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Pliocene deglacial event timelines and the biogeochemical response offshore Wilkes Subglacial Basin, East Antarctica

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ABSTRACT

Significantly reduced ice coverage in Greenland and West Antarctica during the warmer-than-present Pliocene could account for ~10 m of global mean sea level rise. Any sea level increase beyond this would require contributions from the East Antarctic Ice Sheet (EAIS). Previous studies have presented low-resolution geochemical evidence from the geological record, suggesting repeated ice advance and retreat in low-lying areas of the EAIS such as the Wilkes Subglacial Basin. However, the rates and mechanisms of retreat events are less well constrained. Here we present orbitally-resolved marine detrital sediment provenance data, paired with ice-rafted debris and productivity proxies, during three time intervals from the middle to late Pliocene at IODP Site U1361A, offshore of the Wilkes Subglacial Basin. Our new data reveal that Pliocene shifts in sediment provenance were paralleled by increases in marine productivity, while the onset of such changes was marked by peaks in ice-rafted debris mass accumulation rates. The coincidence of sediment provenance and marine productivity change argues against a switch in sediment delivery between ice streams, and instead suggests that deglacial warming triggered increased rates of iceberg calving, followed by inland retreat of the ice margin. Timescales from the onset of deglaciation to an inland retreated ice margin within the Wilkes Subglacial Basin are on the order of several thousand years. This geological evidence corroborates retreat rates determined from ice sheet modeling, and a contribution of ~3 to 4 m of equivalent sea level rise from one of the most vulnerable areas of the East Antarctic Ice Sheet during interglacial intervals throughout the middle to late Pliocene.

1. Introduction

Ice grounded below sea level in the East Antarctic Ice Sheet (EAIS) has a potential sea level equivalent of ~19 m (Fretwell et al., 2013). Such ice is predominantly contained within the Aurora Subglacial Basin, the Recovery Basin, and the Wilkes Subglacial Basin (Fig. 1a). Modern observations in the vicinity of the Aurora Subglacial Basin document significant glacier retreat (Miles et al., 2016) and basal melting driven by ocean warming (Rintoul et al., 2016), while recent modeling work suggests that the Recovery Basin may be particularly vulnerable to melting under future environmental conditions (Golledge et al., 2017a). Furthermore, increased mass discharge by glaciers around the coastline of the Wilkes Subglacial Basin in recent years has been inferred from high-resolution ice velocity maps (Shen et al., 2018). The Wilkes Subglacial Basin is the largest of the three basins, containing a potential sea level contribution of ~3 to 4 m (Pollard et al., 2015). Collapse of marine-based ice in this basin may have important implications for Southern Ocean stratification and temperature, with the potential to amplify melting in other vulnerable regions of the EAIS (Phipps et al., 2016). It is therefore critical to constrain the sensitivity of the Wilkes Subglacial Basin to future, warmer environmental conditions.

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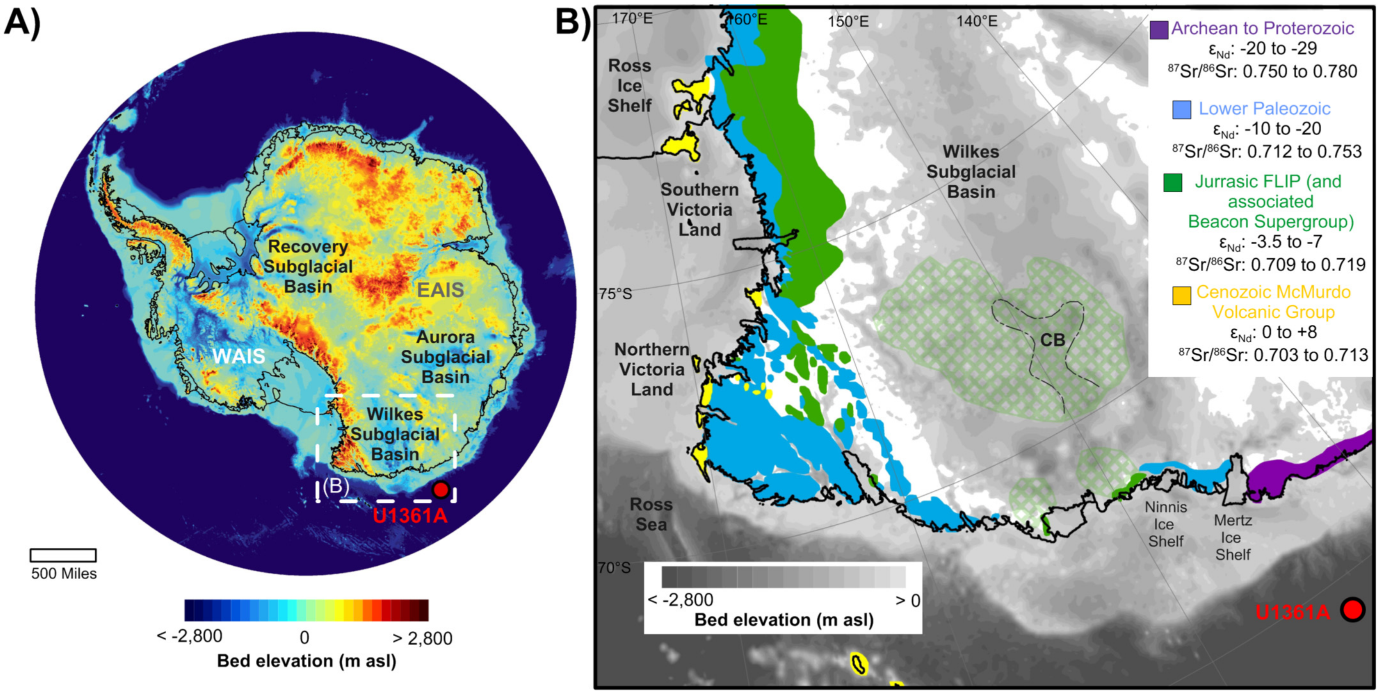

Fig. 1. (A) Topography and bathymetry (meters above sea level, m asl) of the Antarctic continent (modified from Fretwell et al., 2013), highlighting areas below sea level, including the three largest subglacial basins in East Antarctica: the Aurora Subglacial Basin, the Recovery Subglacial Basin and the Wilkes Subglacial Basin. The location of IODP Expedition 318 drill site U1361A (64°24.57′S, 143°53.20′E; 3454 m water depth) offshore of the Wilkes Subglacial Basin is marked. (B) Geological map of the area around the Wilkes Subglacial Basin (after Cook et al., 2013). Topographic map of the Wilkes Subglacial Basin (from Bedmap2; Fretwell et al., 2013) with simplified lithologies and their isotopic characteristics. Areas of inferred Jurassic Ferrar Large Igneous Province (FLIP) from airborne geophysics are shown in hatched marking (Ferraccioli et al., 2009; Frederick et al., 2016; Studinger et al., 2004). CB denotes the Central Basin. (For interpretation of the colors in the figure, the reader is referred to the web version of this article.)

Previous studies within the vicinity of the Wilkes Subglacial Basin have utilized detrital sediment provenance, grain size, ice-rafted debris accumulation, grounding line advances and retreats, and sea ice and temperature reconstructions to reveal a dynamic picture of the early to middle Pliocene and middle Miocene ice margin, with substantial ice retreat into the basin during warmer times, and ice advance onto the outer shelf at colder times (Armbrecht et al., 2018; Cook et al., 2013, 2017; Orejola et al., 2014; Patterson et al., 2014; Pierce et al., 2017; Reinardy et al., 2015; Sangiorgi et al., 2018). Substantial ice retreat into the Wilkes Subglacial Basin during the Pliocene and Miocene is also indicated by models that incorporate complex flow regimes of ice streams, capture marine ice sheet instability, and include parameterizations for cliff failure and hydrofracturing of buttressing ice shelves (de Boer et al., 2015; Pollard et al., 2015; Gasson et al., 2016). However, such models require ground-truthing from the geological record.

The Pliocene (5.3 to 2.6 Ma) is a particularly relevant time period to study in light of future environmental change. Previous studies have suggested substantial changes in the Pliocene cryosphere, with largely ice-free conditions in the Northern Hemisphere (Haywood et al., 2016 and reference therein) and collapse of the West Antarctic Ice Sheet (WAIS) (Naish et al., 2009; Pollard and DeConto, 2009). Estimates of global mean sea level (GMSL) of ∼22 ± 10 m higher than present during the warm Pliocene (Miller et al., 2012) may require not only collapse of the vulnerable polar ice in Greenland and West Antarctica, but also significant contributions from East Antarctica (see also Dutton et al., 2015 for discussion).

In the following, we present the first orbitally-resolved sediment provenance records from offshore of the Wilkes Subglacial Basin during the middle and late Pliocene. Our new data yield intriguing insights into the timescales and mechanisms of the equilibrium response of the EAIS to warmer than present environmental conditions in the geological past, and thereby provide important constraints for ice sheet modeling of future ice sheet behavior.

2. Materials and methods

Here we study three distinct periods of past warmth from the middle Pliocene (86.75–89.56 mbsf; ∼3.9 Ma), the late Pliocene (64.05–67.87 mbsf; ∼3.1 Ma), and the Plio-Pleistocene boundary (47.55–50.35 mbsf; ∼2.5 Ma). The material utilized is from IODP Site U1361A (64°24′S, 143°53′E; 3454 m water depth), which recovered a near-continuous Pliocene record (Escutia et al., 2011), comprised of alternating diatom-poor laminated muds and diatom-rich/bearing silty-mud units (Fig. 2), representing repeated glacial and interglacial cycles. Interglacial periods are associated with peak diatom abundance counts (Armbrecht et al., 2018; Taylor-Silva and Riesselman, 2018) and higher productivity (Patterson et al., 2014).

2.1. Age model at U1361A

Linear interpolation between paleomagnetic tie points is used to date U1361A Pliocene material following Tauxe et al. (2012) and Patterson et al. (2014) (Supplementary Table 1). The section studied is mostly continuous with one core gap between ∼3.6 to ∼3.33 Ma, which is thought to be related to the "super-glacial" M2 (Tauxe et al., 2012). We sampled for sediment provenance and biogenic silica concentrations (wt% BSi) at sub-orbital resolution (∼10 cm sampling corresponding to ∼2–4 kyr resolution). Areas of high core disturbance from either drilling or bioturbation were avoided. Two of the high-resolution intervals studied, the Plio-Pleistocene boundary (47.55–50.35 mbsf, ∼2.50 Ma), and the