IODP Expedition 374: Ross Sea West Antarctic Ice Sheet History

Site U1523 Summary

Background and Objectives

International Ocean Discovery Program (IODP) Site U1523 is located on the southeastern flank of the Iselin Bank, ~50 km to the northwest of the Pennell Trough, at 74°9.02′S and 179°47.70′W in 828 m of water. The site is on the outermost continental shelf edge and lies beneath the modern-day Antarctic Slope Current (Orsi et al., 2009). The targeted sediments are drift deposits, characterized by stratified, parallel seismic reflectors with high to medium amplitude. Undulations in the seafloor and subseafloor reflectors occur towards the top of the bank, 12 km to the west of Site U1523, and are interpreted as iceberg scour marks. The scour marks cross cut into the youngest strata, and iceberg keels ploughing into this sediment may act to remobilize sediment deposited on the bank. Further west (~80 km), seismic profiles show flat-topped ridges interpreted to represent grounding zone wedges. Ice sheet models suggest that during the Last Glacial Maximum these likely formed as a consequence of eastward ice flow from an ice divide forming on the bathymetric high of the Pennell Bank (Golledge et al., 2013). Consequently, sediment supply at this site could arise from a combination of sources, including icebergs and suspended sediment from the east via the Antarctic Slope Current; downslope delivery via glacial outwash and glaciogenic debris flows at the margin of an ice sheet grounded on northernmost Pennell Bank to the west of the site; downslope delivery by suspended sediment scoured by icebergs to the west of the site; and pelagic sedimentation. Bottom currents associated with the Antarctic Slope Current in this region are modeled to be between ~10–20 cm/s (Padman and Fricker, 2005), and winnowing of fines is expected during periods of enhanced bottom current flow. Jacobs et al. (1974) reported strong diurnal signals and average and maximum velocities above 17 cm/s and 40 cm/s, respectively, at 4 m above the seafloor in 527–1201 m water depth in the Ross Sea.

The primary objectives of Site U1523 are to reconstruct fluctuations in the Antarctic Slope Current during the Neogene and Quaternary (Objective 3) and to recover a high-resolution record that can be correlated to inner and outer shelf records of ice sheet advance and retreat (e.g., Site U1522 and ANDRILL AND-1B [Naish et al., 2009]). In order to achieve this, Site U1523 aimed to sample the upper sedimentary section above the RSU4 unconformity. The record of deposition and winnowing beneath the Antarctic Slope Current from Site U1523 will enable testing of the hypothesis that changes in the strength of this wind driven ocean current regulated the southward transport of warm Circumpolar Deepwater onto the Ross Sea continental shelf during past ice sheet retreat events. Another objective is the reconstruction of ice proximal oceanic temperatures and surface water properties during periods of pelagic/hemipelagic sedimentation. This will constrain the magnitude of polar amplification during past warm periods of the Neogene and Quaternary (Objective 2). An additional objective is to identify processes that govern sediment transfer between the outermost continental shelf and the upper continental slope/rise.

Operations

After a 147 nmi transit from Site U1522 that averaged 11.5 kt, the vessel arrived at Site U1523 (proposed Site RSCR-14A) at 0158 h (UTC + 13 h) on 29 January 2018. This site is an alternate that was occupied after coring at Site U1522 demonstrated that core recovery would likely be poor in the targeted upper interval of the original proposed primary Site EBOCS-04B. We planned to core two holes: one cored with the advanced piston corer (APC) to refusal, followed by an APC/extended core barrel (XCB) hole to 450 m drilling depth below seafloor (DSF). Instead, we ultimately cored five holes at Site U1523 due to difficult coring conditions that required additional holes to achieve the objectives. Prior to starting coring, we conducted a seafloor camera survey to ensure we could avoid large rocks. The survey included tagging the seafloor at four potential hole locations.

Hole U1523A was cored with a combination of the APC and half-length APC (HLAPC) coring systems to 46.3 m DSF when we were unable to land the HLAPC core barrel. The hole was terminated and we pulled the drill string above the seafloor to try to clean out the bottom-hole assembly (BHA). After we were unable to reestablish circulation through the drill string, we had to pull the pipe back to the surface to clean the debris (rocks and sand/gravel) from the BHA. The debris was curated as a ghost core. The APC/XCB BHA was reassembled, run back to the seafloor, and Hole U1523B was cored to a final depth of 164.4 m DSF. Towards the end of coring operations in Hole U1523B, hole cleaning became a problem and off bottom torque steadily increased despite efforts to clean the hole. In addition, the rotary coring with the XCB system yielded very poor recovery, so we terminated operations in Hole U1523B with the intention of using the HLAPC in Hole U1523C to target specific stratigraphic gaps not recovered in Holes U1523A and U1523B. After pulling clear of the seafloor from Hole U1523B, it became apparent that our ability to circulate through the bit jets was compromised. After attempting to clear the bit jets, we started Hole U1523C and drilled without coring to 43.3 m DSF. At that depth, we completely lost circulation through the drill string and we were forced to terminate operations and pull the drill string back to the rig floor.

We then decided to use the rotary core barrel (RCB) system to core and log to at least 300 m DSF. Hole U1523D was drilled without coring from the seafloor to 135.0 m DSF. RCB coring then penetrated from 130.5 m DSF to a final depth of 307.8 m DSF. We opted not to deepen the hole further due to very poor recovery (0.9 m [<1%]). At the end of coring operations, the hole was displaced with heavy mud (10.5 lb/gal) and logged with two tool strings: a modified triple combo 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 (HLDS) was run without the source for measurement of borehole diameter with the caliper. After completion of logging we used the APC and HLAPC to spot core in Hole U1523E to cover stratigraphic gaps from Holes U1523A and U1523B. Hole U1523E was successfully spot cored to 130.8 m DSF. After completion of coring, the drill string was recovered and the rig floor was secured at 0547 h on 3 February 2018, ending Hole U1523E and Site U1523. A total of 147.5 h (6.15 d) was spent on Site U1523.

We collected a total of 64 cores at Site U1523. The APC coring system was deployed five times, recovering 41.57 m of sediment (91%). The HLAPC coring system was used 33 times, collecting 87.99 m (59%). The XCB coring system collected 3.16 m of core (5%) over eight cores. The RCB system was deployed 18 times over 172.8 m, recovering 0.9 m (0.5%).

Principal Results

The upper ~155 m of sediment recovered at Site U1523 is divided into three lithostratigraphic units (I to III [oldest]) dated to the late Miocene to Pleistocene. Below ~155 m core depth below seafloor (CSF-A), poor recovery in Hole U1523D precluded definition of lithostratigraphic units. Above 155 m CSF-A there are also several intervals characterized by poor recovery, fall-in, and washed gravel. This compromises our ability to identify lithological variations and some contacts between units, but may indicate the presence of unrecovered sand- and/or gravel-rich beds. When recovered, the contacts between units are mostly sharp. The major facies at Site U1523 are massive diamict, mud, diatomite to diatom-rich mudstone, diatom-bearing mudstone, and sand. The assemblage of facies reflects open water to ice-proximal depositional environments on the outer Ross Sea continental shelf since the late Miocene.

Lithostratigraphic Unit I consists of ~35 m of Pleistocene massive to laminated bioturbated greenish gray to grayish brown diatom-bearing mud interbedded at decimeter-scale with foraminifer-bearing/rich sand with dispersed clasts and clast-rich sandy to muddy diamict. Large rock clasts of diverse lithologies, mud clasts, and pyrite staining occur throughout, and some shell fragments and lignite are observed in some intervals. The base of Unit I is defined by a decrease in foraminifer abundance and increase in diatom abundance. Unit II is an ~60 m thick sequence of Pliocene to Pleistocene massive to laminated greenish gray diatom-bearing mud and olive brown to olive gray diatom-rich mud interbedded at decimeter- to meter-scale with massive gray to greenish gray muddy sand, sand, and diamict. Bioturbation is common throughout Unit II and it is defined by the presence of both diatom-rich mud/diatom ooze and glauconite, which is most abundant in sand beds. Pyrite staining, large rock clasts, and mud clasts are observed throughout, and shell fragments, bryozoans, and worm tubes are observed in some intervals. The base of Unit II is defined by the deepest diatom-rich sandy mud. Unit III includes ~50 m of upper Miocene massive to laminated pale green, grayish green, and dark gray diatom-bearing mud interbedded at decimeter-scale with greenish gray mud with dispersed clasts, sandy mud, and diamict. Unit III is similar to Unit II, but distinguished by a decrease in diatom content and increase in terrigenous component relative to Unit II.

Core catcher samples from Holes U1523A, U1523B, U1523D, and U1523E were examined for siliceous (diatoms, radiolarians, silicoflagellates, ebridians, and chrysophycean cysts), calcareous (foraminifers), and organic (dinoflagellate cysts and other aquatic palynomorphs, pollen, and spores) microfossils. Diatom remains were encountered in all samples, and radiolarians are generally rare, but several intervals record higher abundance and better preservation that provide important biostratigraphic control, especially for the upper Miocene. A distinctive modern open ocean radiolarian assemblage is present in the mudline sample of this site, which contrasts with the coastal assemblage present in the mudline sample from our previous Site U1522. Organic and calcareous microfossils occur sporadically throughout the entire recovered sequence. Dinocysts are often rare, except in the upper Pliocene and upper Miocene intervals. Foraminifers are most abundant in the upper Pleistocene. A unique monospecific assemblage of agglutinated benthic foraminifers was observed in the upper Miocene of Holes U1523B and U1523E, and foraminifer assemblages could be correlated between different holes.

Diatoms, radiolarians, and dinocysts provide a sequence of biostratigraphic datums, which allow for correlation across holes, as well as development of a composite age model. Three broad stratigraphic intervals, separated by disconformities, correspond generally to lithostratigraphic units and represent deposition of (1) an upper Pleistocene age interval comprising largely mixed and reworked sediments (corresponding to lithostratigraphic Unit I), (2) an upper Pliocene to lower Pleistocene interval (Unit II), with sediment accumulation rates approaching 23 cm/ky of diatom-rich mud and diatom ooze, and (3) an upper middle Miocene to upper Miocene interval (Unit III).

Paleomagnetic analyses of Holes U1523A, U1523B, and U1523E focused on constructing a magnetostratigraphy using the characteristic remanent magnetization (ChRM). The natural remanent magnetization (NRM) of archive-half core sections was measured before and after progressive alternating field (AF) demagnetization in 5 mT steps up to 20 mT. NRM intensities prior to demagnetization are mostly ~10^{-1} A/m and agree well with the Whole-Round Multisensor Logger (WRMSL), Section Half Multisensor Logger (SHMSL), and Kappabridge magnetic susceptibility values. This agreement suggests that all of these parameters are approximately equally influenced by magnetic concentration, which seems to be relatively constant throughout all three lithostratigraphic units. NRM inclinations are predominantly positive prior to demagnetization, but group in clusters of normal and reversed polarity after AF demagnetization. Discrete samples were used to test the fidelity of the archive-half NRM measurements in a 20 mT peak AF demagnetization sequence. At least three components are present with variable coercivities: a viscous remanent magnetization, a drilling overprint, and a third component with higher coercivity that most likely carries the ChRM.

The normal and reversed polarity zones identified in both archive halves and discrete samples are correlated to the geomagnetic polarity timescale using constraints from biostratigraphic datums. These tie points allow us to tentatively identify the tops of Subchron C2An.1n and Chron C4An. Measurements of anisotropy of magnetic susceptibility (AMS) on discrete samples demonstrates that the magnetic fabric is generally oblate. However, k_{min} inclinations $<60°$ frequently occur and coincide with intervals of coarser grain sizes, suggesting a change in compaction in these intervals relative to fine-grained intervals.

Physical property measurements were conducted on cores from Holes U1523A, U1523B, and U1523E. In general, the whole-round core bulk density, magnetic susceptibility (MS), and *P*-wave velocity measurements are in good agreement with discrete moisture and density (MAD) samples and point measurements of MS and *P*-wave velocity on the section halves. Downhole changes in physical properties are in good overall agreement with the defined lithostratigraphic units based on sedimentological characteristics, and changes in physical properties can provide insight into lithologic variations within each unit. MS is highly variable in Unit I, corresponding to alternating sandy and muddy layers with abundant clasts and muddy diamict. Bulk density increases downhole and is anticorrelated with porosity, which decreases downhole in Unit I, suggesting compaction. Below Unit I, bulk density and porosity show significant variation that likely reflects diatom content. For instance, low bulk density, MS, and natural gamma radiation (NGR) values in the middle of Unit II (~60–70 m CSF-A) are correlated with diatom-rich mud intervals. Relatively high and stable NGR values in Unit III indicate relatively high clay mineral content in the massive bioturbated to laminated diatom-bearing mud and sandy mud.

Samples for headspace gas, interstitial water (IW) chemistry, and bulk sediment geochemistry were analyzed at Site U1523. Concentrations of methane and ethane are close to or below the detection limit, respectively. In addition to low-resolution IW sampling (~1 sample per core or every other half-length core) throughout Holes U1523A, U1523B, and U1523E, a high-resolution profile of IW chemistry was obtained for the upper 8 m in Hole U1523B. Low-resolution downhole trends suggest manganese and sulfate reduction in the suboxic to anoxic transition zone (by ~130 m CSF-A). Rapid increase in silica and manganese concentrations in the upper ~2 m probably reflect shallow diagenesis of silica. Bulk sediment total organic carbon and calcium carbonate contents are generally low (<0.6 wt% and <2.5 wt%, respectively). Total organic carbon is generally slightly lower in the diatom-bearing mud and diamict of Unit III. Higher carbonate content (up to ~15 wt%) is observed in foraminifer-bearing sandy mud in lithostratigraphic Units I and II. Total organic carbon/total nitrogen ratios do not display a discernible trend and suggest mixed input of marine and terrestrially derived organic matter. Handheld X-ray fluorescence (XRF) data indicate lower and more invariant Ba/Al ratios compared with Sites U1521 and U1522. In contrast, significant downhole variations are observed in ratios of refractory elements such as Th/Ti, which, alongside ratios like Fe/Ti, may serve as a provenance proxy at this site.

Downhole logging in Hole U1523D consisted of two tool strings that included a modified triple combo with the sonic tool and without the source in the density tool, and the Formation MicroScanner (FMS). The triple combo measured borehole diameter, NGR, resistivity, sonic velocity, and MS. The triple combo tool string reached to 292 m wireline log depth below seafloor (WSF), ~15 m above the total borehole depth, whereas the FMS tool string reached to 288 m WSF. The downhole logging data will be key for interpreting lithologic variation below

155 m CSF-A in Hole U1523D where overall core recovery was very poor (0.5%), as well as in poorly recovered intervals in the upper parts of the site. Although the caliper data identified a number of minor washouts, borehole conditions were reasonable and the log data show good correspondence with the core data over the ~80 m where there is overlap. Interestingly, although the trends and relative changes in magnitude of the NGR log data are similar to those from the cores, the core data are higher than those measured in situ. On the other hand, core-based *P*-wave velocity data are consistently lower than those from the downhole sonic log. The resistivity data show clear alternations of high and low resistivity throughout the borehole that may correspond to alternating layers of fine and coarse sediments. These are also apparent in the FMS resistivity images, together with localized high-resistivity spots that are interpreted as clasts within diamictite.

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