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Invited research article

On the influence of post-LGM ice shelf loss and grounding zone sedimentation on West Antarctic ice sheet stability

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ABSTRACT

The Whales Deep Basin in eastern Ross Sea was occupied by the paleo-Bindschadler Ice Stream during the Last Glacial Maximum (LGM). Previous studies showed that megascale glacial lineations (MSGLs) extend to the continental shelf edge. In a landward direction, these lineations are buried by an overlapping stack of backstepped grounding zone wedges (GZWs). The constraints require that the West Antarctic Ice Sheet (WAIS) grounded at least seven times within 60 km of the shelf edge but the morphological relationships in the Whales Deep Basin cannot be used to uniquely reveal the magnitudes of either grounding line and/or calving front retreat and re-advance between the successive groundings. Here we show a new regional transect of cores from the basin which demonstrates that there were no major back and forth oscillations of either the grounding line or calving front during the overall retreat of grounded and floating ice. Instead, the new sedimentologic data show that a small ice shelf formed as the grounding line retreated from the shelf edge and backstepped over the outer continental shelf. An event bed records breakup of the ice shelf that covered the outer shelf. The stratal relationships indicate that the ice-shelf collapse occurred during the fourth grounding and that the grounding line remained on the outer continental shelf for three additional groundings. We infer that accelerated ice stream flow (due to loss of buttressing) increased sediment flux to the grounding line and thinned the WAIS at the grounding line. Following the seventh grounding, thinning contributed to an abrupt 200 km retreat of the grounding line to the middle continental shelf and a large ice shelf re-formed over the middle continental shelf. A series of small-scale moraine ridges formed as the grounding line shifted south towards Roosevelt Island. The facies relationships on the middle continental shelf indicate that the calving front then shifted abruptly to its modern position. The ground-truth of the seafloor geomorphology presented here is important because it is a necessary framework for constraining retreat chronology for a central part of the WAIS that was not influenced by East Antarctic Ice Sheet overflow.

1. Introduction

During the last glacial maximum (LGM), the Antarctic Ice Sheets were significantly larger with grounded ice on the outer continental shelves (e.g., Bentley et al., 2014). The Ross Sea Embayment received grounded-ice drainage from large areas of both the East- and West Antarctic Ice Sheets (Fig. 1a) (e.g., Denton and Hughes, 2002). The large-scale trough-bank topography of Ross Sea includes six basins (Fig. 1b) that were eroded by fast flowing ice streams (e.g., Hughes, 1973). The available bathymetric data from below the Ross Ice Shelf (Bentley and Jezek, 1981) suggests that the paleo glacial-trough basins of the outer and middle continental shelf extend to the mouths of modern-day ice streams (Rignot et al., 2008).

Integration of sedimentological, geomorphological and micropaleontological data has proven very useful for characterizing the post-LGM retreat of the WAIS from the Ross Embayment (e.g., Shipp et al., 1999; Domack et al., 1999; Licht et al., 1999; Conway et al., 1999; McKay et al., 2008; Mosola and Anderson, 2006; Greenwood et al., 2012; Bart and Owolana, 2012; Bart and Cone, 2012; Anderson et al., 2014; Halberstadt et al., 2016). These studies indicate a step-wise retreat of grounded and floating ice. Evidence for pauses in grounding line retreat comes from trough-confined GZWs. The GZWs represent subaqueous depositional features formed at the marine terminus of ice streams when the grounding line was sufficiently stationary for a significant volume of sediments to accumulate (e.g., Alley et al., 1989; Dowdeswell et al., 2008).

A previous study of central and eastern Ross Sea provided strong evidence that the number and location of GZWs varied within the individual troughs (Mosola and Anderson, 2006). Two recent studies (Bart et al., 2017a, in review) presented a revised reconstruction of

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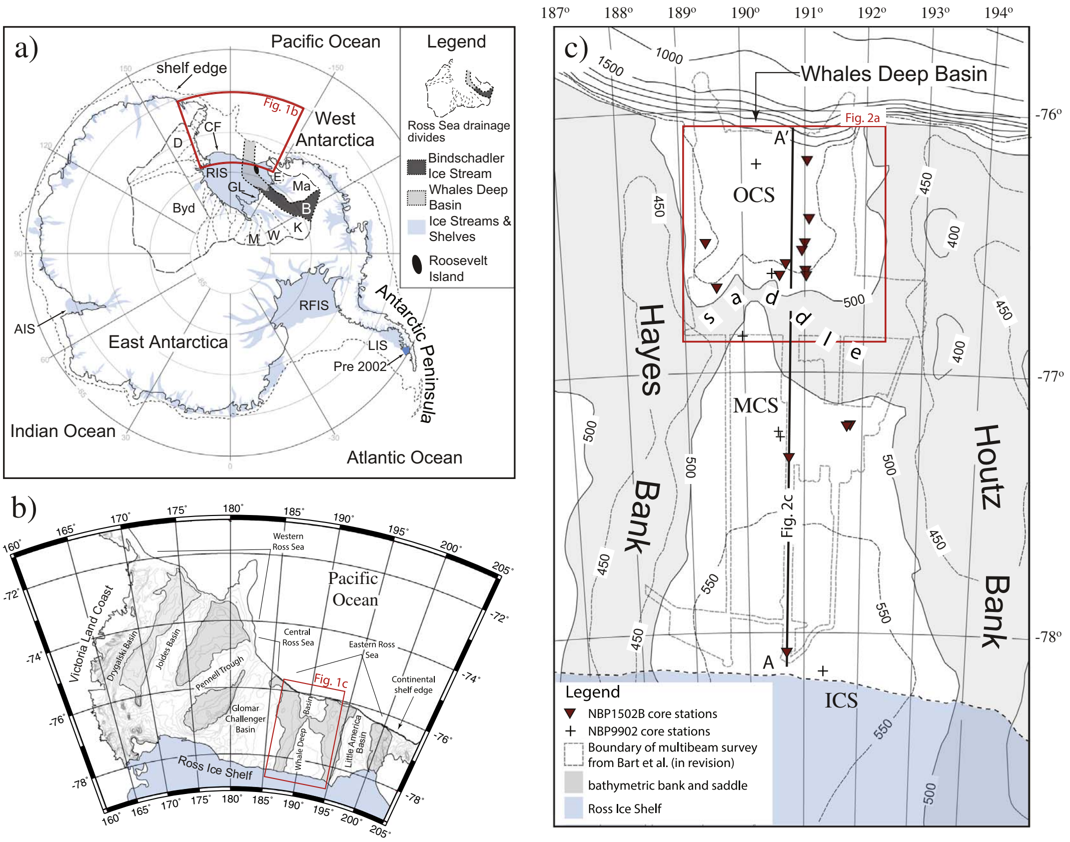

Fig. 1. a) Map of Antarctica showing ice streams and ice shelves in blue. The heavy and light dashed lines show the Ross Sea drainage and sub-drainage area divides (respectively) for grounded ice flowing from East and West Antarctica. D, Byd, M, W, K, B, Ma and E are David, Byrd, M, Whillans, Kamb, Bindschadler and Echmelyer ice streams. RIS = Ross Ice Shelf. CF = calving front. RFIS = Ronne Filchner Ice Shelf. LIS = Larsen Ice Shelf. The dark grey shade shows the modern limit of the Bindschadler Ice Stream and the light grey shade shows the LGM limit of the paleo Bindschadler Ice Stream. The red box shows the location of the image shown in Fig. 1b. b) Ross Sea bathymetry from Davey and Nitsche (2005) showing the location of named trough basins. The banks are shown in grey. The contour interval is 50 m. The red box shows the location of the image shown in Fig. 1c. c) Bathymetry map of the Whales Deep Basin. The banks are shown in grey. Paleo-ice-stream-trough; eastern Ross Sea, Antarctica. *NBP1502B* multibeam survey outlined in grey. The bold red line marks the location of the north-south seismic profile shown in Figs. 2d and 11b. The grey line polygon from the center of the trough shows the outline of the multibeam swath bathymetry used by Bart et al. (in revision) to map GZWs from seafloor geomorphology. Inverted red triangles are core locations referenced in the text from expedition *NBP1502B*. Crosses are core locations from *NBP9902* used by Mosola and Anderson (2006). The red box shows the location of the image shown in Fig. 2a. OCS = Outer continental shelf. MCS = Middle Continental Shelf. ICS = Inner Continental Shelf.

WAIS retreat for the Whales Deep Basin in eastern Ross Sea, which was formerly occupied by the paleo-Bindschadler Ice Stream. Their study was based on a significantly larger-area multibeam swath bathymetry survey and its correlation to additional seismic reflection data (Figs. 1 and 2). The correlations showed that the WAIS retreat in the Whales Deep Basin was significantly more complex than was possible to reconstruct with the previously available data (Mosola and Anderson, 2006). In particular, the additional geophysical data showed that the WAIS occupied at least seven grounding line positions as it vacated the Whales Deep Basin (Fig. 2a) (Bart et al., in revision). The reconstructed grounding line positions correspond to the topset-foreset boundary of stacked GZWs 1 through 7 from oldest to youngest on the outer continental shelf (Figs. 2c). The seven GZWs are arranged in an overlapping stacking pattern, which defines a compound GZW (CGZW). The CGZW is manifest as a large bathymetric saddle across the Whales Deep Basin located ~60 km south of the continental shelf edge (Figs. 1c, 2a,c).

The geomorphologic and subsurface evidence shown in Fig. 2a,b provide unambiguous evidence as to the former locations of grounding line positions, but these data cannot be used to directly determine the pattern with which grounding line and calving front oscillations occurred between groundings. The CGZW may have formed during a single prolonged interval during which the WAIS grounding line remained relatively stationary on the outer continental shelf. Conversely, the grounding line and calving front may have experienced major retreat followed by re-advance during successive groundings. The latter scenario is suggested by the occurrences of long and deep iceberg furrows that crosscut the topsets of GZW1, GZW2 and GZW3 (Fig. 2b). A key observation evident from the large-area multibeam survey of the outer continental shelf is that the furrows on GZW2 and GZW3 project landward below the deposits of GZW7 (Figs. 2b). By stratigraphic superposition, those furrows had to form by icebergs that drifted across open water sometime after GZW3 but before GZW7.

The two hypotheses outlined above have very different implications as to how WAIS kinematics either contributed or responded to post-LGM eustatic change through time. A detailed understanding of these recent oscillations may provide insight into how future climatic changes might alter the modern-day extent/volume of ice and vice versa. Here we utilize a new core transect from the Whales Deep Basin to investigate how the grounding line and calving front oscillated during its overall retreat from the outer and middle continental shelf.

2. Background

2.1. Whales Deep Basin bathymetry

The Whales Deep Basin in the eastern Ross Sea is located between the Glomar Challenger and Little America Basins. The basin is 250 km long (from the shelf edge to the northern end of the Ross Ice Shelf calving front) and approximately 100 km wide between the crest of the Hayes and Houtz Bank (Fig. 1c). Roosevelt Island, a shallow bank to