IODP Expedition 382: Iceberg Alley and Subantarctic Ice and Ocean Dynamics

Site U1538 Summary

Background and Objectives

International Ocean Discovery Program (IODP) Site U1538 (proposed Site SCO-11A) is located 365 km north–northeast of the South Orkney Islands at 57°26.52′S, 43°21.47′W, in 3131 m of water. The site lies in the Pirie Basin, situated at shot point 4900 on seismic reflection profile SCAN 2013 13, 9 km east of the crossing line SCAN 2013 11. Site U1538 is located in the center of a small basin and provides the most undisturbed stratigraphy among the six potential drill sites of Pirie Basin. The seismic presite survey was conducted with a 3-channel SPARKER system, so the depth penetration and resolution of the profile is limited compared to the multichannel seismic records of Dove Basin Sites U1536 and U1537, and it is more difficult to follow prominent reflectors and assign seismic units. However, extended Plio–Pleistocene sections (seismic Units I and II) are expected. Identification of Reflector D and acoustic basement is questionable.

Previous piston coring in Pirie Basin was conducted 9 km west of Site U1538 at Site MD-07-3133 (alternate Site SCO-01), along seismic line SCAN 2013 13. Site MD07-3133 recovered a 36 m long sediment core that reaches back to Marine Isotope Stage (MIS) 3. This implies that the high sedimentation rates observed at Dove Basin Sites U1536 and U1537 could be doubled in Pirie Basin. However, Site MD07-3133 is located at a rather marginal position of the small basin in the northern Pirie Basin with potential seismic discontinuities below ~160 mbsf. Therefore, the primary Site SCO-11, in the central part of that basin, was chosen for drilling to achieve a mostly undisturbed recovery and the thickest Pleistocene section.

Sediments in the southern Scotia Sea are primarily deposited by contourite currents along the pathway of the Antarctic Circumpolar Current (ACC). Pirie Basin is located further north than Dove Basin, closer to the center of the ACC, and is expected to be less influenced by Weddell Sea Bottom Water (WSBW). The contourites are generally lens shaped with a total thickness of up to 1 km, similar to the sediment deposition observed above basement in Dove Basin (Maldonado et al., 2006).

At Site U1538 the main objective was to obtain a complete record of ice and ocean dynamics in the center of Iceberg Alley since the late Neogene in the more northerly of our two drilling areas in the Scotia Sea. Specific objectives in Pirie Basin include (1) the reconstruction of past variability in Antarctic Ice Sheet (AIS) mass loss and the related sea level history at a site with potentially more ice-rafted debris (IRD) derived directly from the Pacific side of the West Antarctic Ice Sheet through clockwise transport within the ACC; (2) to capture the northern, more Circumpolar Deep Water (CDW)–dominated part of the Drake Passage throughflow and associated north–south shifts of frontal systems, water mass properties, ocean temperature, and

sea ice extent; and (3) to reconstruct changes in atmospheric circulation and dust-climate couplings between Patagonia and Antarctica and related atmospheric circulation changes throughout the Plio–Pleistocene in a more proximal location relative to the dust source (e.g., Patagonia).

Operations

We arrived at Site U1538 at 0240 h on 4 May 2019 after the 127 nmi northwest transit from the Dove Basin area.

We started Hole U1538A at 1615 h on 4 May. The seafloor depth was 3130.6 m below sea level as calculated from the mudline. Over the next 6 d, full-length advanced piston coring/extended core barrel (APC/XCB) Cores U1538A-1H to 75X penetrated from the seafloor to 676.0 m below sea floor (mbsf) and recovered 476.4 m (70%). Formation temperature measurements were made while taking Cores 6H, 9H, 12H, 15H, and 18H.

At 1130 h on 5 May, after taking Core 17H, an iceberg and a bergy bit entered the red zone, so we raised the drill string to 45 mbsf and offset 35 m to the northwest to allow the bergy bit to pass. At 1530 h the larger of the two icebergs was clear of the red zone and we lowered the drill string back to 159.8 mbsf and resumed coring. Because Core 30H was difficult to extract from the formation and required a drillover to retrieve it, we switched to half-length APC (HLAPC) coring for Cores 31F to 34F, reaching 294.4 mbsf.

At that point the hole was deep enough that we would want to reenter it if forced off site by an iceberg, so at 1720 h on 6 May we deployed a free-fall funnel (FFF) to enable reentry. We resumed coring at 1830 h, taking Core 35F, which also required a drillover, so we switched to XCB coring for the rest of Hole U1538A. From 1300 to 1500 h on 8 May we waited for a large iceberg to pass the edge of the red zone (3 nmi from the ship), with the drill bit close to the bottom of the hole. After taking Core 66X (597.9 mbsf), coring was interrupted from 0415 to 0900 h on 9 May when an iceberg passed through the red zone. We raised the drill string to 45 mbsf and waited until after the iceberg passed, with a closest distance of 1.2 nmi from the ship, before resuming coring. From 1930 to 2100 h ship heave was about 4 m, which was too high to maintain a consistent weight on bit, so we stood by and waited for heave to subside. The final cores of Hole U1538A, Cores 69X to 75X, were recovered without interruption. We stopped coring at 1315 h on 10 May after reaching the maximum depth of 676 mbsf permitted by the IODP Environmental Protection and Safety Panel for this site.

We decided to forego downhole logging of Hole U1538A because ship heave exceeded 3 m and was forecast to become higher, which would pose a risk to the downhole logging tools and increase uncertainty in the depth registration of the logging data. Because the hole had a FFF, it was possible that we could return to log it if sea and heave conditions became calmer before the

end of operations at this site. We displaced the hole with 10.5 ppg heavy mud to help stabilize the borehole walls in case we were able to log.

We started Hole U1538B at 1900 h on 10 May. Core U1538B-1H recovered 7.8 m and was sampled for pore water at high resolution. We then offset 20 m to the south.

We started Hole U1538C at 2135 h on 10 May. Cores U1538C-1H to 12H penetrated from the seafloor to 105.9 mbsf and recovered 98.9 m (93%). One HLAPC core, Core 6F, was taken to adjust the depth offset to splice over core breaks in Hole U1538A. At 1000 h on 11 May, the sea and wind conditions had deteriorated to the extent that we could not safely handle the core barrel on the rig floor. We waited with the drill string in the hole, but it was apparent that conditions would not improve soon, so at 1500 h we raised the drill string clear of the seafloor, ending Hole U1538C. The next 28.5 h were spent waiting on weather. The ship's heave (being the maximum peak to peak heave over a 10 min interval) remained above 5 m until 1930 h on 12 May. At that time we were able to resume rig floor operations.

Hole U1538D started at 2145 h on 12 May. Cores U1538D-1H to 14H penetrated from the seafloor to 126.4 mbsf and recovered 114.6 m (91%). A formation temperature measurement was made while taking Core 12H. We had to stop coring in order to leave time to raise the drill string and secure the bottom-hole assembly for transit before stormy weather and high seas arrived early on 14 May. The last core came on deck at 1240 h on 13 May, and the bit was clear of the seafloor at 1430 h, ending Hole U1538D.

Having completed operations at Site U1538, we started the sea voyage to Punta Arenas, Chile, at 0000 h on 14 May. We had to leave Site U1538 earlier than originally planned because of deteriorating weather and sea conditions. This earlier departure briefly opened a short time window to core an additional ~100 m hole at Site U1534, which lies almost directly along the course from Site U1538 to Punta Arenas. However, headwinds slowed our progress to the extent that we no longer had time to carry out this plan, so we proceeded directly to Punta Arenas.

Principal Results

The lithology at Site U1538 is divided into two units. Lithostratigraphic Unit I, from the seafloor to 308 mbsf, consists of dark greenish gray, silty clay-rich and silty clay-bearing diatom ooze alternating with diatom-rich and diatom-bearing silty clay. Some intervals of diatom ooze were over 20 m thick. IRD dropstones were small and rare on the split core surface, but more of them were evident in the core X-ray images. From ~38 to 39 mbsf and from ~122 to 124 mbsf, dispersed diagenetic carbonate occurred in layers >50 cm thick. Similar diagenetic carbonate had been found at Sites U1536 and U1537 as discrete mm- to cm-thick layers. Unit II is distinguished by increased compaction (semi-lithified silty clay and diatomite) and an increase in the abundance, size, and lithology of gravel and pebble-sized IRD. Within Unit II, distinct layers

of enriched IRD were observed. Thin (<5 cm) diagenetic carbonate layers and lenses are present at ~351 and ~504 mbsf.

Diatoms and radiolarians were found in all core catcher samples and additional samples were collected from selected depths, allowing us to identify 75 biostratigraphic events. Based on these events, we estimate sedimentation rates of ~22 cm/ky between the seafloor and 432 mbsf (~1.75 Ma), followed by ~2.5 cm/ky from 432 to 469 mbsf (~3.6 Ma), and finally ~12 cm/ky from 447 mbsf to the base of Hole U1538A. The deepest sample revealed that sediments recovered at this site date back to ~4.2–4.7 Ma. Overall preservation was relatively good in all samples and only limited reworking of diatoms was detected.

Palynomorphs (dinocyst, acritarch, prasinopytes, pollen, spores, copepod, and fungi remains) were identified in all 30 samples processed for palynology. Dinocyst diversity was generally low with varying abundance throughout. Reworked pollen and spores were found throughout while in situ specimens were only detected in certain intervals. Samples for the analysis of ancient DNA were also collected from the upper 93 m and are anticipated to record the Holocene and the last interglacial.

Paleomagnetic investigations at Site U1538 involved measurement of the natural remanent magnetization (NRM) of archive halves from all holes before and after demagnetization in a peak alternating field (AF) of 15 mT. All discrete samples from Site U1538 were subjected to AF demagnetization at 5, 10, and 15 mT to verify the archive-half measurements. Directional data agree well between archive-half and discrete samples in APC and HLAPC cores. XCB cores often had a large amount of scatter in archive-half measurements, making those data difficult to interpret. However, discrete samples taken from large, intact pieces in the XCB cores appear to reliably record the polarity and can be used for magnetostratigraphy. We identified polarity zones from the Brunhes Chron (C1n) to the middle Gilbert Chron (C3n; tentatively the Sidufjall subchron, 4.8–4.9 Ma). However, not all polarity zones of the 2012 Geologic Time Scale (GTS) were identified, including the C2An (Gauss Chron) and C3n (middle Gilbert Chron) Subchrons. This is probably a result of discontinuous recovery and the slow sedimentation rate between ~1.75 and 3.6 Ma. The presence of the iron sulfide mineral greigite is suspected in some intervals.

In Hole U1538A headspace gas analyses, methane is the dominant hydrocarbon and is present only in low concentrations (2.0–5.4 ppmv), whereas ethane (C_2H_6) concentration is below the detection limit. Also, we found relatively low inorganic carbon (0.2–0.75 wt%), total nitrogen (0.04–0.23 wt%), and $CaCO_3$ (0.02–4.2 wt%) contents.

Pore water geochemical data were generated on 40 samples from Hole U1538A to a depth of 671 mbsf. The inorganic geochemical data of Site U1538 fall at the more extreme end of pore water properties observed during Expedition 382. While the cores are not methanogenic, sulfate is depleted below 60 mbsf. Minor dissolved sulfate concentrations were detected below 500 mbsf (SO_4 <1.5 μM). Significant organic matter degradation is apparent in the upper 120 m, with

elevated phosphate concentrations and a pronounced Br/Cl gradient. Barite dissolution is evident at depths without resolvable sulfate between 60 and 445 mbsf, resulting in the highest dissolved barium concentrations of the Expedition 382 sites. The spatial evolution of Ba enrichment also differs from the previous sites in that Ba concentrations are above 600 μM from 250 to 500 mbsf before more rapidly decreasing within a few tens of meters underneath this zone. Dissolved Mn enrichment is observable in the uppermost 50 m at Site U1538, followed by Fe enrichment below, suggesting Mn-Fe oxide mobilization in the upper 260 m. Calcium concentrations decrease significantly from 11.7 to 1.9 mM within the sulfate reduction zone, recover to stable intermediate concentrations throughout the upper half of Site U1538, and become enriched deeper down. Together with equally increasing B and Sr concentrations, this suggests increasing exchange reactions between the dissolved and solid phases in the older sediments. While chloride concentrations decrease with depth, together with pore water salinity, sodium concentrations increase. Authigenic clay formation is apparent in decreasing potassium and magnesium concentrations in deeper parts of Site U1538. In comparison to the pore water profiles from Scotia Sea Sites U1536 and U1537, these data highlight the more exotic character of the profiles from Site U1538.

The Whole-Round Multisensor Logger (WRMSL) was used to measure bulk density (GRA), magnetic susceptibility (MS), and *P*-wave velocity at 1 cm intervals, a higher spatial resolution than the 2.5 cm spacing used at the other sites. The core section halves were scanned on the X-ray imager. Discrete measurements collected in section halves include at least three *P*-wave velocity measurements per core, and 150 thermal conductivity measurements (2–3 per core). Moisture and density measurements were made on 145 discrete samples from Hole U1538A. Light reflectance and MS point measurements were collected at 1 cm intervals on section halves from Cores U1538A-1H to 35F, and at 2 cm from the remaining cores of this site. Formation temperature measurements were taken with Cores U1538A-6H, 9H, 12H, 15H, and 18H with the advanced piston corer temperature tool (APCT-3), yielding temperatures of 4.85°–13.8°C.

In the upper 220 m, physical properties records have 10–20 m long amplitude cycles (e.g., bulk density values cycling from lows of 1.2 to highs of 1.7 g/cm^3, and NGR values from lows of 10 to highs of 40 counts/s). Below that depth, the cycles have shorter periods and slightly lower amplitudes but are superimposed on longer scale baseline changes. An exception is the high amplitude MS cycles from 310 to 450 mbsf, underlain by low baseline MS values from 450 to 550 mbsf. The overall cycles and patterns are comparable in amplitude and thickness to those seen at Sites U1536 and U1537 in Dove Basin to the southwest. Downhole sediment compaction is reflected in increased density and *P*-wave velocity with depth. An increase in baseline values of NGR, density, and *P*-wave velocity is associated with a change in the seismic facies at ~370 mbsf.

A spliced record for Site U1538 was constructed for the top 124 m composite depth from Holes U1538A, U1538C, and U1538D. It is based predominantly on correlation of MS and GRA data.

Integrating the core stratigraphy with the seismic profiles using discrete sample caliper velocity data to transform depths to two-way traveltime, we identified Reflector A-2 at ~77 mbsf in Core U1538A-10H. This reflector separates higher variability of physical properties above from lower variability below. A more detailed acoustic to core correlation, based on data obtained with the parametric subbottom profiler TOPAS, was possible in the upper ~135 m of Hole U1538A. Accordingly, besides identifying Reflector A-2, additional reflectors could be correlated to changes in physical properties at ~13, 45, and 90 mbsf. Assuming a depth to two-way traveltime conversion based on the caliper velocity measurements, Reflector A was identified by a decrease in GRA at ~371 mbsf in Core U1538A-43X. Reflector B was observed at ~513 mbsf in Core 57X. We were also able to identify Reflector C by a sharp increase in WRMSL *P*-wave velocity at ~575 mbsf in Core 64X. Determining ages for these basin-wide reflectors will be important in the assessment of the geodynamic history of the Scotia Sea.