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Late Pleistocene evolution of Scott Glacier, southern Transantarctic Mountains: implications for the Antarctic contribution to deglacial sea level

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ABSTRACT

Glacial deposits preserved adjacent to Scott Glacier, southern Transantarctic Mountains, provide a record of past fluctuations in the thickness of the West Antarctic Ice Sheet. Geologic mapping of these deposits, in conjunction with emerging ^{10}Be surface-exposure data, indicate that the most recent expansion of Scott Glacier occurred during the last glacial maximum in response to grounding of ice in the Ross Sea Embayment. At that time, the ice surface at the confluence of Scott Glacier and the West Antarctic Ice Sheet lay at ~1100 m elevation. While this ice-surface reconstruction is in accord with other geologic estimates from throughout the Ross Sea Embayment, it contrasts with most computer-based simulations, which tend to overestimate former ice thickness in the southern Ross Sea. Together with recently modelled estimates of Antarctica's contribution to sea level, this finding calls into question an Antarctic source for meltwater pulse 1A.

1. Introduction

Most of the change in Antarctic ice volume since the last glacial maximum (LGM) occurred in West Antarctica, where grounded ice filled what are now marine embayments (e.g. Bentley and Anderson, 1998; Denton and Hughes, 2000, 2002; Anderson and Shipp, 2001). In the Ross Sea Embayment (RSE) (Fig. 1), for instance, the distribution of glacial landforms on the seafloor – including flutings, drumlins, till sheets, and the continuation of modern ice stream troughs – indicates that the ice sheet advanced as far as the outer continental shelf (Shipp *et al.*, 1999; Anderson *et al.*, 2002). This scenario is supported by geologic evidence from the Transantarctic Mountains (TAM), where outlet glaciers of the East Antarctic Ice Sheet (EAIS) thickened in response to grounded ice in the Ross Sea (Mercer, 1968; Bockheim *et al.*, 1989; Denton *et al.*, 1989; Orombelli *et al.*, 1990; Bromley *et al.*, 2010), and from the McMurdo Sound region, where grounded Ross Sea ice dammed large proglacial lakes in the Dry Valleys (Hall *et al.*, 2000). Though less well-documented, similar advances of the grounding line likely occurred in the Weddell, Amundsen, and Bellingshausen Seas and the Amery Basin (Elverhøi, 1981; Denton *et al.*, 1992; Bentley and Anderson, 1998; Lowe and Anderson, 2002; Johnson *et al.*, 2008; White *et al.*, 2011).

Although the lateral extent of the WAIS at the LGM is relatively well defined, uncertainty remains over the former thickness of the ice sheet. Glacial-geologic evidence from the southern TAM suggests the ice sheet attained surface elevations of ≥1100 m at Reedy Glacier (Bromley *et al.*, 2010), ~1250 m (Denton *et al.*, 1989) or 1150 m (our observation: see footnote[1]) at Beardmore Glacier, and 1100 m at Hatherton Glacier (Bockheim *et al.*, 1989). Farther north, the LGM ice surface was ~710 m on eastern Ross Island (Denton and Marchant, 2000), ~640 m on Minna Bluff (Denton and Marchant, 2000), 350 m at Hjorth Hill (Hall and Denton, 2000), and ~400 m at Terra Nova Bay (Orombelli *et al.*, 1990). Adjacent to the eastern RSE, Stone *et al.* (2003) reported geologic evidence from the Ford Range, Marie Byrd Land, suggesting the former ice-sheet surface there exceeded 1165 m elevation. Despite the consistency within the geologic dataset, these estimates differ from modelled reconstructions of the ice sheet, most of which infer thicker ice in the Ross Sea at the LGM. For example, the reconstructions of Denton and Hughes (2000, 2002), based on earlier glacial geologic data, call for ice-surface elevations of approximately 1600 m in the southern Ross Sea, whereas that of

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[1] During a 2010 visit to Mt. Kyffin, Beardmore Glacier, we interpreted a drift edge on the peak's northern flank as the LGM ice limit. Below the limit, white granite boulders are relatively unweathered, whereas above the limit boulders of the same lithology exhibit pronounced exfoliation and minor cavernous weathering. The drift edge lies at ~1150 m, approximately 100 m below an older yet more conspicuous drift limit.

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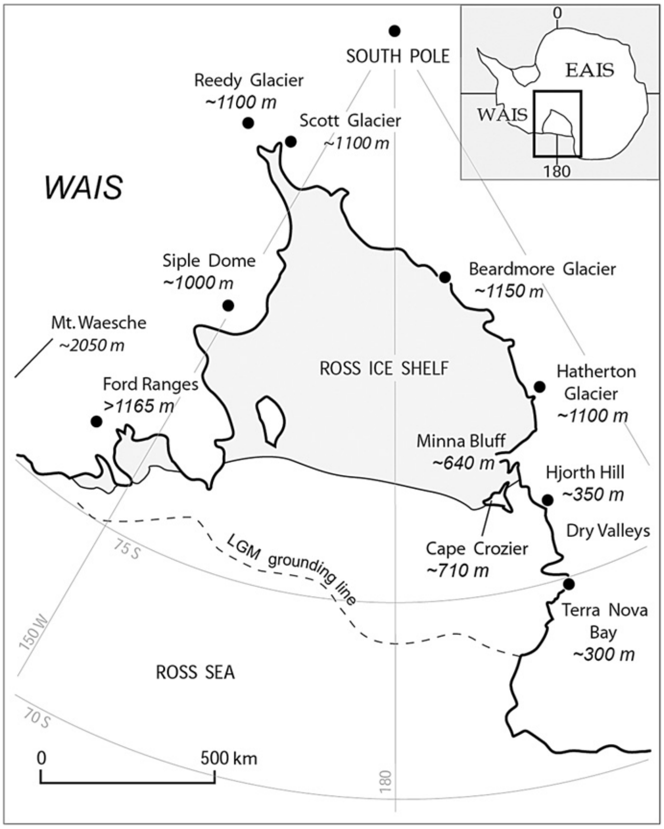

Fig. 1. Map of the Ross Sea Embayent, showing locations of sites mentioned in the text. The approximate LGM position of the WAIS grounding line is marked by the dashed line. Former ice-surface elevation data are shown for each site.

Huybrechts (2002) prescribes even thicker ice (>2000 m surface elevation) along the southern TAM front. In contrast, estimates from Siple Dome (Fig. 1) are more in keeping with the new geologic evidence, suggesting relatively low surface elevations (~1000 m) close to the centre of the former ice sheet (Waddington *et al.*, 2005; Price *et al.*, 2007).

Deglaciation of the RSE following the LGM is resolved broadly on the basis of marine (Licht *et al.*, 1996; Domack *et al.*, 1999; Licht and Andrews, 2002; and references therein) and terrestrial radiocarbon data (Bockheim *et al.*, 1989; Hall and Denton, 1999, 2000; Baroni and Hall, 2004), radar-based model data from Roosevelt Island (Conway *et al.*, 1999), and surface-exposure ages from Reedy Glacier (Todd *et al.*, 2010). These data indicate that (i) recession in the RSE occurred mainly during the Holocene and (ii) that grounding-line retreat may have slowed/stopped in recent millennia. In the north-east RSE, a comprehensive set of ^{10}Be surface-exposure ages from the Ford Range indicates that post-LGM deglaciation in Marie Byrd Land was underway by at least 10 ka, with little change since 2–3 ka (Stone *et al.*, 2003). A similar situation was reported by Todd *et al.* (2005) and Bentley *et al.* (2010) from the Marble Hills, eastern Ellsworth Mountains, and by Johnson *et al.* (2008) from the Pine Island Glacier region, where cosmogenic surface-exposure ages suggest a gradual and continued thinning of the WAIS until the Late Holocene.

The former volume and deglacial history of the WAIS both are critical for understanding Antarctica's contribution to global sea-level change during and since the LGM. This is particularly the case for hypotheses addressing the origins of deglacial events, such as meltwater pulse 1A (MWP-1A) (Fairbanks, 1989). Although it has been argued that this apparent ~20 m jump in sea level at 14.6 ka was caused by melting of northern-hemisphere ice sheets (Peltier, 1994; Flower *et al.*, 2004), in particular the Laurentide Ice Sheet, modelling of post-glacial sea-level change suggests Antarctica as an alternative source (Clark *et al.*, 1996, 2002, 2009; Weaver *et al.*, 2003; Carlson, 2009). If true, corroborating evidence should be found in the glacial-geologic record from Antarctica, particularly in reconstructions of former ice-sheet volume and the timing of deglaciation. To begin to address this issue, we present a reconstruction of former ice-sheet thickness in the southern RSE based on a glacial-geologic record from Scott Glacier.

Scott Glacier (Fig. 1) is an outlet of the EAIS located in the southern TAM. Today, the glacier drains into the Ross Ice Shelf (Fig. 2). However, during the LGM and most of the subsequent deglaciation, Scott Glacier formed a tributary of the expanded ice sheet in the RSE. We used the glacial-geologic record from Scott Glacier to reconstruct the former surface elevation of this ice sheet at the LGM. Scott Glacier is ideal for this study for two reasons. First, the glacier is located in the far southern RSE and thus affords a close measure of LGM ice thickness from the heart of the former ice sheet. Second, glacial deposits are well preserved in the mountains alongside Scott Glacier, allowing for accurate reconstruction of the LGM ice-surface profile. These deposits form the basis of a cosmogenic ^{10}Be chronology, which is the focus of a separate paper (Stone

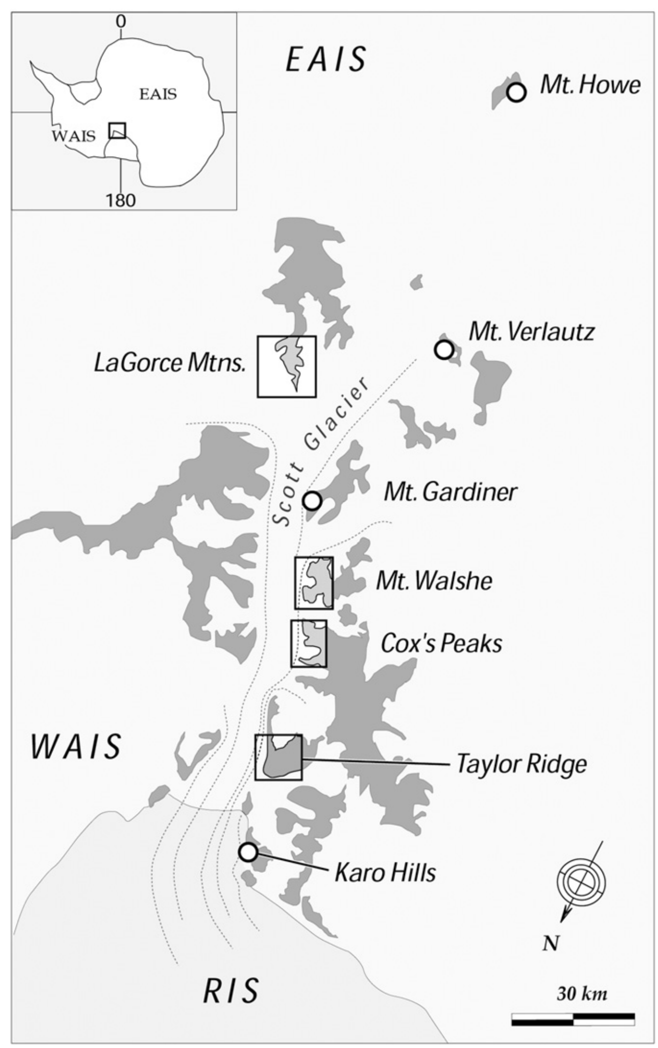

Fig. 2. Locations of study sites along Scott Glacier and positions of the modern grounding line and Ross Ice Shelf (light grey shading).