IODP Expedition 374: Ross Sea West Antarctic Ice Sheet History

Site U1524 Summary

Background and Objectives

International Ocean Discovery Program (IODP) Site U1524 is located on the continental rise at 74°13.05′S and 173°37.98′W in 2394 m water depth on the southwestern levee of the Hillary Canyon. The levee at this site has a relief of ~500 m, and is located ~120 km north of the Ross Sea ice shelf edge. The head of the Hillary Canyon system is located at the mouths of the Pennell Trough and the Glomar Challenger Trough. 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 dense waters formed on the Ross Sea continental shelf cascading through the troughs and down the continental slope and rise. The site also lies beneath the modern-day eastward flowing Antarctic Slope Current (ASC). The targeted sediments are interpreted from seismic profiles to be channel-overspill and drift deposits, characterized by stratified, parallel seismic reflectors with high to medium amplitude.

The primary objectives of Site U1524 were to obtain a near-continuous post-RSU3 (upper Miocene to Pleistocene) and pre-RSU3 (middle to upper Miocene) sediment sequence to provide a high-resolution chronology and an ice-distal record of glacial/interglacial cycles. The continental rise location of Site U1524 should allow a more complete assessment of oceanic response to Antarctic Ice Sheet (AIS) variability. The record of deposition from Site U1524 was anticipated to be primarily influenced by Ross Sea Bottom Water flowing down Hillary Canyon, but also by an along-slope component due to the easterly flowing ASC. Consequently, this site will enable assessment of the oceanographic influence on ice sheet variability and bottom water production (Objective 2). The direct record of AABW flow down the Hillary Canyon obtained at Site U1524 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. The 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, and provenance studies of the terrigenous sediment may allow for identification of changing ice sheet drainage pathways through the Neogene and Quaternary. Site U1524 near the crest of the levee of the Hillary Canyon will also provide a high resolution distal record for documenting the proximal deep sea response to ice sheet change on the continental shelf, which is recorded in the Ross Sea inner (ANDRILL Site AND-1B; Naish et al., 2009) and outer continental shelf (IODP Site U1522). Ice rafted debris could be sourced by icebergs calving from the Ross Sea, as well as transported from the east via the ASC, providing a proxy for dynamic ice discharge from the Pacific coastline sector of the West Antarctic Ice Sheet. Pelagic deposits deposited during periods of high productivity or a lull in turbidity current overspill deposition will provide a proxy record 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 retreat or advance at these times (Objective 3). In addition, continuous deposition was anticipated at this site through much of the Neogene and Quaternary to 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).

Operations

After a 52 nmi transit from Site U1523 that averaged 11.1 kt, the vessel arrived at Site U1524 (proposed Site RSCR-10A) at 1027 h (UTC + 13 h) on 4 February 2018. This site is an alternate for primary proposed Site RSCR-02B. We decided to occupy the alternate site because the highest priority target is shallower, the seismic facies show less evidence for transported sediment, and the sea-ice edge was further away. The original plan called for three holes: one cored to refusal with the advanced piston corer (APC), followed by an APC/extended core barrel (XCB) hole to 350 m drilling depth below seafloor (DSF). The third hole was to be cored to 1000 m DSF with the rotary core barrel (RCB), then logged with three tool strings. We ultimately cored three holes. Hole U1524A was cored with the APC/XCB to 299.5 m CSF-A. Hole U1524B consisted of a single mudline core collected for high-resolution sampling. Hole U1524C was an RCB hole cored to 441.9 m DSF.

Hole U1524A was cored to APC refusal at 270.3 m DSF. We deployed the half-length APC (HLAPC); however, the first core advanced only 0.4 m to 270.7 m DSF, indicating HLAPC refusal. We then deployed the XCB system and cored to 299.5 m DSF; however, each XCB returned with a shattered liner and highly disturbed sediment. At that point we had to terminate coring to pull out of the hole due to approaching sea ice. After pulling out of the hole, enough time remained to collect a single mudline core (Hole U1524B) for high-resolution interstitial water and microbiological studies. After terminating coring in Hole U1524B, we retrieved the drill string and departed Site U1524 at 2030 h on 6 February. With sea ice estimated to remain over Site U1524 for at least 2 d, we opted to occupy Site U1525 (proposed Site RSCR-03A) located only 47 nmi away but in a position south of the sea ice edge. After ice monitoring determined that the sea ice was moving away from Site U1524, we ended operations at Site U1525 at 0535 h on 9 February to return to Site U1524. After arriving back at Site U1524 at 1006 h we prepared for RCB coring operations in Hole U1524C. While deploying the drill string, we lowered the subsea camera to retrieve the beacon, which had failed to release when abandoning the site. After retrieving the beacon, Hole U1524C was drilled without coring to 260.5 m DSF, then RCB cored to 441.9 m DSF when we were forced to terminate operations due to a mechanical breakdown of the port stern tube shaft and arrangement that ended Expedition 374 science operations. The rig floor was secured for transit at 1835 h on 11 February, ending Site U1524. Total time spent at Site U1524 was 117.25 h (4.9 d).

We collected a total of 54 cores at Site U1524. The APC system was deployed 31 times, collecting 284.17 m of core (102%). The HLAPC system was deployed once, recovering 0.43 m of core (108%). The XCB system collected 5.51 m over three cores (19%). The RCB system was used 19 times, collecting 19.2 m of core (11%).

Principal Results

Site U1524 includes three holes, with the deepest cored to 441.9 m coring depth below seafloor (CSF-A). The upper Miocene to Pleistocene sediment recovered is divided into three lithostratigraphic units (I [youngest] to III [oldest]). Unit I is subdivided into three subunits (IA, IB, and IC). Contacts between units and subunits are mostly gradational and distinguished by gradual changes in biogenic content.

Lithostratigraphic Unit I consists of ~200 m of upper Pliocene to Pleistocene unconsolidated massive to laminated diatom-bearing/rich mud interbedded with muddy diatom ooze. A gradual downhole increase in diatom content characterizes this unit, and is used to distinguish three subunits based on increasing percentage of biogenic material. Subunit IA consists of ~78 m of massive to laminated light yellowish brown to brown diatom-bearing/rich mud interbedded at the decimeter- to meter-scale with greenish gray diatom-bearing/rich mud to sandy mud with dispersed clasts. Sand laminae and lenses are increasingly abundant towards the base of the unit. A 20 cm thick volcanic ash layer is present in Subunit IA. The base of this subunit is marked by a transition from olive gray diatom-rich mud to greenish gray diatom-rich mud with sandy mud interbeds. Subunit IB (~78 m thick) consists of meter-scale interbeds of olive gray and greenish gray diatom-rich mud/sandy mud to muddy diatom ooze with dispersed clasts. The abundance of millimeter-scale silty to sandy laminations increases downhole within this unit. The base of Subunit IB is defined by an increase in thickness and frequency of sandy mud beds with clasts. Subunit IC consists of ~45 m of interbedded olive gray diatom-rich mud and muddy diatom ooze that is similar to Subunit IB but features an increase in the biogenic component with thinner greenish gray beds and thicker beds of sandy mud with dispersed clasts. Pyrite staining is present throughout this subunit. The boundary between Unit I and Unit II is marked by a sharp contact between diatom-rich mud and a muddy diatom ooze. Unit II consists of ~117 m of massive to laminated olive gray muddy diatom ooze interbedded with bioturbated to laminated greenish gray diatom ooze and diatom-rich sandy mud. The olive gray muddy diatom ooze beds include pyrite staining and sand/silt laminations, whereas the greenish gray diatom ooze beds contain more intense bioturbation. The contact between Units II and III is defined by the first downhole occurrence of massive diamict. Unit III (120 m thick) consists of massive to laminated diatom-rich dark greenish gray mud interbedded with greenish gray massive diatom-rich sand and sandy mud with dispersed clasts, muddy diamict, and muddy diatom ooze. The lower contacts of sandy mud beds are usually gradational and bioturbated.

The major facies at Site U1524 are diatom-bearing mud, diatom-rich mud, diatom ooze, sandy mud, and muddy diamict. The assemblage of facies reflects pelagic sedimentation with ice rafting and winnowing/redeposition by downslope, along-slope, and turbidity currents. The sediment recovered at Site U1524 reveals reworking by these current systems superimposed on variations in terrigenous and marine sediment supply since the late Miocene on the upper continental rise of the Ross Sea.

Forty-seven core catcher samples from Holes U1524A and U1524C were analyzed for siliceous (diatoms, radiolarians, silicoflagellates, ebridians, and chrysophycean cysts), calcareous (foraminifers), and organic (dinoflagellate cysts and other aquatic palynomorphs, pollen, and spores) microfossils. The mudline and core catcher samples from Core U1524B-1H were also examined. The occurrence and abundance of the different microfossil groups varies greatly throughout the sediment column of Site U1524. Rich assemblages of diatoms, silicoflagellates, and ebridians occur throughout, whereas radiolarians are generally rare, but common to abundant in several samples, particularly in the lower Pliocene and Miocene intervals where they provide valuable biostratigraphic control. Foraminifers and palynomorphs are generally sparse.

Although all investigated microfossil groups supply valuable information, radiolarians and diatoms provide well-constrained age-diagnostic taxa used to develop an age-depth model for the site. Reworking and mixing of diatom assemblages of multiple ages limited the biostratigraphic utility of diatoms from the seafloor down to ~80 m CSF-A. The underlying stratigraphic sequence can be assigned to several biostratigraphic zones that are sometimes bounded by unconformities that also correspond to the lithostratigraphic units. The interval from ~80–120 m CSF-A is dated to the early Pleistocene. Below this is an ~160 m thick Pliocene interval rich in diatoms. A disconformity representing >1.0 My is interpreted between ~273 and 283 m CSF-A. An ~30 m thick interval of lower Pliocene between ~283–310 m CSF-A overlies another disconformity interpreted between ~310 and 320 m CSF-A. Sediment below this hiatus is dated to >8.5 Ma (late Miocene), with the deepest sample from the site (~437 m CSF-A) dated to <10 Ma.

Paleomagnetic investigations primarily focused on generating a magnetostratigraphy to assist with establishing a chronostratigraphy. Natural remanent magnetization (NRM) measurements were generally conducted prior to and after alternating field demagnetization with peak fields of 10 and 20 mT. Initial NRM intensities oscillate around ~10^{-1}–10^{-3} A/m and decrease after demagnetization to ~10^{-2}–10^{-5} A/m. These oscillations agree well with variations in magnetic susceptibility (MS), suggesting that magnetic particle concentration has a comparable effect on these parameters and potentially decreases downhole. After removal of the drilling-induced, downward-directed overprint, inclinations cluster in generally steep upward and downward directions. These clusters represent normal and reversed polarity zones, respectively, that can be tied to the geomagnetic polarity timescale using independent biostratigraphic datums. We identify all normal and reversed (sub)chrons between Chron C1n (Brunhes; 0–0.781 Ma) and the top of Subchron C2An.2r (3.207 Ma). Magnetic fabric experiments were also conducted to check for subtle disturbances that may yield unreliable directions, as well as differential compaction in the different lithostratigraphic units. Generally, most samples have an undisturbed oblate fabric that is common in sedimentary settings, but the degree of anisotropy is variable between lithostratigraphic units and may relate to factors such as differences in sedimentation rate.

Physical properties measurements were conducted on whole-round cores from Holes U1524A and U1524C, together with additional measurements on split-core sections and discrete samples. In general, data from whole-round measurements show similar trends with those from split-core measurements. There is a small deviation between whole-round measurements of gamma ray attenuation (GRA) bulk density and *P*-wave velocity compared with discrete measurements below ~100 m CSF-A in Hole U1524A, which is likely due to core expansion generated by degassing during the equilibration of the cores to room temperature. Downhole changes in physical properties are in good overall agreement with the defined lithostratigraphic units based on sedimentological characteristics, and changes in physical properties in each unit can provide insight into lithologic changes within each unit.

Overall, there is a good correlation between MS, natural gamma radiation (NGR), and bulk density measurements. These parameters are inversely correlated with the sediment color spectra b* parameter and appear to relate to diatom content, with a general increase downhole over tens of meters, together with variability due to interbedded lithologies. Taken together, these results suggest that sedimentary deposition is governed by variations in biogenic and terrigenous inputs. Apparent cyclicity is observed in these parameters. Overall, these parameters suggest a higher terrigenous content in Subunit IA, decreasing terrigenous content and increasing biogenic content throughout Subunits IB and IC, and maximum biogenic content in lithostratigraphic Unit II, which is predominantly diatom ooze. Lithostratigraphic Unit III again has higher terrigenous content, corresponding to interbedded diamict and diatom-rich mud. Downhole formation temperature measurements with the advanced piston corer temperature tool (APCT-3) indicate a geothermal gradient of 58°C/km, which, when combined with thermal conductivity measured on sediment cores from Site U1524, indicates heat flow of 53.7 mW/m^2.

Samples for headspace gas, interstitial water (IW) chemistry, and bulk sediment geochemistry were analyzed at Site U1524. Concentrations of methane and ethane are close to or below the detection limit in the top ~100 m CSF-A, but increase to higher concentrations below that depth (to 42,000 ppmv at 180 m CSF-A). Interstitial water sampling was conducted at low resolution (~1 sample per core in the upper 100 m and approximately every third core below that depth, depending on core recovery) in Holes U1524A and U1524C. A high-resolution IW profile was also obtained for the upper 7.56 m CSF-A in Hole U1524B. Low- and high-resolution downhole trends show clear manganese and sulfate reduction in the suboxic to anoxic transition zone in the upper ~90 m CSF-A. A rapid increase in silica concentration in the upper 2 m CSF-A probably reflects shallow diagenesis of silica. Elevated barium concentration below ~90 m CSF-A may indicate barite dissolution in an environment where IW is undersaturated with respect to barite. Bulk sediment total organic carbon and calcium carbonate contents are generally low throughout the site, but reveal distinct variability in lithostratigraphic Unit I. Higher percentages of carbonate content are observed in lithostratigraphic Subunits IB and IC, and in a carbonatecemented mudstone in Unit III. Total nitrogen content in the bulk sediments is very low, and total organic carbon/total nitrogen ratios display similar trends to total organic carbon.

References

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