Quaternary Science Reviews 158 (2017) 58–76

Contents lists available at ScienceDirect

Quaternary Science Reviews

journal homepage: www.elsevier.com/locate/quascirev

Deglacial history of the Pensacola Mountains, Antarctica from glacial geomorphology and cosmogenic nuclide surface exposure dating

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ARTICLE INFO

Article history:
Received 22 April 2016
Received in revised form
20 September 2016
Accepted 27 September 2016

Keywords:
Antarctica
Cosmogenic isotopes
Glacial geomorphology
Ice sheet history

ABSTRACT

The retreat history of the Antarctic Ice Sheet is important for understanding rapid deglaciation, as well as to constrain numerical ice sheet models and ice loading models required for glacial isostatic adjustment modelling. There is particular debate about the extent of grounded ice in the Weddell Sea embayment at the Last Glacial Maximum, and its subsequent deglacial history. Here we provide a new dataset of geomorphological observations and cosmogenic nuclide surface exposure ages of erratic samples that constrain the deglacial history of the Pensacola Mountains, adjacent to the present day Foundation Ice Stream and Academy Glacier in the southern Weddell Sea embayment. We show there is evidence of at least two glaciations, the first of which was relatively old and warm-based, and a more recent cold-based glaciation. During the most recent glaciation ice thickened by at least 450 m in the Williams Hills and at least 380 m on Mt Bragg. Progressive thinning from these sites was well underway by 10 ka BP and ice reached present levels by 2.5 ka BP, and is broadly similar to the relatively modest thinning histories in the southern Ellsworth Mountains. The thinning history is consistent with, but does not mandate, a Late Holocene retreat of the grounding line to a smaller-than-present configuration, as has been recently hypothesized based on ice sheet and glacial isostatic modelling. The data also show that clasts with complex exposure histories are pervasive and that clast recycling is highly site-dependent. These new data provide constraints on a reconstruction of the retreat history of the formerly-expanded Foundation Ice Stream, derived using a numerical flowband model.

1. Background and rationale

The Antarctic Ice Sheet is the largest potential contributor to future sea-level rise. It is currently losing mass (King et al., 2012; Shepherd et al., 2012) and some studies suggest that the rate of mass loss is accelerating (Harig and Simons, 2015; Velicogna et al., 2014; Williams et al., 2014). Understanding the past history of the ice sheet is important because: it can inform how the ice sheet has responded to past environmental changes, and record its trajectory preceding the observational record; it allows us to test ice sheet models by hindcasting; and it provides us with inputs for models of glacial isostatic adjustment (GIA), which are needed to interpret satellite gravimetric measurements of ice mass loss (Bentley, 2010).

The Weddell Sea sector of the ice sheet has not seen the same level of attention as other areas such as the Amundsen Sea and Ross Sea. This is despite some studies suggesting that the area is particularly susceptible to ice shelf thinning (Hellmer et al., 2012) and grounding line retreat (Ross et al., 2012; Wright et al., 2014). Part of this sensitivity derives from the fact that the southern part of the area is overdeepened, particularly in the east, where several subglacial basins are comparable in depth to other deep but grounded parts of the West Antarctic Ice Sheet, for example, along the Amundsen Sea coast. The largest trough in the Weddell Sea, the Foundation-Thiel Trough, is 1300–1500 m deep and extends north-south for >1000 km, right across the Weddell Sea continental shelf to the shelf break (Fig. 1). Its position, size and extent mean that it was once occupied by a major ice stream (the “Thiel Trough Ice Stream”) draining ice through an area east of Berkner Island. This ice stream is likely to have exerted a key control on regional ice elevation.

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http://dx.doi.org/10.1016/j.quascirev.2016.09.028

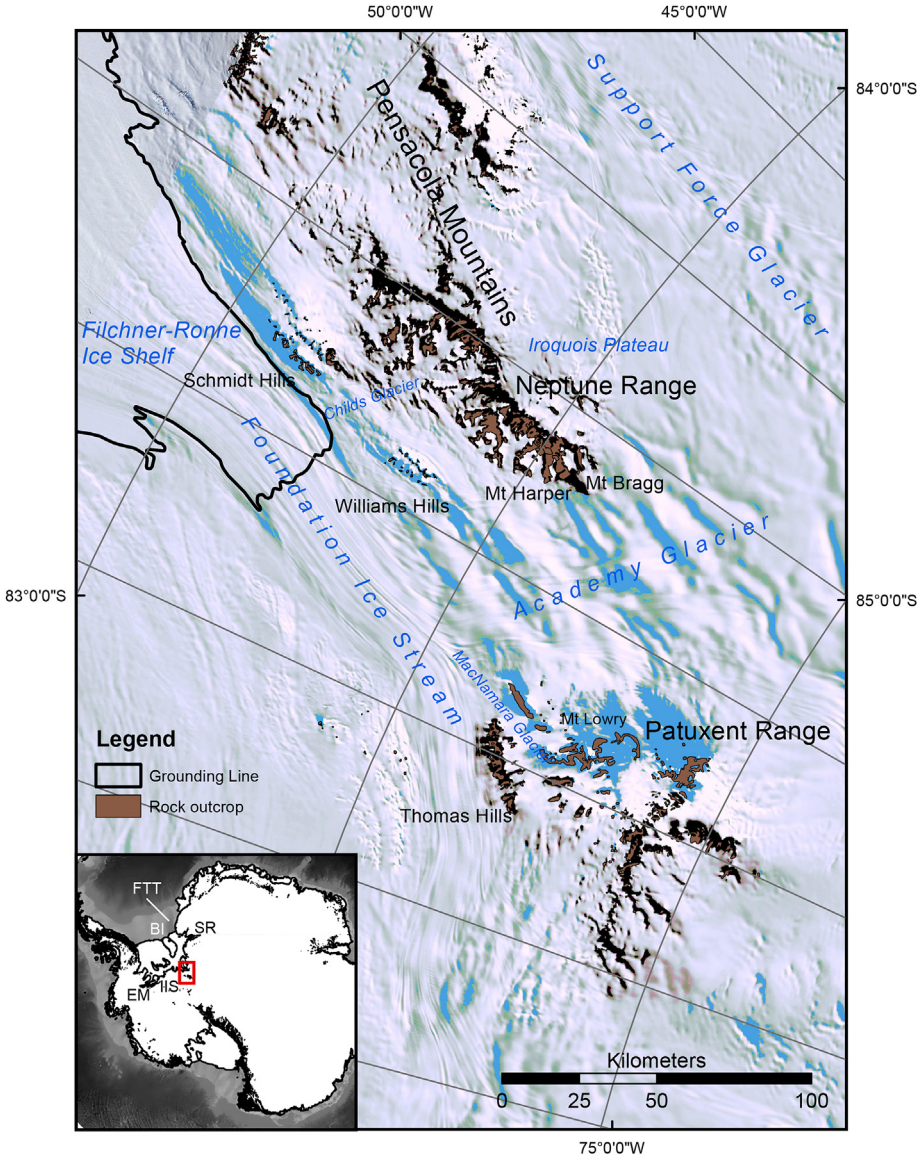

Fig. 1. Location Map of the Pensacola Mountains study area, adjacent to the Foundation Ice Stream and its tributary the Academy Glacier. Background is Landsat imagery from the LIMA mosaic. Rock outcrop and grounding line are from Antarctic Digital Database. Bathymetry is from BEDMAP2 (Fretwell et al., 2013). Inset shows location within the southern Weddell Sea embayment. BI=Berkner Island; EM = Ellsworth Mountains; FTT=Foundation-Thiel Trough; IIS=Institute Ice Stream; SR=Shackleton Range.

At present there are two alternative models for the Last Glacial Maximum (LGM) extent of ice in the Weddell Sea embayment (Bentley et al., 2014; Hillenbrand et al., 2014). The first, based largely on marine geological evidence is an extensive model with ice grounded over the outer continental shelf (Hillenbrand et al., 2012; Larter et al., 2012). The implication of this model is that the Thiel Trough Ice Stream would be grounded as far as the shelf break. The second, based largely on terrestrial evidence of minor elevational change of the ice sheet at the LGM (Bentley et al., 2010; Hein et al., 2011; Mulvaney et al., 2007) is a restricted model with the grounding line of the Thiel Trough Ice Stream confined to the mid- to inner-shelf (Bentley et al., 2010; Hillenbrand et al., 2014; Le Brocq et al., 2011; Whitehouse et al., 2012).

In addition to the debate on ice sheet extent, the timing of post-glacial thinning in the Weddell Sea is not yet well understood. This hampers the development of ice loading models for GIA modelling, and the understanding of recent (Late Holocene) change in the region. For example, although most studies have assumed a simple retreat from LGM to present, a recent study has demonstrated that a Late Holocene re-advance of the ice sheet may explain some formerly puzzling observations from GPS and glaciological surveys (Bradley et al., 2015). Such a readvance has important implications for our understanding of ice sheet stability, in that it implies that some grounding lines on inward dipping bedrock beds may be advancing (Bradley et al., 2015). Such 'unstable advance' has been suggested on theoretical grounds (Schoof, 2007). We require further observational data on ice sheet retreat timing to test the validity of such ideas.

Our aim in this paper is to determine former ice sheet extent and elevation change adjacent to the southern extension of the Thiel Trough Ice Stream (Fig. 1). The glacial geology of this area contains a record of ice thickness change that can yield information on the extent of ice along the Foundation-Thiel Trough, and the timing of its thinning from the local last glacial maximum (LLGM) (Clark et al., 2009) to its present configuration. This paper describes the geomorphological evidence of former thicker ice levels in the