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Studies from the ANDRILL,
Southern McMurdo Sound Project, Antarctica
Initial Science Report on AND-2A

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Overview

In late 2007, ANDRILL's Southern McMurdo Sound (SMS) Project, one of the larger IPY-endorsed programmes, recovered core and geophysical data from a 1138.54 m-deep drill core (AND-2A) from a 8.5 m-thick floating sea-ice platform over approximately 380 meters of water (77°45.488S; 165°16.613E). This second drillhole of the ANDRILL programme's campaign in the western Ross Sea, Antarctica, complements and extends the first drilling season's results (Naish et al., 2007a, b, 2009). These two deepest drillholes in Antarctica demonstrated ANDRILL's consistent ability to recover high quality marine and glacial marine sedimentary drill core (>98% core recovery) from high latitude ice-covered areas. This high percentage recovery results from a drilling technology that utilizes a sea-riser system, a circulating drilling fluids system, a continuous wireline diamond-bit coring, and three sizes of nested drill-strings that also serve to case the borehole as drilling progresses.

Technological success of the operations team in recovering this long, high quality core is mirrored by the successful activities of the science team working 'on-ice' at the drillsite and at McMurdo Station, and 'off-ice' at their home institutions during the initial Core Characterization Phase of the SMS Project, to generate a diverse array of scientific data. These data form the base of chapters in this Initial Report, and fill the on-line archive on ANDRILL's SMS Project 'Science Drive' (www.andrill.org), which will be open and available after the SMS Project moratorium period in June 2010. These data will help guide future studies on this important drillcore during the Science Documentation Phase of the SMS Project, and into the future.

A range of whole-core physical properties including wet bulk density, P-wave velocity, and magnetic susceptibility were determined at the drillsite. These data complement the graphical sediment logs and core descriptions, XRF scans, digital core imagery, and a variety of analyses done on discrete core samples collected in Antarctica. In addition, a comprehensive set of nearly continuous downhole measurements from a range of tools and a borehole televiewer complement and match the excellent core physical (MSCL) and chemical (XRF scanning) properties data and stratigraphic logs. Downhole operations also produced: the first Antarctic in situ stress measurements through hydrofracture experiments near the bottom of the borehole; the successful reconstruction and orientation of the core, using physical features, borehole tele-imaging, core orienting tool; and a vertical seismic profile (VSP) study with three-component data. The resulting integration of downhole data with core physical-properties, stratigraphic logs, and data produced through various analyses on discrete samples will contribute to our understanding of lithological cyclicity and climate, diagenesis heat flux and fluid flow, structure and stress, and volcanogenic evolution of the Victoria Land Basin region.

A primary goal of the SMS Project was to recover a stratigraphic sequence deposited during the middle Miocene, which has long been held as one of the fundamental time intervals in development of the modern Antarctic ice sheets (*e.g.*, Zachos et al., 2001; Shevenell et al., 2004). Deep-sea stable isotope records suggest the middle Miocene encompassed a change from the warm mid-Miocene Climatic Optimum (MMCO), ~17.5 to 14.5 million years ago (Ma), to the onset of major cooling between ~14.5 to 13.5 Ma, which is commonly interpreted as the major cause of the formation of a quasi-permanent ice sheet in East Antarctica (*e.g.*, Haywood et al., 2008, and references contained therein).

The AND-2A drillcore recovered a 600 m-thick stratigraphic interval documenting the Antarctic coastal environment during the warm middle Miocene climatic optimum. A disconformity separating the middle and upper Miocene intervals in the AND-2A drillcore represents a substantial climate step into cold, glacial conditions of the late Miocene. Lower and middle Miocene shallow marine sediments were deposited in the subsiding Victoria Land Basin, during the relatively steady 'thermal subsidence' phase 4 of Fielding et al. (2006), on the coastal plain and continental shelf seaward of the rising Transantarctic Mountains. This stratigraphic sequence records repeating lithological changes in glacial marine, terrigenous, volcanic and biogenic sediments. Fossils preserved in these strata suggest non-polar climate conditions similar to southern Patagonia and southwestern New Zealand today, influenced by high sediment discharge from river run-off, and high coastal turbidity. This region was influenced by local glaciers from the adjacent Transantarctic Mountains (TAM), ice sheet advances from East and West Antarctica, and water depth changes, all of which imparted a readable history on the accumulating sediments.

An excellent chronostratigraphic framework, developed through integrated diatom biostratigraphy, magnetostratigraphy, and radiometric dating of volcanic materials, provides age control for the drillhole and confirms its prediction to contribute to the establishment of a well-dated history of Neogene Antarctic ice sheet variation and climate evolution. The AND-2A drillcore also recovered

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the richest Cenozoic macropaleontological resource in Antarctica, with more than 600 productive marine horizons, which will aid in the reconstruction of terrestrial and marine temperature variation from a variety of climate proxies.

Results from the AND-2A drillcore, obtained from sediments deposited in a setting proximal to ice sheet influence and sea-level change, will be instrumental in guiding interpretations from the deep-sea chemostratigraphic records of $\delta^{18}\text{O}$, Mg/Ca, etc., and coastal sequence stratigraphic records of glacio-eustasy. The data presented in the present Initial Report volume are vital to the Scientific Committee on Antarctic Research (SCAR) scientific research programme - Antarctic Climate Evolution (ACE - <http://www.ace.scar.org/>) (Florindo & Siebert, 2008), whose objective is the integration of new Antarctic geological and paleoclimatic data into climate and ice sheet models. Empirical data generated from ANDRILL studies will help calibrate these numerical models, enabling new constraint to be placed on estimates of ice volume variability, sea-level change, terrestrial and marine paleotemperature, and the timing of development and paleodistribution of Antarctica's terrestrial and marine biota.

In particular, the recovery of middle Miocene Antarctic stratigraphic sequences (between ~375 to ~125 mbsf) will greatly improve the evaluation of global proxy records that invoke a change from a warm climatic optimum to the onset of major cooling and the formation of a quasi-permanent ice sheet on East Antarctica. The underlying lower Miocene interval (from the bottom of the drillcore at 1138.54 mbsf up to ~375 mbsf) records glacial and interglacial cycles and the initial warming phase of the Mid-Miocene Climatic Optimum. The AND-2A drillcore represents the third high-quality drillcore in Southern Victoria Land to record early Miocene paleoenvironmental changes (the other two records are preserved in the CRP-1 and CRP-2 drillcores; Cape Roberts Science Team, 1998, 1999), so that the timing and magnitude of glacial and eustatic variations can be examined at several sites along the Southern Victoria Land margin.

The uppermost section of AND-2A core, Pliocene to Pleistocene in age (from ~125 mbsf to the top of the drillcore), provides an original record that will complement and build on coastal and fjord sediment records from previous drillcores north of the drill site (Dry Valley Drilling Project (DVDP) -10, -11 and Cenozoic Investigation in the Western Ross Sea Project (CIROS) -2) (Hambrey and Barrett, 1993; Barrett, 2008). This upper Miocene to Recent section overlaps with core intervals recovered in deeper water sedimentary record from the AND-1B drillcore in the McMurdo Ice Shelf area (Naish et al., 2007a, b). The AND-2A drillcore results presented herein will contribute to the sediment archive that documents a dynamic glacial history of Late Neogene alternation between 'interglacial' and 'glacial' conditions (Barrett, 2007; Naish et al., 2009).

In addition to their paleoclimatic implications, the ongoing study of the drilled strata, with their variable clast compositions reflecting an evolving provenance, high content in Cenozoic volcanic detritus and fall-out products, and abundant structures related to brittle deformation, demonstrate the value of these new data toward interpretations of the glacial history of the Ross Embayment, the volcanic evolution of the Erebus Volcanic Province and the tectonic evolution of both the Antarctic Rift system (Victoria Land Basin - VLB) and the adjacent sector of the Transantarctic Mountains. Ongoing study of the AND-2A drillhole and core, will also provide important calibration and chronostratigraphic framework for the broad network of seismic lines for Ross Sea, achieved through Antarctic Offshore Stratigraphy (ANTOSTRAT) coordination (e.g., see <http://www.scar.org/publications/reports/19/>). The SMS site is well connected to the grid of seismic lines in the Western Ross Sea, hence the AND-2A drillcore will provide excellent chronostratigraphic control for regional seismic surfaces, for interpreting regional stratal architecture, and for dating Neogene subsidence and rifting history.

Programmes like ANDRILL are extremely important because of uncertainties about the future behavior of Antarctic ice sheets and resultant sea-level change. Stratigraphic records will be used to determine the behavior of ancient ice sheets and to understand factors driving past ice sheet, ice shelf and sea-ice growth and decay. This new knowledge will enhance our understanding of Antarctica's potential responses to future global climate changes.

This volume presents the initial science results of the AND-2A drill-hole. It derives from the web-based On-Ice Report and includes the results of Core Characterization Phase activities conducted off-ice, prior to the Core Workshop held at Florida State University, Antarctic Marine Geology Research Facility, April 30 - 4 May 2008, where nearly 95 scientists, students and educators presented their ongoing research on AND-2A materials. The 12 chapters contained herein provide an operational overview of the drilling operations, the curation and management of the cores, and the initial descriptive characterization the drillcore and borehole set out under major discipline areas, and a description of ANDRILL's Education and Outreach during the IPY.

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Dedication

This volume is dedicated to the memory of Detlef (Dietz) Warnke (1928-2008), our friend, colleague and SMS Science Team member. Dietz left an endearing and enduring memory with those who had the pleasure of working with him.

Acknowledgements

The ANDRILL (ANTarctic geological DRILLing) programme's Southern McMurdo Sound (SMS) Project is a multinational collaboration between the Antarctic Programmes of Germany, Italy, New Zealand and the United States. Antarctica New Zealand is the Project Operator, and has developed the drilling system in collaboration with Alex Pyne at Victoria University of Wellington and Webster Drilling and Enterprises Ltd.

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Frank Niessen	core physical properties/logging
Roseanne Nyland	student; petrology, volcanology
Christian Ohneiser	student; paleomagnetism
Donato Pace	student; clast petrology
Michael Palin	zircon chronochemistry
Molly Patterson	student; paleontology/forams
David Pollard	numerical modeling; ice sheets and climate
Ian Raine	paleontology/terrestrial palynology
Peter Reiners	chronostratigraphy
Sergio Rocchi	igneous petrology/geochemistry
Leonardo Sagnotti	paleomagnetism/chronostratigraphy
Francesca Sangiorgi	post-doc.; organic geochemistry
Henning Schroeder	student; downhole geophysics
Anji Seth	stratigraphic modelling
John Simes	technician; palynology
Mario Sprovieri	geochemistry/stable isotopes
Chris Stefano	student; geochemistry/Sr dating
Bryan Storey	sedimentology/stratigraphy
Lora Teitler	student; sedimentology/stratigraphy
Nick Thompson	student; sedimentology/stratigraphy
Aradhna Tripathi	stable isotope geochemistry
Marina Verducci	geochemistry/stable isotopes
Ken Verosub	chronostratigraphy/paleomagnetism
Giuliana Villa	paleontology/nannofossils
Dietz Warnke	sedimentology/stratigraphy
Sophie Warny	palaeontology/palynology
Veronica Willmott	organic geochemistry
Gary Wilson	chronostratigraphy/paleomagnetism
Terry Wilson	core physical properties/logging
Sherwood Wise, Jr.	paleontology/nannofossils
Anastasia Yatsenko	student; downhole geophysics
Massimiliano Zattin	chronostratigraphy/fission-track