IODP Expedition 318: Wilkes Land Glacial History

Site U1357 Summary

26 February 2010

The primary objective at Site U1357 (ADEL-01B) was to recover a continuous ~200 meter Holocene sedimentary section from the Adélie Basin located on the Antarctic continental shelf off the Wilkes Land Margin. The Adélie Basin is a 1000 meter deep glacially-scoured trough separated from the Adélie Depression (70 km to the east) by the 200 m deep Adélie Bank. Previous piston- and kasten-coring of the upper sediment column shows that sediments in the Adélie Basin are deposited as annual-to-near-annual layers averaging 2 cm in thickness. The thickness of the Holocene sedimentary section above the last glacial diamict (190 m) is consistent with this high rate of sedimentation being maintained for the past 10,000 years.

The ultra-high resolution Adélie Basin Holocene section will be used to produce the first annually-resolved time series of oceanographic and climatic variability derived from a Southern Ocean marine sediment core. These data can be directly compared to annual ice core records from Antarctica's coastal ice domes as well as other marine sediment cores from the Antarctic Peninsula and other parts of the East Antarctic Margin. The site is sensitive to drainage winds from Antarctica as well as the polar easterly winds, sea ice extent, the Southern Annular Mode (SAM), and the position of the southern boundary of the Antarctic Polar Frontal Zone in the Indian and Pacific oceans. Little is known about past variability in these systems from marine records and there are none with annual or near-annual resolution. The Adélie Basin site lies directly downwind and down-current from the Mertz Glacier

polynya (Masson et al., 2001; 2003) and therefore collects biogenic materials produced in one of Antarctica's major coastal polynyas. The Mertz Glacier polynya and underlying Adélie Depression may produce as much as 25% of all Antarctic Bottom Water (Rintoul, 1998; Marsland et al., 2004; Williams et al., 2008). Given the known presence of benthic foraminifera in the Adélie Basin and the substantial bottom water temperature anomaly associated with local High Salinity Shelf Water, Site U1357 has the potential to yield information on Antarctic Bottom Water production through time. Understanding Holocene climate variability at this East Antarctic site will aid in determining the range and characteristics of natural climate variability during a period of relatively constant atmospheric carbon dioxide levels. This record will also aid in the assessment of different forcing factors (solar, ocean-atmosphere interaction, volcanic) responsible for climate change over the past 10,000 years.

Sediments accumulate in the 1000 m deep Adélie Basin as a thick drape overlying a high amplitude reflector with no underlying penetration. The strong reflector is interpreted as a glacial diamict. The East Antarctic Ice Sheet expanded to the shelf edge during the last glacial maximum (Domack, 1982; Barnes, 1987; Eittreim et al., 1995) and the Adélie Basin was filled with ice. Ice lift-off and southward retreat from other deep shelf basins of East Antarctica occurred between 10,000 and 11,000 years ago (Siegert et al., 2008; Leventer et al., 2006); this is the expected age range of the lowermost sediments recovered from Site U1357. The seismic line shows 190 meters of continuous, horizontal, parallel reflectors at the site, consistent with a drape of Holocene sediment undisturbed by sea level change or glacial erosion.

Three holes were cored at Site U1357. In Hole U1357A, Cores U1357A-1H to -21X penetrated to 186.6 mbsf, recovered 183.87 m of diatomaceous ooze and penetrated the underlying last glacial diamict. After offsetting the ship 50 m to the east of Hole U1357A, we cored Hole U1357B. Cores U1357B-1H to -19H penetrated to 170.7 mbsf and recovered 172.44 m (101%) of sediment. Hole U1357C, offset 25 m west of Hole U1357A, produced Cores U1357C-1H to -11H, penetrated to 103.8 mbsf, and recovered 110.7 m (107%) of sediment. Cores from Hole U1357A were split and described during the expedition. Cores from Holes U1357B and U1357C were preserved as whole round sections for post-cruise splitting, describing, and sampling. All cores from this site contained sediments that vigorously degassed methane and hydrogen sulfide upon decompression to 1 atmosphere. Gas pressure caused expansion of the sediment section resulting in the loss of some sediment from core breaks as well as section breaks, particularly above 40 mbsf. This was minimized by drilling small holes in the core liners at regular intervals.

The sediments from Site U1357 consist of three lithologic units. The uppermost unit is 170 m of laminated Holocene diatom ooze (Unit I). Unit I overlies a 15 m transitional unit of sand and silt-bearing diatom ooze (Unit II), which in turn sits on a hard, carbonate-cemented and poorly sorted gravelly siltstone (Unit III, a diamict). Units I and II exhibit regular laminations defined by color (alternating dark olive brown to light greenish brown layers) and textural variability. Individual laminae range in thickness from 1 to 3 cm and extend throughout the entire 186 m thick section lying on top of the diamict.

Based on analysis of multiple samples from core breaks and section breaks Site U1357 sediments contain a well-preserved Holocene Southern Ocean diatom flora with varying contributions from cool open-ocean and sea-ice associated taxa (Armand et al., 2005; Crosta et al., 2005). Radiolarians, silicoflagellates, and sponge spicules are common and well preserved. Organic-walled dinoflagellates cysts are present as well as motile stages, abundant tintinnid loricae, copepod remains.

Light and dark laminae were sampled throughout the Holocene section. Based on trends in diatom assemblage succession within paired laminae as well as previous work from the Adélie Basin region (Denis et al., 2006) and other laminated diatom sections from the east Antarctic margin (e.g., Stickley et al., 2005; Maddison et al., 2006), each light/dark laminae couplet is provisionally interpreted as a single season of biogenic production and accumulation. It is assumed that diatomaceous sediments begin to accumulate during spring sea ice retreat following the development of early season phytoplankton blooms in the Mertz Glacier polynya. Blooms persist through summer open water conditions, and conclude with the autumn regrowth of sea ice and destabilization of the water column. The unusually high accumulation rates (averaging 2 cm/year) are likely the result of syndepositional focusing processes that sweep biogenic debris from the shallow Adélie and Mertz banks into the deep shelf troughs of the Adélie Basin and Adélie Depression.

A low diversity assemblage of calcareous planktic (*Neogloboquadrina pachyerma* and *Globigerina bulliodes*) and benthic foraminifera (*Globocassidulina subglobosa* and *Triloculina frigida*) occurs in Site U1357 Holocene sediments. Planktic foraminifera

were observed throughout the sedimentary section and benthic foraminifera were observed in several core break samples that were sieved. The occurrence of well-preserved calcareous foraminifera is unusual in Antarctic shelf basins as shelf bottom waters are highly undersaturated with respect to calcite. High sedimentation rates likely contribute to foraminiferal preservation in the Adélie Basin sediments.

In addition to abundant diatoms and foraminifera, sediments from Hole U1357A contain large quantities of fish debris, including at least 44 layers of concentrated fish vertebrae. With abundant phosphatic, calcareous, opaline, and organic biogenic detritus, Site U1357 sediments offer an unusually diverse array of assemblage-based and geochemical environmental tracers for shore-based studies.

Site U1357 sediments posed a significant challenge for the analysis of physical properties. The sediments are so diatomaceous that they exhibit extremely low magnetic susceptibility. Whole-round core analysis of all three holes using a Bartington Loop sensor and split core analysis using a point source magnetic susceptibility sensor on Hole U1357A did not yield useful data for hole-to-hole correlation. The production of mm-scale pockmarks from degassing of methane and hydrogen sulfide throughout the sediment column makes bulk density determination difficult using discrete sample analysis or with the Gamma-ray attenuation. Natural Gamma Ray (NGR) levels are minimal because of the low concentration of terrigenous material in Lithostratigraphic Unit I. Nevertheless, with sufficient background count correction, NGR track scans yielded useful data for the correlation of cores from all of Holes U1357B and U1357C and a portion of cores from Hole U1357A.

Additional information for hole-to-hole correlation was provided by magnetic susceptibility determination of over 1800 discrete samples that had been taken through Hole U1357A at 10 cm intervals for post-cruise foraminiferal analysis. Each dried sample was weighed and analyzed with the Kappa Bridge KAY-4 magnetic susceptibility detector. The Kappa Bridge has roughly 2 orders of magnitude greater sensitivity than the whole core loop or split core point source sensors. The resulting data set suggests that magnetic susceptibility measurements of discrete samples will be of use in developing a robust hole-to-hole correlation.

Site U1357 is located close to the south magnetic pole and we observed the expected high inclinations in the paleomagnetic signature of split core sections. After processing and matching paleomagnetic declinations across core breaks, Hole U1357A yielded a paleomagnetic secular variability profile that appears to match a geomagnetic secular variation model spanning the last seven thousand years (CALS7k.2 of Korte and Constable, 2005) for 66ºS, 144ºE. The age-depth relationship predicted by application of this model to the secular variation signal obtained from Hole U1357A is consistent with that expected for this site based on radiocarbon dating of the upper 50 m of the sediment column (Costa et al., 2007) and the overall sediment sequence thickness.

Geochemical analysis of 96 sediment samples from Hole U1357A yielded $CaCO_3$ contents ranging from 1 to 3 wt% for most of the hole with one distinct carbonate-rich layer ($CaCO_3$ >9 wt%) at 126.34 mbsf. Organic C content is uniformly high (for Antarctic shelf sediments) at between 1 and 2 wt%. C/N ratios of between 7 and 12 are consistent with relatively well-preserved and labile marine organic matter. SiO_2 concentrations are high (76-91 wt%), and are accompanied by low concentrations of

TiO_2 (<0.3 wt%) and Al_2O_3 (<5.6 wt%), as expected for a nearly pure diatom ooze with little terrigenous input. The authigenic phosphate mineral struvite ($NH_4MgPO_4 \cdot 6H_2O$), which forms through bacterial biomineralization in anoxic sediments in the presence of ammonium, was observed at several depths.

Headspace methane concentrations varied by over an order of magnitude down core, increasing from 5,000 to 43,000 ppm from 0 to 20 mbsf and then declining to highly variable concentrations at greater depths, mostly between 5,000 and 18,000 ppm. Significant concentrations of H_2S were detected as well, consistent with anoxic diagenesis of organic rich sediments. An extensive microbiology program, focusing on phospholipid analyses and molecular 16S rRNA sequencing, was completed in the upper 20 m of Hole U1357C. Pore water samples collected from adjacent whole-round core samples show no detectable $SO_4^=$ except in core top samples suspected of contamination with seawater. Ammonium increases almost linearly from near surface values of 900 μM to 4500 μM at 18 mbsf. Total dissolved inorganic carbon and alkalinity increase to 18 mbsf as well, to values of 79.6 mM and 88 mM, respectively, while pH drops to 7.5 at 20 mbsf. These profiles are consistent with bacterially mediated diagenesis within anoxic pore waters. Methane is derived from CO_2 reduction following the removal of $SO_4^=$. Pore waters were not analyzed deeper than 20 mbsf in the core but samples for 16S rRNA sequencing were taken from core ends to the maximum depth of penetration at Hole U1357C (103.8 mbsf).

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