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Oceanographic variability on the West Antarctic Peninsula during the Holocene and the influence of upper circumpolar deep water

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ABSTRACT

Recent intensification of wind-driven upwelling of warm upper circumpolar deep water (UCDW) has been linked to accelerated melting of West Antarctic ice shelves and glaciers. To better assess the long term relationship between UCDW upwelling and the stability of the West Antarctic Ice Sheet, we present a multi-proxy reconstruction of surface and bottom water conditions in Marguerite Bay, West Antarctic Peninsula (WAP), through the Holocene. A combination of sedimentological, diatom and foraminiferal records are, for the first time, presented together to infer a decline in UCDW influence within Marguerite Bay through the early to mid Holocene and the dominance of cyclic forcing in the late Holocene. Extensive glacial melt, limited sea ice and enhanced primary productivity between 9.7 and 7.0 ka BP is considered to be most consistent with persistent incursions of UCDW through Marguerite Trough. From 7.0 ka BP sea ice seasons increased and productivity decreased, suggesting that UCDW influence within Marguerite Bay waned, coincident with the equatorward migration of the Southern Hemisphere Westerly Winds (SWW). UCDW influence continued through the mid Holocene, and by 4.2 ka BP lengthy sea ice seasons persisted within Marguerite Bay. Intermittent melting and reforming of this sea ice within the late Holocene may be indicative of episodic incursions of UCDW into Marguerite Bay during this period. The cyclical changes in the oceanography within Marguerite Bay during the late Holocene is consistent with enhanced sensitively to ENSO forcing as opposed to the SWW-forcing that appears to have dominated the early to mid Holocene. Current measurements of the oceanography of the WAP continental shelf suggest that the system has now returned to the early Holocene-like oceanographic configuration reported here, which in both cases has been associated with rapid deglaciation.

1. Introduction

Relatively warm (>1 °C), nutrient rich and CO_2 saturated upper circumpolar deep water (UCDW) is transported around the Antarctic continent in the Antarctic Circumpolar Current, which is in turn driven by the Southern Hemisphere Westerly Winds (SWW). Where the Antarctic Circumpolar Current flows close to the Antarctic continental shelf edge, along the West Antarctic Peninsula (WAP), Bellingshausen and Amundsen Seas, upwelled-UCDW frequently spills onto the shelf via bathymetric troughs, circulating relatively warm water under ice shelves and contributing to their basal melting and retreat (Walker et al., 2007; Jenkins and Jacobs, 2008; Wåhlin et al., 2010; Jacobs et al., 2011). More frequent and/or stronger incursions of UCDW are believed to contribute to recent, rapid warming (Vaughan et al., 2003), accelerated ice sheet thinning (Pritchard et al., 2012), reduced sea ice extent and notable changes in phytoplankton communities (Montes-Hugo et al., 2009) along the WAP in recent decades (Ducklow et al., 2012). The rapid deglacial retreat of the Marguerite Bay ice stream from ~9.6 ka BP, is widely considered to have been driven by enhanced incursions of warm UCDW encroaching onto the WAP continental shelf (Bentley et al., 2011; Kilfeather et al., 2011). While predicted intensification of the SWW in coming years (Swart and Fyfe, 2012) may continue to promote UCDW-

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upwelling and further threaten WAP ice shelf stability, a consensus on how UCDW-upwelling along the WAP responded to changing SWW in the past has yet to be achieved (Ishman and Sperling, 2002; Shevenell and Kennett, 2002; also see discussion in Bentley et al., 2009). The aim of this paper is to assess the sensitivity of UCDW-upwelling along the WAP to past changes in SWW by analysing the exceptionally well preserved planktonic and benthic foraminifera, diatoms and pigments in marine sediment core TPC522, from Marguerite Bay (Fig. 1). These biogenic components provide proxies for reconstructing past surface and bottom water conditions and documenting the changing influence of UCDW on the inner WAP continental shelf. We compare these reconstructions with other Southern Hemisphere records to infer the sensitivity of UCDW-upwelling to past changes in SWW intensity and position, and the impact of UCDW-upwelling on deglaciation.

1.1. Regional setting

Piston core TPC522, collected on British Antarctic Survey cruise JR179 in 2008 recovered 11.7 m of sediment from inner Marguerite Bay (67° 51′.33 S 68° 12′.28 W; Fig. 1). The site of TPC522, in 910 m of water, is downstream of Marguerite Trough, a bathymetric low which funnels UCDW directly from the continental shelf edge into Marguerite Bay (Klink et al., 2004; Martinson et al., 2008; Moffat et al., 2009). These incursions of UCDW are modified and cooled through mixing with overlying relatively cold and fresh Antarctic Surface Water (AASW) such that modified-UCDW (m-UCDW) floods the continental shelf to the base of the pycnocline (Martinson et al., 2008; Fig. 2A). The presence of m-UDCW beneath the pycnocline on the WAP is identified by temperature and salinity maxima as well as oxygen minima (Klink et al., 2004). Being enriched in nutrients and remineralised organic matter, m-UCDW is also depleted in ^{13}C and has diagnostic benthic δ^{13}C values <0.4‰ (Mackensen, 2012). Deep mixing of the AASW occurs during the winter months when m-UCDW-derived heat and nutrients may be incorporated into surface waters (Smith et al., 1999; Prézelin et al., 2000). Subsequent stratification during the summer months as

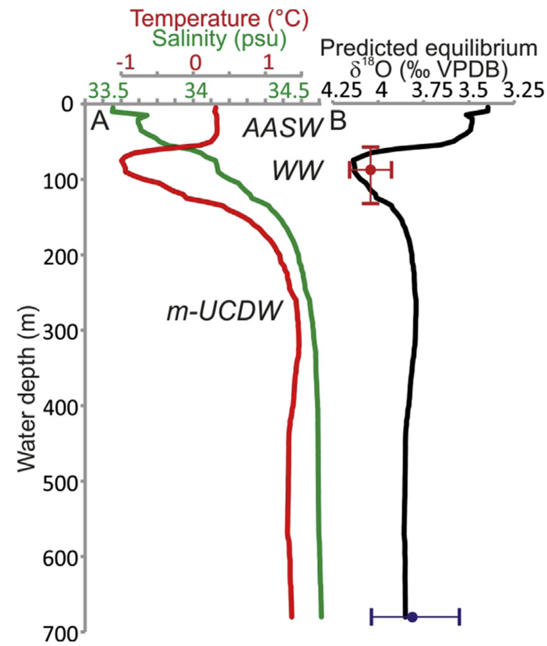

Fig. 2. Modern temperature and salinity profile and predicted $\delta^{18}O_{CaCO3}$ within Marguerite Trough. (A) temperature (red) and salinity (green) from CTD25 (Number 7; Fig. 1) collected 2nd April 2008. Antarctic Surface Water (AASW), Winter Water (WW), modified-UCDW (m-UCDW), (B). predicted $\delta^{18}O_{CaCO3}$ calculated from temperature and salinity following Shackleton (1974). Mean $\delta^{18}O$ *N. pachyderma* sin. (after vital effect correction of 0.63‰ from BC523 surface sediments is shown by a red data point with horizontal bars showing standard deviation and vertical bars showing the corresponding calcification depth based on modern predicted $\delta^{18}O_{CaCO3}$. The mean $\delta^{18}O$ *B. aculeata* from BC523 surface sediments is shown by the blue data point with horizontal bars showing standard deviation confirming that *B. aculeata* calcifies close to equilibrium with seawater $\delta^{18}O$. Note that TPC522 is at 910 m water depth. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

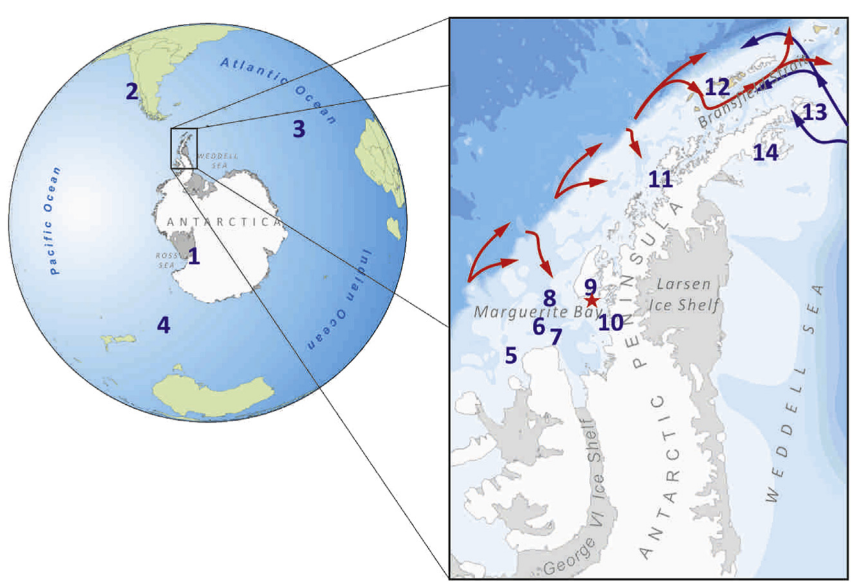

Fig. 1. Location of TPC522 (red star) and other sites (numbered in blue) discussed in this paper. 1. Taylor Dome Ice Core (Steig et al., 1998), 2. Chilean Margin (GeoB 3313_1; Lamy et al., 2002), 3. South Atlantic (TN057-13), 4. Tasmanian Gateway (E27-23; Anderson et al., 2009), 5. Lützow-Holm Bay (Igarashi et al., 2001). On the inset map red arrows indicate the flow of UCDW along the WAP with incursions onto the shelf through bathymetrical lows including Marguerite Trough. Additional sites are; 6. Rothschild Trough (Graham and Smith, 2012), 7. CTD 25; 8–9. Marguerite Bay mid-shelf (Kilfeather et al., 2011); 10. Ryder Bay, Rothera Oceanographic and Biological Time-Series site (Hendry et al., 2009), 11. Neny Fjord, (Allen et al., 2010), 12. Palmer Deep (Ishman and Sperling, 2002; Shevenell and Kennett, 2002; Taylor and Sjunneskog, 2002; Shevenell et al., 2011; Etourneau et al., 2013); 13. James Ross Island Ice Core (Mulvaney et al., 2012). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)