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Late Neogene climate and glacial history of the Southern Victoria Land coast from integrated drill core, seismic and outcrop data

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ABSTRACT

Late Neogene stratigraphy of southern Victoria Land Basin is revealed in coastal and offshore drill cores and a network of seismic data in McMurdo Sound, Antarctica. These data preserve a record of ice sheet response to global climate variability and progressive cooling through the past 5 million years. Application of a composite standard age model for diatom event stratigraphy to the McMurdo Sound drill cores provides an internally precise mechanism to correlate stratigraphic data and derive an event history for the basin. These marine records are indirectly compared to data obtained from geological outcrop in the Transantarctic Mountains to produce an integrated history of Antarctic Ice Sheet response to climate variability from the early Pliocene to Recent. Four distinct chronostratigraphic intervals reflect stages and steps in a transition from a relatively warm early Pliocene Antarctic coastal climate to modern cold polar conditions. Several of these stages and steps correlate with global events identified via geochemical proxy data recovered from deep ocean cores in mid to low latitudes. These correlations allow us to consider linkages between the high southern latitudes and tropical regions and establish a temporal framework to examine leads and lags in the climate system through the late Neogene and Quaternary. The relative influence of climate–tectonic feedbacks is discussed in light of glacial erosion and isostatic rebound that also influence the history along the Southern Victoria Land coastal margin.

1. Introduction

In December 2006, the ANDRILL (Antarctic Geological Drilling) Program completed its first drill hole (AND-1B) during the McMurdo Ice Shelf Project (Naish et al., 2007b; Naish et al., 2009), coring to 1238 m below the sea floor from a floating ice shelf platform (Falconer et al., 2007). The upper 600 m of the AND-1B core preserves a late Neogene (Pliocene to Recent) history of Antarctic Ice Sheet behavior recording a sequence of sediment and rock that reflects West Antarctic ice sheet oscillation in response to orbital forcing (Naish et al., 2009). The successful recovery of AND-1B adds to the existing set of drill cores in the McMurdo Sound region (Fig. 1) and provides additional paleoenvironmental data from a key 'offshore' geographic location. Integration of geologic data from these drill cores allows regional evaluation of stratigraphic packages in the context of ice sheet history and tectonic events. The successful recovery of AND-1B provides offshore data in a geologic transect from the McMurdo Dry Valleys to eastern McMurdo Sound, and allows an examination of the interaction of ice flowing into McMurdo Sound from West Antarctica and from the East Antarctic Ice Sheet via outlet glaciers that cut through the Transantarctic Mountains. In order to utilize the drill core data and construct an accurate geologic history for the region, robust correlation models are required to tie the drill cores and identify isochronous horizons and overlapping stratigraphic intervals. Magnetostratigraphic data and radiogenic isotope ages from volcanogenic material, including primary ash and reworked clasts support the primary correlation tool provided by diatom biostratigraphy. Our ability to correlate using diatom event stratigraphy is enhanced due to the large dataset available from the circum-Antarctic. Demonstration of this ability is a focus of the present paper.

Over the past 35 years, the Deep Sea Drilling Project (DSDP) and Ocean Drilling Program (ODP) have undertaken fourteen legs in sub-Antarctic and Antarctic waters to recover rock and sediment cores

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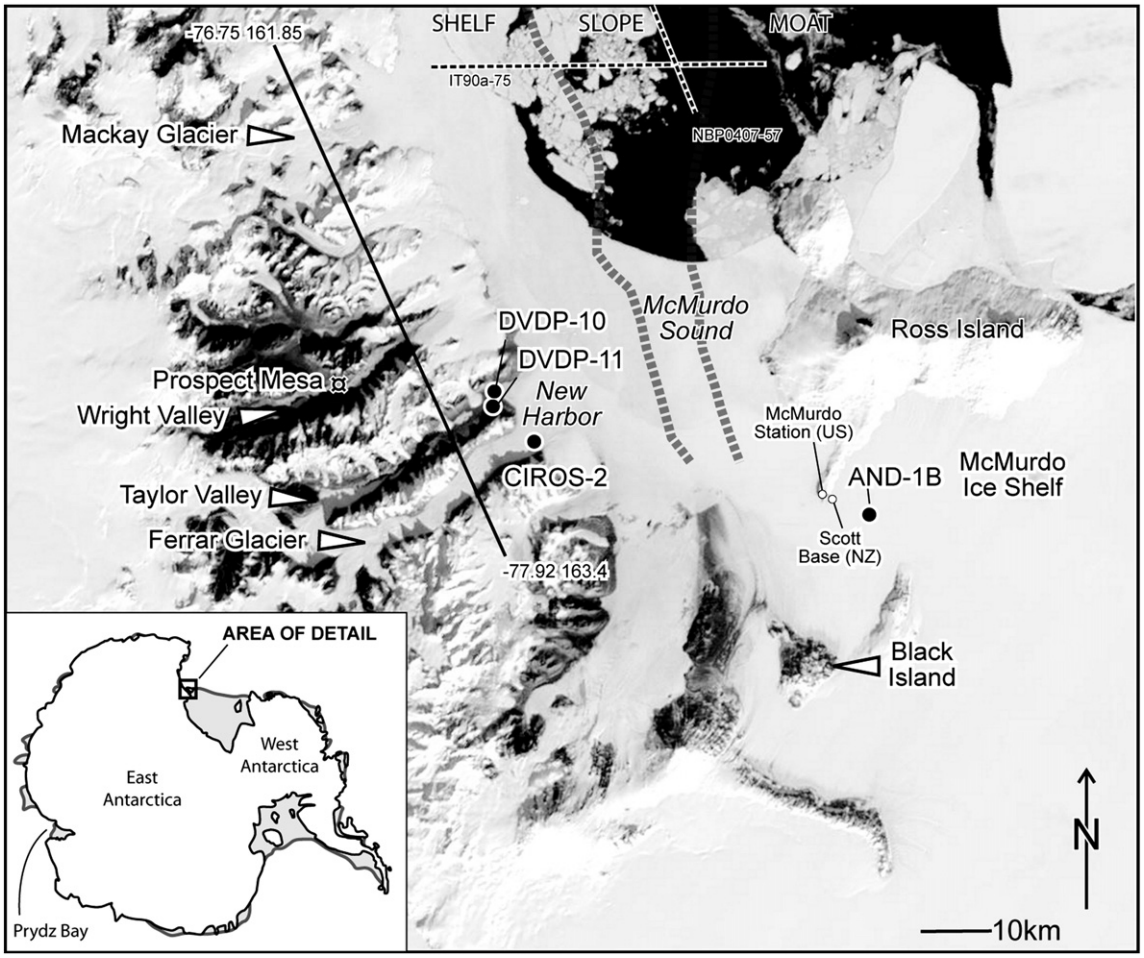

Fig. 1. McMurdo Sound Region, Antarctica. Key features referred to in the paper include: drill cores (large black circles); seismic lines IT90-a-75 and NBP0407-57; Prospect Mesa; location of the paleo-shelf and -slope (gray dashed line) identified in seismic data; and location of topographic profile (black line with latitude and longitude) illustrated in Fig. 8.

from the ocean basins and continental shelves around the continent. In addition to drilling in the deep ocean basins and on the outer continental shelf, records from locations proximal to the modern Antarctic coast have also been recovered by international drilling efforts including the Dry Valley Drilling Project (DVDP), Cenozoic Investigations in the Western Ross Sea (CIROS) Project, Cape Roberts Project (CRP), and ANDRILL (Fig. 1). Many of these drilling projects recovered sections of late Neogene strata, which contain excellent records of siliceous microfossils including marine diatoms. Detailed analysis of many of these sections has led to the development of a robust diatom taxonomy and biostratigraphy for the circum-Antarctic and continental shelf (Harwood and Maruyama, 1992; Censarek and Gersonde, 2002; Zielinski and Gersonde, 2002; Bohaty et al., 2003; Stickley et al., 2004; Olney et al., 2007; Winter et al., 2010b). While these biostratigraphic studies established key datums and several studies established zonation schemes (e.g. Harwood and Maruyama, 1992; Winter and Harwood, 1997; Censarek and Gersonde, 2002; Zielinski and Gersonde, 2002; Winter et al., this volume), age resolution has remained limited.

A re-examination of published diatom occurrences and a quantitative analysis of the data under constrained optimization (CONOP) were conducted by Cody et al. (2008). Highest Occurrence (HO) and Lowest Occurrence (LO) data for 116 diatom species from 32 Neogene sequences were integrated with paleomagnetic data to construct a composite standard sequence of First and Last Appearance Datums (FAD's and LAD's). The study produced two models with independent estimates of local occurrences and total ranges of fossil diatoms in the southern high latitudes. Time-calibration of the diatom event data produced an effective resolution between 0.11 and 0.13 m.y., greatly enhancing the age resolution provided by existing zonal schemes. An additional 64 taxa, several paleomagnetic reversals, and three age events (dates on volcanic ash and clasts) have been incorporated into the latest version of the CONOP models, including new data from the AND-1B core (Cody et al., this volume).

In this study we utilized a new "hybrid model" of Cody et al. (this volume) to re-examine age–depth models for the coastal drill cores in McMurdo Sound. Furthermore, we integrated the coastal cores with the AND-1B drillcore sequence, seismic data, and geologic outcrop from the Dry Valleys region in order to produce a regional correlation model. We then used this new correlation model to examine climatic evolution and tectonic history inferred from distinct chronostratigraphic intervals. A central goal of this work was to better understand the behavior of the West Antarctic Ice Sheet and margins of the East Antarctic Ice Sheet under varying climate.

2. Establishing a robust chronostratigraphic framework

A high-resolution age model that allows robust correlation between different sites is required to develop a coherent Neogene history of the Antarctic continental margin and the ice sheets. The ability to identify coeval points between sites with a high level of confidence is critical, although achieving this can be problematic due to inherent limitations in the biostratigraphic record. Quantitative biostratigraphy provides objective, statistical solutions to the correlation problem. In this study we applied a numerical optimization method (Kemple et al., 1995) to