IODP Expedition 374: Ross Sea West Antarctic Ice Sheet History

Site U1522 Summary

Background and Objectives

International Ocean Discovery Program (IODP) Site U1522 is located in the Glomar Challenger Trough at 76°33.2262′S and 174°45.4652′W in 558 m of water. During the middle Miocene this site was located near the eastern edge of a wide embayment ~80 km southeast of the shelf break. Coring at this site was anticipated to recover a sedimentary sequence that spans the middle Miocene to the Pleistocene (coinciding with the seismic unconformities RSU3 to RSU1). It targeted laminated and massive acoustic facies, interpreted as interlayered stratified diamictite/mudstone and diatomite (glaciomarine/open marine) and massive diamictite (tills), respectively.

The upper ~400 m (1.2 s two-way traveltime [TWT]) of sediment consists of tabular units that are interpreted as aggradational subglacial till sheets deposited by a grounded ice sheet (i.e., lithified/compacted sediments) during the late Pleistocene (Alonso et al., 1992; De Santis et al., 1995). Underlying the till sheets is ~300 m of acoustically laminated facies, interbedded with more transparent lens-shaped layers, interpreted as glaciomarine or hemipelagic sediments and ice proximal deposits (Böhm et al., 2009). This site will enable us to determine if ice sheet overriding events observed in the ANDRILL AND-1B site, beneath the modern Ross Ice Shelf, advanced to the shelf edge, and will therefore help constrain the contribution of Antarctica's ice sheets to Pliocene sea level lowstands (Objective 1) (Naish et al., 2009; Miller et al., 2012). During periods of glaciomarine deposition, this site will provide an opportunity to reconstruct the paleooceanographic and paleoecological conditions at the outermost Ross Sea continental shelf (Objective 2). It is anticipated these sequences, combined with downhole logging to fill in unrecovered sections, may also provide insights into the orbital controls on marine-based ice sheet extent (Objective 4).

Operations

After an 88 nmi transit from Site U1521 that averaged 10.7 kt, the vessel arrived at Site U1522 (proposed Site EBOCS-03C) at 0629 h (UTC + 13 h) on 22 January 2018. The original operations plan consisted of a single rotary core barrel (RCB) hole to 545 m drilling depth below seafloor (DSF); however, after requesting and receiving approval from the Environmental Protection and Safety Panel (EPSP) and Texas A&M Safety Panel, we ultimately cored Hole U1522A to 701.8 m DSF (Cores U1522A-1R through 76R). Core recovery was very poor from 0–203.2 m DSF, moderate from 203.2–424.5 m DSF, and improved significantly below that depth. Hole cleaning became problematic near the end of coring operations and off-bottom torque steadily increased, despite multiple heavy mud sweeps to clean the hole. At the end of coring operations, the hole was displaced with heavy mud (10.5 lb/gal) and logged with three tool strings: a modified triple combo, the Versatile Seismic Imager (VSI), and the Formation MicroScanner (FMS). The Dipole Sonic Imager (DSI) was run on the triple combo instead of with the FMS, and the Hostile Environment Litho-Density Sonde was run without the source for measurement of borehole diameter with the caliper. Operations at Site U1522 concluded at 1311 h on 28 January. A total of 149.25 h (6.2 d) were spent on Site U1522. RCB coring in Hole U1522A penetrated to 701.8 m DSF and recovered 279.57 m of core (40%).

Principal Results

The 695.74 m succession of upper Miocene to recent sediment cored at Site U1522 is divided into four lithostratigraphic units (I to IV [oldest]). Unit III is further subdivided into Subunits IIIA–IIIC. Several intervals are characterized by very poor recovery, consisting primarily of washed gravel and fall in. This compromises our ability to identify the lithological variations in some units, but may indicate the presence of unrecovered sand- or gravel-rich beds. The dominant facies throughout the cores is massive diatom-bearing diamictite, although some intervals have thin beds of laminated mudstone, carbonate-cemented mudstone, and mud-rich diatomite.

Lithostratigraphic Unit I consists of ~200 m of Pleistocene diatom-bearing sandy mud, muddy sand, and muddy diamict. The upper ~3 m of the unit consists of unconsolidated, diatom-rich sandy mud to diatom-bearing sandy mud with dispersed clasts. Recovery is mostly poor between ~3 and ~200 m core depth below seafloor (CSF-A), consisting primarily of washed cobble and gravel resulting from drilling disturbance. A few recovered intervals contain massive clast-rich diatom-bearing muddy diamict. The base of Unit I is defined by increased lithification of the diamict. Lithostratigraphic Unit II consists ~195 m of Pliocene massive diatom-bearing sandy to muddy diamictite, with clast-rich and clast-poor intervals interbedded over tens of meters. Diatom-bearing mudstone and deformed (physically intermixed during deposition) discontinuous laminae to centimeter-scale beds are occasionally present within the muddy diamictite. Lithostratigraphic Unit III (~250 m) includes upper Miocene diatomite and diatom-bearing/rich diamictite and is subdivided into three subunits based on the style of interbedding and presence of lithological accessories. Clasts occur throughout, but there are changes in clast assemblage and composition among subunits. Subunit IIIA consists of massive bioturbated diatomite with glauconite and interbedded massive diatom-rich sandy and muddy diamictite with predominantly small (<1 cm) mudstone clasts. Subunit IIIB consists of interbedded diatom-bearing sandy and muddy diamictite with common chert clasts. Subunit IIIC consists of diatom-bearing sandy diamictite. Some intervals contain stratification characterized by thin beds of laminated mudstone and changes in matrix color, whereas massive diamictite beds are heavily bioturbated. While there are diverse clast lithologies throughout the recovered succession, this is the only interval where basalt clasts are common, suggesting a switch in provenance at this time. The base of Subunit IIIC is defined by interbeds of stratified and massive diamictite and diatomite. Lithostratigraphic Unit IV consists of ~50 m of upper Miocene interbedded diatom-bearing sandy diamictite, diatomite, and massive sandy diamictite.

Micropaleontological investigations were performed on all core catcher samples and two additional samples from split core sections to obtain biostratigraphic ages and preliminary paleoenvironmental information through examination of diatom, radiolarian, foraminifer, and palynomorph assemblages. Abundance and preservation of the different microfossil groups strongly varies throughout the sequence. In general, all microfossil groups are rare and comprise a combination of in situ and reworked taxa in the upper ~200 m CSF-A. Diatoms and radiolarians are more abundant between ~200 and 400 m CSF-A and dinoflagellates are common in the lower part of that interval. Below ~400 m CSF-A, radiolarians are absent, whereas palynomorphs and foraminifers are sparse. The diatom assemblage between ~400 and 480 m CSF-A is poorly preserved and primarily reworked, whereas below ~480 m CSF-A, diatom assemblages are mixed, with a few intervals of well-preserved diverse assemblages interspersed with mostly fragmented sparse assemblages.

The mudline sample contains a modern low diversity radiolarian assemblage that is typical of the Antarctic continental shelf, including mainly *Antarctissa* spp., together with significant numbers of *Rhizoplegma boreale* and the *Phormacantha hystrix*/*Plectacantha oikiskos* group. Below the mudline sample, the upper ~200 m CSF-A is tentatively assigned a Pleistocene age; however, the combination of sparse microfossils and mix of in situ and reworked taxa hinders straightforward age assignment and environmental reconstructions. Calcareous benthic foraminifers are represented by few specimens of typical late Neogene Ross Sea shelf species, although many of the specimens are likely reworked. One sample at ~135 m CSF-A contains a well-preserved assemblage that includes the planktonic foraminifer *Neogloboquadrina pachyderma*.

The interval between ~200 and 400 m CSF-A is assigned a Pliocene age based on diatoms and radiolarians, which were critical for providing age constraints at this site. One sample from ~400 m CSF-A contains well-preserved diatom, radiolarian, and dinocyst taxa that are indicative of high productivity environmental conditions that were warmer than today. From ~400 to 480 m CSF-A, microfossil assemblages are sparse and poorly preserved and reworking makes age assignment and environmental reconstructions difficult. Below ~490 m CSF-A, the absence of diatom *Thalassiosira torokina* indicates a late Miocene age >9 Ma. From ~490 m CSF-A to the base of the cored interval at 695.74 m CSF-A, diatom and dinocyst assemblages suggest an expanded upper Miocene sequence. A few samples from this interval contain well-preserved, diverse dinocyst assemblages that include the late Miocene species *Selenopemphix bothrion* (Harland and Pudsey, 2002). This assemblage suggests high productivity, likely with reduced sea ice relative to present day.

Paleomagnetic investigations primarily focused on measurements of archive-half core sections to determine the characteristic remanent magnetization (ChRM) and to construct a magnetostratigraphy. The natural remanent magnetization (NRM) of most archive-half core sections was measured before and after progressive alternating field (AF) demagnetization, usually in 5 mT increments up to 20 mT. NRM intensities commonly decrease by approximately one order of magnitude throughout this demagnetization sequence, and in general agree with the magnetic susceptibility measured with the Whole-Round Multisensor Logger (WRMSL) and Section Half Multisensor Logger (SHMSL). NRM inclinations are predominantly positive prior to demagnetization, and reveal scattered clusters of normal and reversed polarity after 20 mT peak AF demagnetization.

Discrete samples were used to test the fidelity of the archive-half NRM measurements by progressive demagnetization in 2 mT steps up to 20 mT, 5 mT increments up to 60 mT, and 10 mT steps up to 80 mT. The NRM directions of a majority of these discrete samples quickly become erratic, but several samples contain a stable direction that matches the archive-half directions. The normal and reversed polarity zones identified in both archive halves and discrete samples cannot yet be confidently correlated to the geomagnetic polarity timescale with the available biostratigraphic age control; postcruise work to refine the biostratigraphy should improve the correlation. Discrete samples were also used to measure the anisotropy of magnetic susceptibility (AMS) to determine magnetic fabric characteristics.

Physical property measurements were conducted on all cores collected. In general, the whole-round core bulk density and magnetic susceptibility (MS) measurements show similar trends to those from discrete moisture and density (MAD) samples and point measurements of MS on the section halves. Overall, downhole trends in MS, natural gamma radiation (NGR), bulk density, *P*-wave velocity, and porosity correspond well with the defined lithostratigraphic units. In general, higher MS corresponds to higher NGR, bulk density, *P*-wave velocity, and lower porosity, and is likely related to the dominance of a mud-rich matrix within the diamictite recovered at this site. NGR, density, and *P*-wave velocity are lower in Unit II (diatom-bearing sandy and muddy diamictite) relative to Units III and IV, possibly indicating a change in the clast or matrix composition. Within Subunits IIIB, IIIC, and IV, variations in physical properties are related to lithology (muddy diamictite vs. sandy diamictite), and the relative abundance of diatoms, mud clasts, carbonate nodules, and basalt clasts. Within these units, higher MS, NGR, density, *P*-wave velocity, and lower porosity correspond to higher proportions of basalt and/or metasedimentary clasts, and diatom-bearing lithologies. Lower MS, NGR, density, *P*-wave velocity, and higher porosity corresponds to higher proportions of mud clasts, carbonate nodules, and diatom-rich lithologies.

Headspace gases are low in the uppermost ~200 m CSF-A and display variable methane and increasing ethane concentrations from ~200 m CSF-A to the bottom of the hole. Interstitial water analyses of the mudline and five whole-round samples indicate early diagenesis immediately below the sediment/water interface, with sulfate reduction in the upper 100 m CSF-A and manganese reduction down to 215.4 m CSF-A. Total organic carbon and calcium carbonate contents are generally low (<0.6 wt% and <3.5 wt%, respectively). Carbonate content increases slightly downhole, with values generally higher between ~400 and 630 m CSF-A. The slightly elevated carbonate content and decreasing total organic carbon/total nitrogen ratio between ~400 and 630 m CSF-A may suggest more marine conditions during deposition of the diamictite of lithostratigraphic Unit III compared with Units I and II. Systematic variations in handheld X-ray fluorescence (XRF) data indicate the potential for detailed reconstruction of sediment provenance, particularly in Units II to IV.

Downhole logging consisted of three tool strings that included a modified triple combo with the sonic tool and without the source in the density tool, the Versatile Seismic Imager (VSI) to conduct a vertical seismic profile (VSP) experiment, and the Formation MicroScanner (FMS). The triple combo measured borehole diameter, NGR, resistivity, sonic velocity, and MS. The triple combo reached 650.3 m wireline depth below seafloor (WSF), or approximately 50 m above the bottom of the hole. Caliper data show that the borehole size varied significantly, with numerous washed out intervals and multiple ledges, which resulted in the VSI and FMS tool strings reaching only to 297.5 m WSF.

Despite the lower quality borehole conditions compared to our previous Site U1521, downhole data generally match well with results from core measurements. NGR data from downhole logging show good correspondence with NGR data from whole-round cores, whereas the core-based *P*-wave velocity consistently underestimates the velocity relative to the downhole log data although the general trends are similar. Alongside other downhole logging datasets, the FMS resistivity images appear to be of reasonable quality and should help assess lithologies in the poorly recovered upper part of the formation. Checkshot data was successfully collected at eight depths with the VSI tool (geophone). Raw checkshot data were used in preliminary velocity models for initial core-log-seismic integration.

References

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