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Research paper

Correlation of Early Pliocene diatomite to low amplitude Milankovitch cycles in the ANDRILL AND-1B drill core

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A B S T R A C T

In the austral summer of 2006/7 the ANDRILL MIS (ANtarctic geological DRILLing-McMurdo Ice Shelf) project recovered a 1285 m sediment core from beneath the Ross Ice Shelf near Ross Island, Antarctica in a flexural moat associated with volcanic loading. The upper ~600 m of this core contain sediments recording 38 glacial/interglacial cycles of Early Pliocene to Pleistocene time, including 13 discrete diatomite units (DUs). The longest of these, DU XI, is ~76 m-thick, and has been assigned an Early to Mid-Pliocene age (5–3 Ma). A detailed record of the siliceous microfossil assemblages in DU XI is used in conjunction with geochemical and sedimentological data to subdivide DU XI into four discrete subunits of continuous sedimentation. Within each subunit, changes in diatom assemblages have been correlated with the $\delta^{18}O$ record, providing a temporal resolution up to 600 yr, and allowing for the construction of a detailed age model and calculation of associated sediment accumulation rates within DU XI. Results indicate a productivity-dominated sedimentary record with greater proportions of hemipelagic mud accumulating during relatively cool periods. This implies that even during periods of substantial warmth, Milankovitch-paced changes in Antarctic ice volume can be linked to ecological changes recorded in diatom assemblages.

1. Introduction

The warm climate of the Early to Mid-Pliocene (5–3 Ma) has attracted much interest due to its potential use as an analog for the effects of human-induced global warming. To a first approximation, modern conditions and those in the Pliocene are quite similar. Carbon dioxide levels during this interval have been variously estimated to be 30–100% higher than pre-industrial levels (Budyko et al., 1987; Crowley, 1991; van der Burgh et al., 1993; Raymo et al., 1996). This is consistent with modern CO_2 concentrations ~35% higher than the pre-industrial interglacial average of 280 ppm (Petit et al., 1999), which had been stable for thousands of years prior to the Industrial Revolution, but which is predicted to double in the coming decades. Carbon dioxide concentrations of this magnitude place them above the modeled threshold for the onset of Northern Hemisphere glaciation (DeConto et al., 2008) and are consistent with a substantially reduced Northern Hemisphere ice sheet.

There is also ample evidence for a significant reduction in both continental ice sheets and sea ice in and around Antarctica during the Pliocene (Shackleton et al., 1995; Whitehead et al., 2005; Naish et al., 2009;). The sensitivity of Antarctic sea ice to climate perturbations has been suggested as a controlling factor in Pliocene climatic conditions (Jiang et al., 2005). Increased thermohaline circulation is associated with the warmest intervals of the Pliocene and enhanced meridional heat transport to high latitudes would have inhibited the formation of sea ice and enhanced melting beneath ice shelves, promoting their retreat or collapse (Pollard and DeConto, 2009). These effects would act as a positive feedback to global warming by reducing Earth's albedo (Raymo et al., 1996). High carbon dioxide levels, the associated increase in global temperature, reduced Antarctic ice volume, and stronger oceanic circulation patterns resulted in a world characterized by higher sea levels (Naish and Wilson, 2009; Dowsett and Cronin, 1990) and a semi-permanent El Niño (Wara et al., 2005; Shukla et al., 2009). Therefore, a more detailed understanding of early Pliocene climate provides the opportunity to better understand the potential effects of the current warming trend.

As tempting as it is to use this time period as an analog for modern global warming, it is important to note that significant differences exist between early Pliocene and the Anthropocene. Anthropocene is the term proposed by Crutzen and Stoermer (2000) to describe the time since the late 18th century, when the influence of human activities began to have a significant effect on global ecosystems. Although the opening of both the Tasmanian Gateway and the Drake Passage were complete by the beginning of the Pliocene leading to the thermal isolation of Antarctica (Stickley et al., 2004; Livermore et al., 2005; Eagles et al., 2006), the Panamanian Seaway was not completely closed until ~1.9 Ma, although significant water mass reorganization occurred as early as ~4.6 Ma (Haug and Tiedemann,

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1998). A similar reorganization of landmasses was underway in the western Pacific Ocean beginning at ~5 Ma as the northward movement of New Guinea led to changes in water mass movement through the Indonesian Gateway (Cane and Molnar, 2001). These gateways have important consequences for oceanic circulation patterns and associated meridional heat transport. Although not a perfect analog, well dated, high resolution records of Pliocene sediments from Antarctica offer the opportunity to document the changes in Earth's climate that occurred in a climatically sensitive region of the world during a time period with boundary conditions similar to those predicted for the coming decades.

2. The ANDRILL Project

In the austral summer of 2006/7 the ANDRILL MIS (ANtarctic geological DRILLing-McMurdo Ice Shelf) project was launched with the goal of recovering ~1200 m of Neogene sediments from the Ross Sea near Ross Island (Naish et al., 2007). The drill site was located to the east of Hut Point Peninsula, Ross Island, Antarctica in a flexural moat created by the volcanic loading of Ross Island and superimposed on regional subsidence associated with the Terror Rift (Horgan et al., 2005; Naish et al., 2006). The result was the recovery of a continuous (98% recovery) 1285 m sediment core collected from beneath the Ross Ice Shelf (Fig. 1).

Contained within the upper ~600 m of this core were sediments recording at least 38 glacial to interglacial cycles of Early Pliocene to Pleistocene time. The well constrained age model for the ANDRILL AND-1B core has made it possible to recognize distinct 40-kyr cycles within the sediment succession (Naish et al., 2009). These 40-kyr changes in ice volume reflect the influence of the obliquity component of Milankovitch cycles that result from changes in the axial tilt of the Earth with respect to its orbit around the sun. Also included within the sedimentary record are 13 discrete diatomite units (DUs) (Scherer et al., 2007), the longest of which is ~76 m (DU XI) and was deposited during climatic conditions warmer than today (Naish et al., 2009). Biostratigraphic, radiometric and magnetic dating methods constrain the age of DU XI to the Early to Mid-Pliocene (Table 1). The recent transfer of the Gelasian Stage to the Pleistocene Epoch has shifted the Pliocene/Pleistocene boundary to 2.6 Ma; however, this has no effect on the age assignment of DU XI, and all sediments within the unit are assigned a Pliocene age. The continuous nature of the sedimentation through most of this unit lends itself to high resolution studies of micropaleontological assemblage changes during a period of global warmth not observed for several million years.

In this study, a detailed record of the siliceous microfossil assemblages has been generated for DU XI and used in conjunction

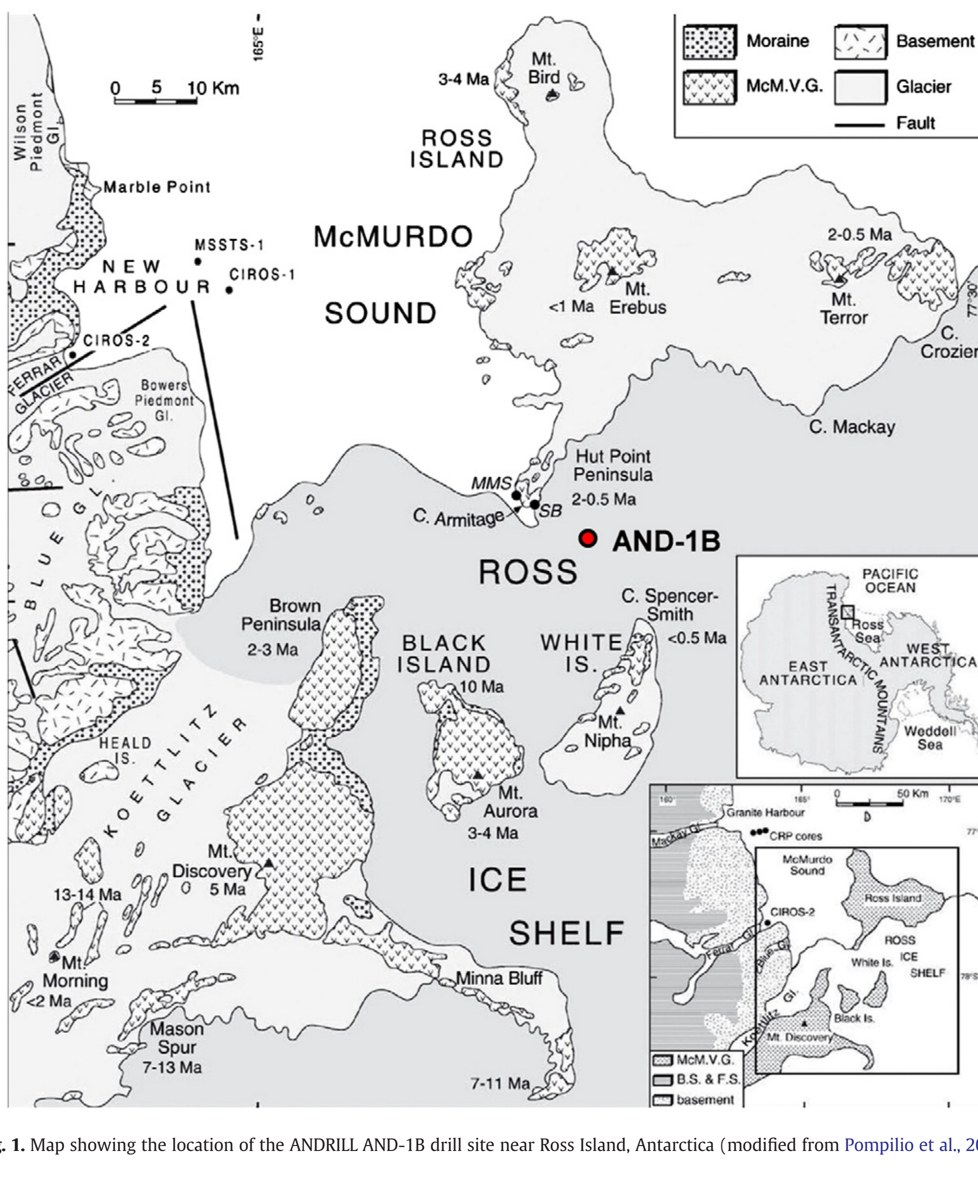

Fig. 1. Map showing the location of the ANDRILL AND-1B drill site near Ross Island, Antarctica (modified from Pompilio et al., 2007).