Quaternary Science Reviews 32 (2012) 25–47

Contents lists available at SciVerse ScienceDirect

Quaternary Science Reviews

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

Marine geological constraints for the grounding-line position of the Antarctic Ice Sheet on the southern Weddell Sea shelf at the Last Glacial Maximum

Claus-Dieter Hillenbrand [a,*], Martin Melles [b], Gerhard Kuhn [c], Robert D. Larter [a]

[a] British Antarctic Survey, High Cross, Madingley Road, Cambridge CB3 0ET, United Kingdom
[b] Institute of Geology and Mineralogy, University of Cologne, Zülpicher Strasse 49a, D-50674 Cologne, Germany
[c] Alfred Wegener Institute for Polar and Marine Research, Am Alten Hafen 26, D-27568 Bremerhaven, Germany

ARTICLE INFO

Article history:
Received 11 July 2011
Received in revised form
14 November 2011
Accepted 17 November 2011
Available online 21 December 2011

Keywords:
Antarctica
Ice sheet
Ice shelf
LGM
Sea level
Weddell Sea

ABSTRACT

The history of grounded ice-sheet extent on the southern Weddell Sea shelf during the Last Glacial Maximum (LGM) and the timing of post-LGM ice-sheet retreat are poorly constrained. Several glaciological models reconstructed widespread grounding and major thickening of the Antarctic Ice Sheet in the Weddell Sea sector at the LGM. In contrast, recently published onshore data and modelling results concluded only very limited LGM-thickening of glaciers and ice streams feeding into the modern Filchner and Ronne ice shelves. These studies concluded that during the LGM ice shelves rather than grounded ice covered the Filchner and Ronne troughs, two deep palaeo-ice stream troughs eroded into the southern Weddell Sea shelf.

Here we review previously published and unpublished marine geophysical and geological data from the southern Weddell Sea shelf. The stratigraphy and geometry of reflectors in acoustic sub-bottom profiles are similar to those from other West Antarctic palaeo-ice stream troughs, where grounded ice had advanced to the shelf break at the LGM. Numerous cores from the southern Weddell Sea shelf recovered sequences with properties typical for subglacially deposited tills or subglacially compacted sediments. These data sets give evidence that grounded ice had advanced across the shelf during the past, thereby grounding in even the deepest parts of the Filchner and Ronne troughs. Radiocarbon dates from glaciomarine sediments overlying the subglacial deposits are limited, but indicate that the ice grounding occurred at the LGM and that ice retreat started before ~15.1 corrected ^{14}C kyrs before present (BP) on the outer shelf and before ~7.7 corrected ^{14}C kyrs BP on the inner shelf, which is broadly synchronous with ice retreat in other Antarctic sectors.

The apparent mismatch between the ice-sheet reconstructions from marine and terrestrial data can be attributed to ice streams with very low surface profiles (similar to those of "ice plains") that had advanced through Filchner Trough and Ronne Trough at the LGM. Considering the global sea-level low-stand of ~130 m below present, a low surface slope of the expanded LGM-ice sheet in the southern Weddell Sea can reconcile grounding-line advance to the shelf break with limited thickening of glaciers and ice streams in the hinterland. This scenario implies that ice-sheet growth in the Weddell Sea sector during the LGM and ice-sheet drawdown throughout the last deglaciation could only have made minor contributions to the major global sea-level fluctuations during these times.

1. Introduction

Information about the contributions of Antarctic Ice Sheet (AIS) build-up in the Weddell Sea sector to the global sea-level low-stand of ca 130 m at the Last Glacial Maximum (LGM) from ca 23–19 ka before present (BP) (e.g. Ritz et al., 2001; Huybrechts, 2002; Saito and Abe-Ouchi, 2010; Le Brocq et al., 2011) and AIS drawdown to global meltwater pulses during the last deglaciation (e.g. Philippon et al., 2006; Bassett et al., 2007; Bentley et al., 2010) will give important clues about AIS dynamics and AIS contribution to future sea-level rise in response to global warming. Furthermore, the Weddell Sea region is a major source for deep and bottom water masses that constitute an essential component of the global thermohaline circulation (e.g. Rahmstorf, 2002). Today, ice–ocean interactions under the Filchner and Ronne ice shelves (Fig. 1) and within polynyas on the southern Weddell Sea shelf generate

* Corresponding author. Tel.: +44 (0) 1223 221340; fax: +44 (0) 1223 221646.
E-mail address: hilc@bas.ac.uk (C.-D. Hillenbrand).

0277-3791/$ – see front matter © 2011 Elsevier Ltd. All rights reserved.
doi:10.1016/j.quascirev.2011.11.017

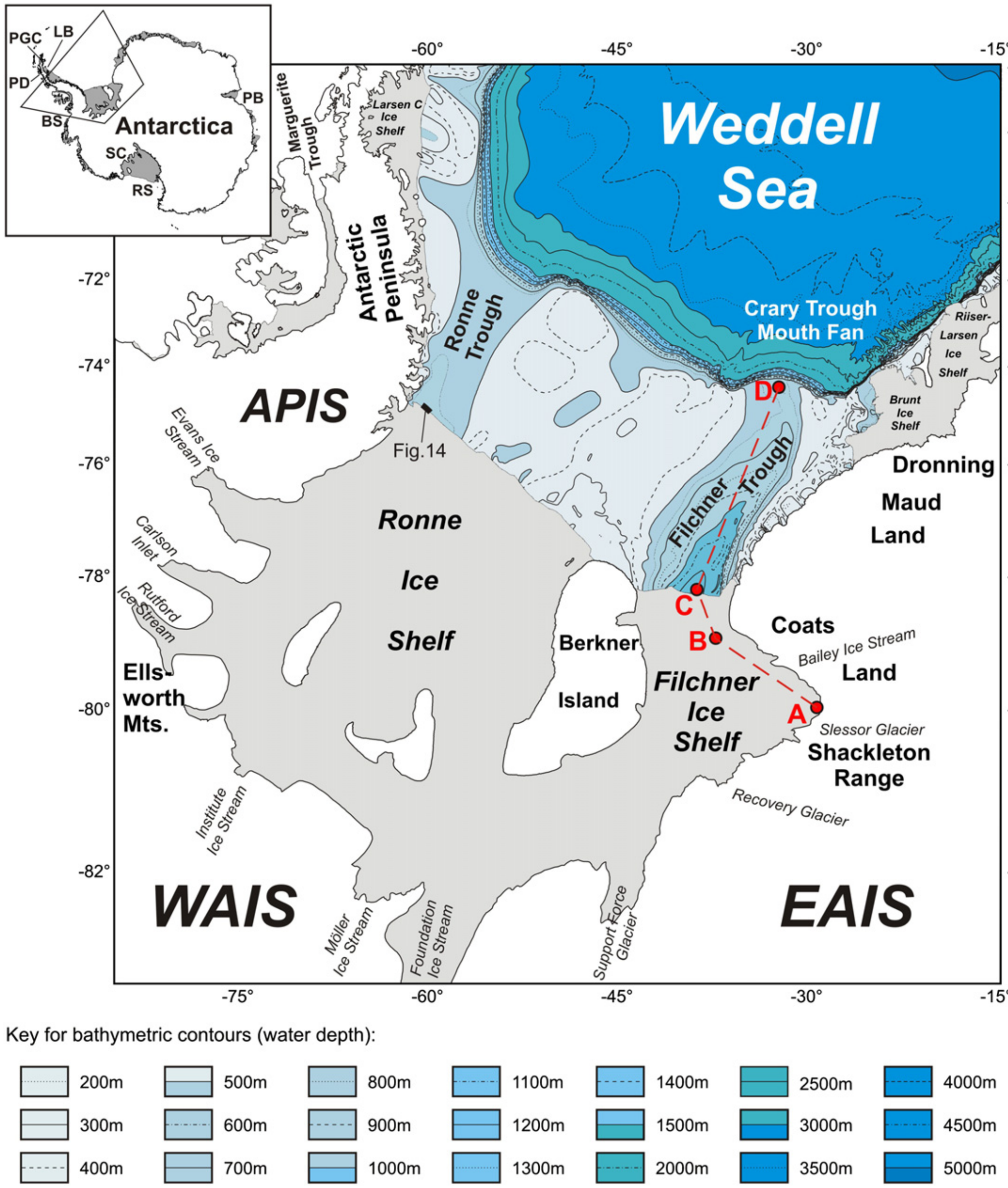

Fig. 1. Overview map of the southern Weddell Sea with bathymetry according to AWI BCWS (1997). APIS: Antarctic Peninsula Ice Sheet, EAIS: East Antarctic Ice Sheet, WAIS: West Antarctic Ice Sheet. Bold black line in inner Ronne Trough shows location of 3.5 kHz acoustic sub-bottom profile presented in Fig. 14. Red dashed line indicates assumed ice-flow trajectory at the LGM (Section 6.3), with the red dots and letters marking the locations referred to in Table 4. Inset map shows location of main map, Siple Coast (SC), Prydz Bay (PB), Palmer Deep (PD), Ross Sea (RS), Bellingshausen Sea (BS), Prince Gustav Channel (PGC) and the Larsen B region (LB) on the eastern Antarctic Peninsula shelf. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

precursor water masses that contribute ca 50–70% to the total formation of Antarctic Bottom Water (AABW) (Naveira Garabato et al., 2002; Nicholls et al., 2009). Modes of AABW formation and flow at the LGM, however, are poorly understood (e.g. Mackensen et al., 1996; Diekmann et al., 2003; Mackensen, 2004; Smith et al., 2010, and references therein). The various scenarios can be verified by information about the LGM position of the AIS grounding line on the southern Weddell Sea shelf, where the most important precursor water masses for AABW are formed today. Knowledge of whether this shelf was a possible source region for AABW at the LGM may help us to understand the role of alternative AABW production mechanisms, such as brine formation in polynyas above the continental slope, directly offshore from the shelf edge (e.g. Weber et al., 1994; Mackensen et al., 1996; Smith et al., 2010).

There is a consensus from terrestrial and marine geological data as well as ice-sheet models that the grounded AIS advanced across the shallower parts of the southern Weddell Sea shelf at the LGM (Bentley and Anderson, 1998; Ritz et al., 2001; Anderson et al., 2002; Denton and Hughes, 2002; Huybrechts, 2002; Bentley et al., 2010; Saito and Abe-Ouchi, 2010). However, the LGM grounding-line position in two palaeo-ice stream troughs on the southern Weddell Sea shelf, the Filchner Trough and the Ronne Trough (Fig. 1), is unclear (Le Brocq et al., 2011). Two questions regarding the configuration of the AIS in the southern Weddell Sea at the LGM are widely debated (see Bentley and Anderson, 1998; Ritz et al., 2001; Anderson et al., 2002; Denton and Hughes, 2002; Huybrechts, 2002; Bentley et al., 2010; Saito and Abe-Ouchi, 2010; Hein et al., 2011; Le Brocq et al., 2011): 1) Was the AIS thick enough to ground in the deepest parts of the Filchner and Ronne troughs?