaciers such as these elsewhere in the region show a similar pattern, and may reflect the continued influence of increased accumulation following the termination of the last ice age.

1. Introduction

One of the most pressing questions regarding the Antarctic Ice Sheet (AIS) concerns its future contributions to sea level (IPCC, 2013). Addressing this question is complicated by the fact that the past behavior and stability of the AIS remains an open debate. This is particularly true in regards to the possible AIS contribution to large-scale sea-level change during the last glacial termination, the largest global warming event of the past ∼100,000 years. For example, a number of glacioisostatic adjustment modeling studies of far-field sea-level data point to Antarctica as a likely source for meltwater pulse 1a (mwp1a), a ∼17 m rise in sea level at ∼14,600 yr BP that may have taken place over a span of just 300 yr (Clark et al., 2002; Bassett et al., 2007; Deschamps et al., 2012). Because the size of mwp1a is much greater than can be accounted for by the West Antarctic Ice Sheet (WAIS) alone, if recession of the AIS contributed to this event it would be evidence of unstable behavior of not only the WAIS, but also of the East Antarctic Ice Sheet (EAIS). Whether the AIS contributed to mwp1a remains controversial. Although some marine records from the Scotia Sea have been interpreted as indicating widespread Antarctic ice loss (Weber et al., 2014), glacial geologic records and exposure ages from the Transantarctic Mountains and Marie Byrd Land, as well as radiocarbon evidence from the western Ross Sea region, suggest gradual deglaciation during the Holocene rather than sudden collapse (e.g., Conway et al., 1999; Hall and Denton, 2000; Stone et al., 2003; Todd et al., 2010; Joy et al., 2014; Anderson et al., 2017; Spector et al., 2017).

The behavior of land-terminating alpine glaciers in Antarctica, and whether these glaciers mimic changes in AIS volume over glacial cycles, also is constrained poorly. Along the Victoria Land coast, land-terminating glaciers now appear to be more extensive than during the last glacial period (Stuiver et al., 1981; Nichols, 1968; Denton et al., 1989). However the precise timing of past changes in terrestrial glacier extent are unclear, as is the universality of this pattern among glaciers in the region.

* Corresponding author. Present address: Department of Earth Sciences, Dartmouth College, Hanover, NH, 03755, United States.
E-mail address: margaret.s.jackson.gr@dartmouth.edu (M.S. Jackson).

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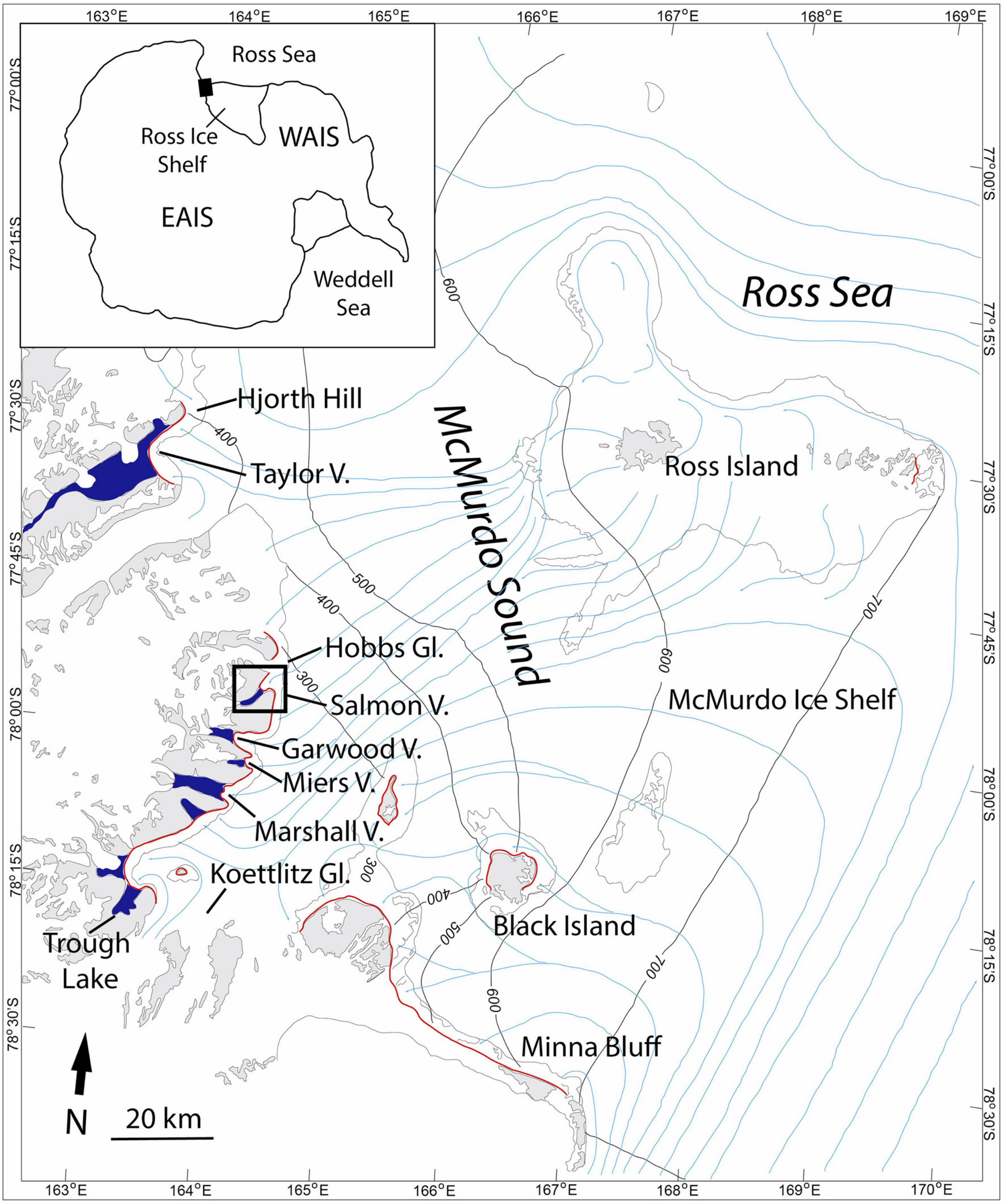

Fig. 1. Inset map of Antarctica. The black box marks the location of McMurdo Sound and the Royal Society Range on the western coast of the Ross Sea. Locations mentioned in the text are labeled. Salmon Valley is boxed in black (as bounded in Figs. 3 and 4). Red lines show the headland moraine system. Dark blue delineates ice-dammed lakes. Ice surface elevations are in meters. Reconstructed flow lines are in light blue. Modified from Denton and Marchant (2000) and Hall et al. (2015). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

Insight into future ice-sheet and alpine-glacier behavior can come from glacial-geologic data that constrain the spatial extent and timing of past changes in ice-sheet size during times of climate change. Here we present new information that bears on the behavior of the AIS during the last termination, including during the interval of mwp1a, from a chronology of changing ice elevation and extent in Salmon Valley on the western coast of McMurdo Sound, adjacent to the western Ross Sea (Fig. 1). These data suggest that grounded ice in the western Ross Sea achieved its maximum elevation early during the last termination and maintained this maximum in the McMurdo Sound region until ~14,000 yr BP. We also constrain past ice elevation and the timing of ice recession in the valley using lacustrine deltas deposited in proglacial lakes. These data indicate that the removal of grounded ice from McMurdo Sound occurred by ~7900 yr BP. In addition, in contrast to former grounded Ross Sea ice, land-terminating alpine glaciers in Salmon Valley have advanced during Holocene time.

1.1. Background and location

1.1.1. McMurdo Sound/Royal Society Range

During the last glacial maximum (LGM), grounded ice fed by both the EAIS and WAIS, as well as by surface accumulation, filled the Ross Sea (Hall et al., 2013; Anderson et al., 2014). A lobe