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L. A. Krissek
Ohio State University

G. Browne
GNS Science

L. Carter
Victoria University of Wellington, lionel.carter@vuw.ac.nz

E. A. Cowan
Appalachian State University, cowanea@appstate.edu

G. Dunbar
Victoria University of Wellington

See next page for additional authors

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L.A. Krissek[1], G. Browne[2], L. Carter[3], E. Cowan[4], G. Dunbar[5], R. McKay[6], T. Naish[7], R. Powell[8], J. Reed[9], T. Wilch[10] and the ANDRILL-MIS Science Team[11]

[1]School of Earth Sciences and Byrd Polar Research Center, The Ohio State University, Columbus, OH 43210 USA (krissek.1@osu.edu)
[2]GNS Science, PO Box 30-368, Lower Hutt, NZ (g.browne@gns.cri.nz)
[3]Antarctic Research Centre, Victoria University of Wellington, Wellington 6005, NZ (lionel.carter@vuw.ac.nz)
[4]Dept. of Geology, Appalachian State Univ., Boone, NC 28608-2067 USA (cowanea@appstate.edu)
[5]Antarctic Research Centre, Victoria University of Wellington, Wellington 6005, NZ (gavin.dunbar@vuw.ac.nz)
[6]Antarctic Research Centre, Victoria University of Wellington, Wellington 6005, NZ (robert.mckay@vuw.ac.nz)
[7]GNS Science, PO Box 30-368, Lower Hutt, NZ (t.naish@gns.cri.nz)
[8]Dept. of Geology & Environmental Geosciences, Northern Illinois Univ., DeKalb, IL 60115 USA (ross@geol.niu.edu)
[9]Dept. of Geological & Atmospheric Sciences, Iowa State Univ., 275 Science I, Ames, IA 50011-3212 USA (jareed@iastate.edu)
[10]Dept. of Geology, Albion College, Albion, MI 49224 USA (twilch@albion.edu)
[11]http://www.andrill.org/support/references/appendixc.html

Summary During the 2006-2007 austral summer, the ANDRILL McMurdo Ice Shelf Project recovered a core 1285 m long (AND-1B) from Windless Bight in McMurdo Sound. This core contains a range of lithologies, including both siliciclastic and volcanic diamictites, sandstones and mudstones; diatomites; and volcanic ash/tuff and one phonolitic lava flow. This sequence has been subdivided into eight lithostratigraphic units and 25 subunits, based on lithological abundances. Eleven lithofacies have been identified, ranging from open marine diatomites and mudstones to turbidites to ice-proximal massive and stratified diamictites. More than 50 glacimarine sequences have been recognized, bounded by glacial surfaces of erosion. Three distinct stacking patterns are present, showing evidence of glacial advance/retreat/advance with varying degrees of preservation. Carbonate and pyrite are the dominant secondary phases in the core. The pyrite overprint is especially notable in volcanic sediments below ~400 mbsf, where it often obscures stratification and sediment texture.

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Introduction

During the 2006-07 austral summer, the ANDRILL program conducted its inaugural season of drilling with the McMurdo Ice Shelf (MIS) project. The MIS drill site was located in Windless Bight, McMurdo Sound, ~10 km from Scott Base, on the 83 m-thick ice shelf underlain by 870 m of water. The major drilling operation took place in a hole designated "AND-1B", with total penetration to 1285 meters below seafloor (mbsf). Core recovery exceeded 95% of the penetrated section, and the quality of the recovered core generally was good to excellent. The length of this core, its high recovery rate, good quality, and range of lithologies present all suggest that the AND-1B core will serve as a benchmark for studies of the Late Cenozoic history of the Ross Sea sector of Antarctica well into the future.

On-ice core characterization included sedimentologic description/study and lithostratigraphic subdivision of the AND-1B core, using standard techniques. Lithologic facies within the core were defined, accompanied by preliminary interpretations of their depositional processes and depositional environments. A preliminary sequence stratigraphic interpretation also was developed for the cored succession. Diagenetic and deformational features within the core were described in general, but detailed analysis of these aspects of the core will take place during post-drilling studies.

Detailed core descriptions and graphic logs were generated using PSICAT, a Java-based logging program written by J. Reed for use in ANDRILL. The detailed logs, at a scale of 4 m/page, as well as summary logs at a variety of scales, will be included in an initial report of the McMurdo Ice Shelf Project, to be published by *Terra Antartica* (Naish et al., in press).

Lithostratigraphy

The AND-1B core has been divided into eight lithostratigraphic units, based on major changes in lithology recognized during core description. This division draws attention to the relative importance of prominent lithologies, such as diamictites, diatomites, and volcanic sediments and rocks. The eight major lithostratigraphic units are divided further into a total of 25 lithostratigraphic subunits, based on smaller-scale lithologic changes.

Lithostratigraphic Unit (LSU) 1 is dominated by diamictites. LSU 2 is dominated by siliciclastics but contains a variety of lithologies, including volcanic sandstones and mudstones, volcanic ash/tuff, and mudstone-rich diatomaceous ooze; as a result of this variability, LSU 2 is subdivided into three subunits. LSU 3 is dominated by diatomites and diamictites, which alternate repeatedly through the ~230 m of this unit. Lesser amounts of siliciclastics also are present. LSU 3 is subdivided into six subunits.

LSU 4 comprises a variety of lithologies, including diatomite, diamictite, mudstone, and volcanic diamictite; it is subdivided into four subunits. LSU 5 is dominated by volcanic sediments (volcanic diamictite, volcanic sandstone, and volcanic mudstone), and includes a phonolitic lava flow ~2.8 m thick; this LSU is subdivided into four subunits. LSU 6 is dominated by siliciclastic diamictites and mudstones, which are separated into three subunits. LSU 7 is composed of volcanic sandstones and volcanic mudstones, whereas siliciclastic diamictite forms LSU 8.

Lithofacies

Eleven recurring lithofacies have been recognized in the AND-1B core, based on a lithology or an association of lithologies, bed contacts and bed thicknesses, sediment texture, sedimentary structures, and, to a lesser extent, color. The entire facies assemblage is interpreted to record marine to subglacial environments of deposition, with Facies 1 through 10 numbered in ascending order from most distal (i.e., least ice-influenced) to most proximal (i.e., most ice-influenced). Facies 11 includes the entire range of volcanic rocks and sediments that are interpreted to be primary and near-primary, and that carry limited information about glacial proximity.

Facies 1 (diatomite) is interpreted to record pelagic sedimentation in an open marine environment, although sometimes affected by iceberg rafting. Facies 2 (mudstone, primarily massive) is interpreted to record environments dominated by hemipelagic suspension settling, which may be either distal or proximal to grounded ice. Siltstone and sandstone laminae within Facies 2 may represent minor influence of distal sediment gravity flows, winnowing by bottom currents, or settling from turbid plumes. Coarser sediments (poorly sorted sands and lonestone clasts) record the influence of ice rafting, at least episodically. Facies 3 (interstratified mudstone and sandstone) is similar to Facies 2, but with an increased importance of sandstone interbeds. This interbedding is interpreted to record the combination of hemipelagic sedimentation and distal to proximal sediment gravity flows, sourced either from grounding line processes or volcanic/tectonic activity. Ice rafting and traction currents may have supplied or modified the coarser-grained component in Facies 3.

Facies 4 (mudstone with dispersed or common clasts) is interpreted to record an environment similar to that of Facies 2, dominated by hemipelagic suspension settling but with increased clast rainout from floating ice. Rainout from icebergs cannot be distinguished from rainout beneath an ice shelf without additional study. Facies 5 (rhythmically interlaminated mudstone/siltstone/sandstone) is interpreted to have been deposited in a quiet-water setting by settling from meltwater plumes. The rhythmic nature of sedimentation may record interactions between the turbid plumes and tidal currents, whereas dropstones and poorly sorted sands record rainout from floating ice.

Facies 6 (sandstone) includes well-stratified sandstones and interbedded siltstones, usually with a strong volcanic component. Facies 6 is interpreted as predominantly the deposits of turbidity currents, based on physical sedimentary structures and the abundance of fining-upward beds. These mass flows originated on slopes composed of volcanic material. Deposits of other flow types (e.g., grain flows) may also be present in Facies 6. Facies 7 (conglomerate) is relatively uncommon in the core, but is interpreted as the product of submarine sediment redeposition. Deformed mudstone intraclasts in some of these conglomerates suggest deposition and deformation by grounded ice. Facies 8 (breccia) is also interpreted as the product of sediment redeposition by mass flow; the dominance of volcanic clasts and/or mudstone intraclasts in Facies 8 suggests derivation of the mass flows from a volcanic source.

Facies 9 (stratified diamictite) is interpreted to record a range of depositional environments, depending on the facies associated with a specific bed: ice rafting or debris flow deposition, rainout of basal glacial debris with reworking by marine glacial outwash, or deposition beneath grounded ice. Facies 10 (massive diamictite) is primarily attributed to subglacial deposition, although rainout from floating ice and deposition by mass flow are also possibilities.

Facies 11 (volcanic rocks and sediments) is interpreted as primary and near-primary volcanic deposits, including volcanic diamictites, lapilli tuffs, and a phonolitic lava flow. Although the diamictites and lapilli tuffs may have been reworked slightly by high-density mass flows and low-density mass flows, respectively, the extent of reworking for Facies 11 is interpreted to be significantly less than the extent of reworking recorded by volcanic-rich equivalents of the other facies.

Sequence Stratigraphy

In a preliminary sequence stratigraphic analysis, more than 50 unconformity-bounded glacimarine sequences have been recognized. Sequences are defined on the basis of vertical stacking patterns of facies, and each has a Glacial Surface of Erosion (GSE) at its base. Each sequence contains a consistent vertical association of facies, interpreted to represent successive glacial advances and retreats across the continental shelf. Three distinct stratigraphic cycle motifs have been recognized in the portions of the core that are not volcanically dominated; no cycle motifs have been identified in the volcanic successions.

One sequence motif is dominated by diamictite, and is interpreted as a glacial advance-retreat cycle that was "top-truncated" by erosion during the subsequent ice advance. This motif is most common in the upper portion (~100 m) of the core.

The second sequence motif includes the most complete record of ice advance, retreat, and readvance; it begins with a basal diamictite overlying a GSE, and grades upward through ice retreat facies to more distal glacimarine deposits, and finally into open-water diatomites. This portion of the motif records the transition from subglacial to open-water settings. The upper half of this motif contains a similar set of facies, but stacked to record ice advance and culminating in a stratified diamictite that is deformed immediately below the overlying GSE. This upper portion of the second sequence motif records the transition from open-water to ice-proximal settings. This motif is most common between ~100 and ~600 mbsf.

The third sequence motif is similar to the second motif, except that diatomite is absent and the upper portion of the cycle is dominated by mudstones. In addition, the upper portion of the motif, which is interpreted to record ice advance, tends to be either absent, truncated or thinned. The third sequence motif is most common below ~600 mbsf, where biogenic silica generally is absent; as a result, it is unclear whether the absence of diatomite has a depositional or a diagenetic (diatomite conversion to opal C-T) cause. Future detailed studies will address this question.

Diagenesis

The two major diagenetic features observed during core description are carbonate cements and nodules and pyrite cements and nodules. Carbonate cements occur in a variety of forms, but the distribution of cement is highly heterogeneous in all lithologies. Carbonate vein fills and fracture fills occur throughout the core, but are best-developed below 600 mbsf, where they occur in a variety of forms.

Pyrite occurs as disseminated pyrite and pyritic grain coatings, concentrated pyrite cement, and pyrite nodules and concretions. All of these forms are rare to absent above ~400 mbsf, but are common to abundant below that level. The pyrite overprint locally obscures sediment texture and stratification below ~400 mbsf, especially in the volcanic sediments.

Discussion and conclusion

The AND-1B core includes some lithologies expected for a Late Cenozoic sequence from McMurdo Sound (e.g., siliciclastic and volcanic ice-proximal to ice-distal facies, and primary to near-primary volcanic sediments and rocks). However, the diatomites, and especially the thick diatomites of LSUs 3 and 4, record extended periods of open water conditions with little or no influence of glacial ice. These diatomites, taken together with the abundance and diversity of unconformity-bounded glacimarine sequences, suggest a very dynamic history of the Ross Ice Shelf and its environs during the Late Cenozoic.

Future studies will investigate the paleoclimatic, paleoceanographic, and paleoglaciological implications of these lithofacies and stratigraphic sequences. Compositional studies will provide information about sediment sources and paleoweathering conditions, as well as the origin and implications of the secondary carbonate and pyrite. The integration of the sedimentary and stratigraphic records with the other ANDRILL research components will provide new insight into the behavior of the Ross Ice Shelf and its effects on Antarctica and the global ocean/climate system.

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