IODP Expedition 374: Ross Sea West Antarctic Ice Sheet History

Site U1525 Summary

Background and Objectives

International Ocean Discovery Program (IODP) Site U1525 is located on the continental slope at 75°0.06′S and 173°55.20′W in 1776 m water depth on the southwestern levee of the Hillary Canyon, in a similar depositional setting to Site U1524 (~87 km northeast). Site U1525 is closer to the continental shelf edge, which lies ~60 km to the south of the site, and the mouths of the Pennell and the Glomar Challenger Troughs. The levee shows asymmetric flanks, with a steep erosional flank to the northeast with a relief of ~500 m, and a less steep southwestern flank with a relief of only 30 m. The northeast flank sharply truncates parallel high amplitude reflectors, outcropping at the seafloor, and chaotic seismic facies suggest that slope failure features affect the mid- to lower units of the seismic profile.

Hillary Canyon is one of the largest conduits for newly formed Ross Sea Bottom Water (a type of Antarctic Bottom Water [AABW]), which is focused in this channel by cascading dense waters formed on the Ross Sea continental shelf passing down the continental rise. The site also lies beneath the modern-day eastward flowing Antarctic Slope Current (ASC), which is thought to be stronger here than at the deeper water Site U1524 (Whitworth et al. 1998; Orsi and Wiederwohl, 2009). Seismic profiles indicate the targeted sediments at Site U1525 are dominated by channel-overspill and drift deposits, as characterized by stratified, parallel seismic reflectors with high to medium amplitude. These strata in the upper ~50 m of the site are believed to be glacial debris flows, interlayered with interglacial hemipelagic units of Pleistocene age, that formed a prograding shelf margin fan at the mouth of the Glomar Challenger Trough since the late Miocene (RSU3).

The continental slope location of Site U1525 should allow for development of a more complete assessment of oceanic forcing of (and response to) Antarctic Ice Sheet (AIS) variability. The record of deposition from Site U1525 was anticipated to be primarily influenced by the Ross Sea Bottom Water (RSBW) flowing down the Hillary Canyon, but this signal is modified by an along-slope component associated with the easterly flowing ASC. Consequently, this site will enable assessment of the ocean forcing for ice sheet variability and drivers of bottom water production (Objective 2). The direct record of RSBW flow down Hillary Canyon obtained at Site U1525 could potentially be extrapolated to high-fidelity paleoceanographic records further afield in the abyssal Pacific Ocean to better constrain the Antarctic influences on the global oceanic deep circulation. Hillary Canyon is also a main route for glacial sediments being eroded and transported by ice streams from the innermost continental shelf to its edge. Provenance studies of the terrigenous sediment may allow for identification of changing ice sheet drainage pathways through the Neogene and Quaternary.

Ice rafted debris could be sourced by icebergs from the Ross Sea, as well as those transported from the east via the Antarctic Slope Current, providing a proxy for dynamic ice discharge from the Pacific Ocean coastline sector of the West Antarctic Ice Sheet. Pelagic deposits would be deposited during periods of high productivity or a lull in turbidity current overspill deposition, and will provide proxy records of surface water properties, including sea ice cover, sea surface temperature, stratification, and salinity. This will enable an assessment of the magnitude of polar amplification during past warm climates (Objective 2), as well as the role of oceanic forcing of ice sheet fluctuations during these times (Objective 3). In addition, continuous deposition was anticipated through much of the Late Neogene and Quaternary at this site, which would allow for assessment of the orbital response of the West Antarctic Ice Sheet, and adjacent oceanic/ biological system over a range of past climatic conditions (Objective 4). The late Quaternary record in the uppermost 50 m of glacial strata can also shed light on recent ice sheet advances.

Operations

After a 50 nmi transit from Site U1524 that averaged 8.9 kt, the vessel arrived at Site U1525 (proposed Site RSCR-03A) at 0200 h (UTC + 13 h) on 7 February 2018. This alternate site was added to the schedule when we were forced to leave Site U1524 temporarily due to encroaching sea ice. The operational plan for Site U1525 consisted of advanced piston corer (APC)/extended core barrel (XCB) coring in a single hole until ice moved away from Site U1524. Hole U1525A was cored to a total depth of 213.2 m drilling depth below seafloor (DSF) using a combination of APC, half-length APC (HLAPC), and XCB coring. The XCB was deployed in the upper part of the hole (43.0–55.7 m DSF) to core past an indurated interval. Next we switched back to piston coring and continued to core using both the APC and HLAPC systems to 131.2 m DSF. We then continued coring with the XCB to 213.2 m DSF. We terminated the hole at that depth after receiving confirmation that the sea ice was expected to clear from Site U1524 by the next day. The rig floor was secured for transit at 0535 h on 9 February to return to Site U1524. A total of 51.25 h (2.1 d) was spent on Hole U1525.

We collected a total of 33 cores at Site U1525. The APC system was deployed eight times, collecting 63.23 m of core (103%). The HLAPC system was deployed 14 times, recovering 52.64 m of core (92%). The XCB system was used 11 times and collected 42.83 m (45%).

Principal Results

Site U1525 cored a single hole to 208.28 m coring depth below seafloor (CSF-A). The 158.70 m of Pleistocene sediment recovered is divided into three lithostratigraphic units (I [youngest] to III [oldest]). Unit II is subdivided Subunits IIA and IIB. A few intervals (typically <15 m in length) are characterized by poor recovery, compromising our ability to identify lithological variations. Unit I consists of ~51 m of unconsolidated massive bioturbated gray diatom-bearing/rich mud to sandy mud with dispersed clasts interbedded on a meter-scale with gray to light yellowish brown clast-poor to clast-rich muddy diamict. Unit I bedding contacts are sharp to gradational. The muddy diamict is overcompacted in some intervals and contains randomly distributed clasts of igneous and metamorphic composition. The base of Unit I is within an interval of poor recovery; however, it is defined by a sharp contact between the overlying diamict and diatom-rich mud. Unit II consists of ~68 m of massive to laminated greenish gray diatom-bearing/rich mud and diatom ooze with dispersed clasts interbedded at decimeter- to meter-scale with sandy mud and diamict. Unit II is subdivided into two subunits based on diatom abundance and the structure and texture of laminations. Subunit IIA contains well-defined millimeter-scale fine sand, silt, and biosiliceous laminations with sharp lower boundaries and internal normal grading. Clasts, soft-sediment deformation features, and microfaulting are observed within the laminated sequences. Subunit IIA also contains intervals of bioturbated foraminifer-bearing sand with sharp upper and lower contacts within the massive diatom-bearing/rich mud beds. The boundary between Subunits IIA and IIB is distinguished by the onset of very thinly laminated silt and mud, with better preservation higher percentages of intact diatom frustules. Subunit IIB contains fine-grained sand and silt laminae within coarser grained sandy mud and diamict beds. Clasts, pyrite staining, and sand pods, lenses, and stringers are observed throughout the subunit. The base of Unit II is defined by a sharp contact between the laminated mud of Unit II and the underlying clast-rich sandy diamict. Unit III consists of ~20 m of massive to laminated greenish gray diatom-rich mud to muddy diatom ooze with dispersed to common clasts interbedded with massive bioturbated greenish gray diatom-rich sandy mud with dispersed clasts and diamict. Clasts, pyrite staining, and coarse sand pods/lenses and stringers occur throughout.

The major facies at Site U1525 are massive to stratified diamict, sand, mud, diatom-bearing mud, and diatom-rich mud to diatom ooze. The assemblage of facies reflects an interplay between distal downslope, along-slope (e.g., winnowing), hemipelagic, and pelagic processes in a relatively ice distal glaciomarine setting. Both thin laminations (millimeter- to centimeter-scale) and thick beds (meter-scale) are recognized in all units, and may be linked to glacial dynamics and ocean circulation variations during the Pleistocene.

Core catcher samples from Site U1525 were analyzed for siliceous (diatoms, radiolarians, silicoflagellates, ebridians), calcareous (foraminifers, nannofossils), and organic (dinoflagellate cysts and other aquatic palynomorphs, pollen, and spores) microfossils. Samples in the upper ~107 m CSF-A of the section are mostly devoid of microfossils, contain only trace numbers, or include a "residual" assemblage of resistant forms that have likely been engaged in multiple phases of transport and reworking by ice and/or bottom currents. Diatom taxa found in this interval were eroded and transported from discrete source beds of Miocene to early Pliocene age. One age-diagnostic radiolarian event is found in this interval and indicates an age >0.65 Ma at ~30 m CSF-A. Several discrete intervals of foraminifer-bearing/rich sand are present near the base of this interval and a sparse, moderately well-preserved Neogene assemblage of calcareous nannofossils was found in one of these beds.

Below ~107 m CSF-A, siliceous microfossils are more abundant and well preserved, and several age diagnostic radiolarians and diatoms were encountered. Although a small background presence of reworked diatoms continues in this interval, the sequence can confidently be assigned an early Pleistocene age. Planktonic and benthic foraminifers are also most abundant and diverse in this lower Pleistocene section and the presence of the temperate planktonic species *Globoconella inflata* at ~89 m CSF-A, and *Globigerina bulloides* and *G. falconensis* at ~125 m CSF-A, indicates the presence of warmer than present waters. Dinocysts are sparse in this interval, and only one sample from the lower Pleistocene (~155 m CSF-A) contains abundant specimens, comprising species so far only known from upper Quaternary sediments of the Atlantic sector of the Southern Ocean, south of the Polar Front.

We developed an age model for Site U1525 using a combination of radiolarian and diatom biostratigraphic events. A hiatus is detected by biostratigraphic (diatom) marker species between ~111 and 117 m CSF-A that constrain the age of sediments below to >2.35 Ma, and above to <1.9 Ma. The lowermost ~100 m of the Site U1525 sequence represents an expanded lower Pleistocene section with a sustained high sediment accumulation rate of >60 cm/ky. Above the disconformity, significant amounts of reworked microfossils in the upper ~107 m CSF-A preclude definitive age assignment for the interval.

Paleomagnetic investigations primarily focused on determining the characteristic remanent magnetization (ChRM) to construct a magnetostratigraphy. The initial natural remanent magnetization (NRM) was measured at 5 cm intervals on most archive-half core sections, followed by NRM measurements after peak alternating field (AF) demagnetization of 10 and 20 mT to remove a potential drilling overprint. The NRM intensity of cores above ~100 m CSF-A decreases up to an order of magnitude after 10 mT, whereas the NRM intensity of cores from deeper than ~100 m CSF-A decreases by 30%–50% after demagnetization. Initial NRM inclinations are generally steep and downward directed, but AF demagnetization removes this overprint to reveal clusters of steep up- and downward-directed inclinations. We interpret these clusters as normal and reversed polarity zones. To test the fidelity of these polarity zones, we also subjected a selected group of oriented discrete samples to a 20-step demagnetization protocol and used principal component analysis to determine the ChRM direction. The discrete and archive-half measurements agree well so that we can correlate the normal and reversed polarity zones to the geomagnetic polarity timescale, aided by the independent biostratigraphic age control. We identify the Jaramillo (0.988–1.072 Ma) and Cobb Mountain (1.173–1.185 Ma) subchrons, as well as the Olduvai chron (1.778–1.945 Ma). We correlate a zone of reversed polarity below the hiatus to Subchron C2r.2r (2.148–2.581 Ma) based on diatom constraints.

Physical property measurements were conducted on all cores of Hole U1525A. In general, the whole-round core gamma ray attenuation (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 over the upper 131 m CSF-A, which were cored with the APC and HLAPC. The switch to XCB coring below that depth has an effect on whole-round measurements, especially MS, natural gamma radiation (NGR), and GRA bulk density because the diameter of XCB cores does not completely fill the core liner. The *P*-wave logger was turned off below 131 m CSF-A.

Lithostratigraphic Unit I shows a downhole increase in MS, NGR, density, *P*-wave velocity, and shear strength, and a decrease in porosity. These changes reflect both compaction and slight changes in lithology within the diatom-bearing sandy mud interbedded with clast-poor muddy diamict. A short interval within Unit I (~15–18 m CSF-A) shows peaks in MS, NGR, density, *P*-wave velocity, and shear strength, and a decrease in porosity that reflect increased clasts, clay, and compaction within this clast-rich diamict unit, which is interpreted as a debris flow. Within Unit II, decimeter-scale cyclicity visible in MS and NGR is likely related to downhole changes in lithology. Shear strength within Unit II also demonstrates downhole cyclicity that may be related to lithologic changes or compaction. Generally lower MS, NGR, density, and *P*-wave velocity within Unit III reflects increased diatom content.

Samples for headspace gas, interstitial water (IW) chemistry, and bulk sediment geochemistry were analyzed at Site U1525. Headspace gas (methane, ethane) concentrations are low in the upper 124 m CSF-A and increase to 6,640 and 7 ppmv, respectively, at 194 m CSF-A. IW analyses of the mudline and twelve whole-round samples indicate biogeochemical zonation with sulfate reduction in the top 100 m CSF-A. Downhole variations in silica concentration broadly correspond with lithological changes, whereas calcium concentration decreases from seawater values in the uppermost 32 m CSF-A to a minimum value around the boundary between lithostratigraphic Subunit IIB and Unit III. Lithium concentration increases by a factor of three along a linear trend below ~60 m CSF-A. Total organic carbon and carbonate contents are low (<1% and 5%, respectively) throughout the site. The highest, and most variable, carbonate content and total organic carbon/total nitrogen ratios occur in the uppermost ~35 m CSF-A within lithostratigraphic Unit I.

References

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