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

Site U1536 Summary

Background and Objectives

International Ocean Discovery Program (IODP) Site U1536 (proposed Site SCO-13) is located 235 km northwest of the South Orkney Islands at 59°26.46′S, 41°3.66′W in 3220 m of water. Site U1536 is the first of two sites drilled in Dove Basin, which is located in the southern Scotia Sea. This site was targeted to recover a complete Neogene record of Antarctic ice and ocean dynamics, examine the character and age of regionally-correlative seismic reflectors, and date the acoustic basement to constrain the tectonic origin of Dove Basin.

Previous piston coring at Site MD-07-3134 in a small subbasin in the northeastern part of Dove Basin recovered a 58 m long, high-accumulation-rate sediment record covering the last glacial cycle (Weber et al., 2012). Site U1536 is located 23 km to the east of that site, in the deeper part of a broad basin and on the western flank of a north–south ridge.

Sediments in the southern Scotia Sea are primarily deposited by contourite currents along the pathway of the Antarctic Circumpolar Current (ACC). Specifically in Dove Basin, contourite deposition is also assumed to be influenced by Weddell Sea Bottom Water (WSBW) flowing from the south through bathymetric gaps around the South Orkney Plateau after exiting the Weddell Sea (Maldonado et al., 2003). The contourites are lens-shaped in seismic profiles, up to 1 km thick in the center of small troughs (Maldonado et al., 2006), and thin toward the edges of the troughs.

Three seismic lines indicate a basin-like structure with several small-scale ridges and continuous reflectors in the central to northern part of Dove Basin. Site U1536 is located at shot point 1709 on multichannel seismic reflection profile SCAN 10/04. The five seismic units that encompass deposition above acoustic basement (Maldonado et al., 2006) served as a framework for drilling. The seismic reflectors show parallel lamination with occasionally undulating structures, indicative of minor synsedimentary downslope transport. This is a fairly common feature in the basin, and none of the expedition’s proposed sites were able to avoid these disturbances completely. Site U1536 provided the best compromise between a relatively thick and undisturbed stratigraphic sequence for climate studies and access to acoustic basement, which was located at a relatively shallow depth of ~900 m below seafloor (mbsf).

At Site U1536, the main objective was to obtain a complete Late Neogene record of ice and ocean dynamics in the center of Iceberg Alley in the more southerly of our two drilling areas in the Scotia Sea. Specific objectives include (1) the reconstruction of past variability in Antarctic Ice Sheet (AIS) mass loss and its related sea level history; (2) a study of the water mass composition of the Drake Passage throughflow and WSBW inflow; and (3) a study of north–

south shifts of the frontal systems in response to changing climate conditions, including changes in water mass properties, ocean temperature, and sea ice extent. An additional goal was to reconstruct changes in dust-climate couplings between Patagonia and Antarctica as well as related atmospheric circulation changes throughout the Plio-Pleistocene in a more distal location relative to the source (e.g., Patagonia). A final science objective at Site U1536 was to drill through the deeper reflectors, specifically the basin-wide Reflector C, to determine the age of this unconformity. This would allow us to date the regional change in bottom water flow, which probably led to the formation of the reflector. We were not able to reach acoustic basement, at ~900 mbsf, to determine its nature and age.

Operations

We arrived at Site U1536 at 0430 h on 6 April 2019 after making two 3.5 kHz survey profiles over the site in a cross shape, each 4 nmi long along the site survey seismic lines. The start of coring was delayed by bad weather and mechanical difficulties with the advanced piston corer (APC) bottom-hole assembly (BHA) that started when the "pig" pipe-cleaning device was not fully pumped out of the bottom of the pipe. This caused a series of misfires of the piston corer, necessitating a pipe trip back to the ship to inspect the BHA.

Hole U1536A started at 0005 h on 9 April. Cores U1536A-1F to 53F penetrated from the seafloor to 354.4 mbsf and recovered 364.3 m (103%). At 2115 h on 11 April an iceberg approached to within 5.7 nmi of the ship, so we stopped coring and raised the drill string to 50 mbsf. When the iceberg was 1.7 nmi away we raised the drill string above the seafloor and moved ~1 nmi to the east–northeast to avoid its path. This ended operations at Hole U1536A.

Hole U1536B started at 0930 h on 12 April. Cores U1536B-1H to 25H penetrated from the seafloor to 226.1 mbsf and recovered 230.7 m (102%). At 1130 h on 13 April we started to raise the drill string because of a large iceberg and a flotilla of smaller icebergs around it. At 1325 h the drill string cleared the seafloor, ending Hole U1536B.

Hole U1536C started at 2035 h on 13 April. Cores U1536C-1H to 40F (and the drilled intervals 31, 91, 111, 131, 161, and 271, which advanced 144.0 m without recovery) penetrated from the seafloor to 352.0 mbsf and recovered 187.4 m (90% of the cored interval). The aim of Hole U1536C was to spot core the upper section to fill gaps in the stratigraphy recovered in Holes U1536A and U1536B, and then to core continuously from 224 mbsf down. After taking Core 37F (341 mbsf) late on 15 April, coring was interrupted for 8 h by an iceberg passing through the red zone. We were able to advance to 352.0 mbsf, but then another iceberg entered the red zone and we had to end Hole U1536C.

Hole U1536D started at 1940 h on 16 April. Core U1536D-1H penetrated from the seafloor to 6.9 mbsf. The core liner shattered and the core had to be pumped out of the barrel, so it could not be used for the intended purpose of pore water sampling. We ended Hole U1536D and raised the drill string to the ship to change the BHA to the rotary core barrel (RCB) BHA.

Hole U1536E started at 2140 h on 17 April. We drilled without recovery to 312 mbsf, and at 0850 h on 18 April we deployed a free-fall funnel. We then continued to drill down to 340 mbsf, just shallower than the depth reached by Holes U1536A and U1536C.

We started coring Hole U1536E at 2000 h on 18 April. Cores U1536E-2R to 33R penetrated from 340.0 to 645.4 mbsf and recovered 113.3 m (36%). Coring was interrupted four times, three times by icebergs and once by bad weather conditions. Two of the icebergs forced us to pull out of the hole and then reenter, guided by the subsea camera. At 1715 h on 24 April, after recovering Core 33R (645.4 mbsf), we decided to stop coring and log the hole. The "quad combo" logging toolstring consisted of tools to measure the magnetic susceptibility, natural gamma radiation, electrical resistivity, sonic velocity, and density of the formation. Starting at 0830 h on 25 April we made downlog and uplog passes with the toolstring, reaching 643 mbsf (~3 m above the bottom of the hole). Ship heave was ~2.5 m during logging, which caused depth discrepancies of a similar magnitude in the logging data. The logging tools were disassembled by 1515 h and the drill string was raised to the ship, which completed operations at Hole U1536E.

Principal Results

APC cores from Holes U1536A, U1536B, and U1536C provide near-continuous stratigraphic coverage down to 354 mbsf, and RCB cores from Hole U1536E provide ~36% coverage from 340 to 645 mbsf. Based on the recovered sediments, three major lithologic units are identified. Unit I, from the seafloor to ~250 mbsf, consists of interbedded diatom oozes and silty clays. Diatom ooze dominated the sediment from the seafloor to 120 mbsf. The terrigenous component in the oozes was generally below 25%, and the biogenic component (mainly diatoms) in the silty clays typically exceeded 25% of the sediment. Unit II, ~250–550 mbsf, is almost exclusively silty clay with varying amounts of biosilica. Lithification increased downhole. Unit III, from ~550 mbsf to the base of Hole U1536E at 643 mbsf, consists of semi- to fully lithified mudstone, some with biosilica, and beds of limestone, some of which were nannofossil bearing to nannofossil rich. Throughout, gravel to pebble-sized ice-rafted debris (IRD) was rare to common and was clearly visible in the core X-ray images. A noticeably higher abundance of dropstones was observed from ~435 to 568 mbsf.

Diatom, radiolarian, foraminifer, and palynomorph biostratigraphic results were consistent for all samples from Holes U1536A, U1536C, and U1523E. We recorded 81 biostratigraphic events, based on which, we estimate sedimentation rates of ~15 cm/ky from the seafloor to 250 mbsf (~1.5 Ma) and ~5.4 cm/ky from 250 to 620 mbsf (~8.4 Ma). A hiatus was observed between Samples U1526E-30R-CC and 31R-CC (~620 mbsf), leaving a biostratigraphic gap spanning

~8.4 to 13.2 Ma. No hiatuses are observed in the Pleistocene (seafloor to 320 mbsf) or Pliocene (320 to 450 mbsf) stratigraphic sections.

All paleomagnetic polarity zones of the 2012 Geologic Time Scale (GTS) were identified in the APC-cored intervals of Site U1536 through to the lower Gauss Chron (C1n–C2An.3n; 3.6 Ma), and polarity transitions were recovered for all polarity zone boundaries except the Reunion Subchron (C2r.2n). Despite discontinuous recovery in the RCB cores, we used initial biostratigraphic data to make tentative ties to the 2012 GTS for intervals between Chrons C2Ar and C3An (3.60 to 6.03 Ma). Below this range we observe intervals of normal and reverse polarity that may potentially be correlated to the 2012 GTS in postexpedition work.

Samples for headspace gas, interstitial water chemistry, and bulk sediment geochemistry were analyzed from Holes U1536A and U1536E. Headspace methane concentrations were generally low (2–4.6 ppmv) throughout the sedimentary sequence. Ethane, propane, and other higher molecular weight hydrocarbons were below detection limit. Site U1536 is characterized by moderately reducing sedimentary conditions, as indicated by the disappearance of dissolved sulfate concentrations at ~100 mbsf and a reappearance of resolvable dissolved sulfate at ~300 mbsf. The reducing conditions associated with this microbially mediated sulfate reduction in the upper section exert strong control over the interstitial water profiles of several parameters measured on board, including alkalinity, Ca, PO_4, Ba, Sr, and Mn. Bulk sediment total organic carbon and total nitrogen contents are generally low, with concentrations ranging from 0.1 to 0.8 wt% and from 0.02 to 0.09 wt%, respectively.

Physical properties records reflect the lithology of the sediments. Silty-clay-bearing diatom ooze, interpreted to be interglacial sediment, shows high *P*-wave velocity (PWL) values and low gamma ray density (GRA), natural gamma radiation (NGR), and magnetic susceptibility (MS) values. Also, the color reflectance component b* (the variability between yellow and blue) shows more yellowish colors for the diatom-rich interglacial periods. Variability in b* has been shown to be a good indicator for temporal variability of biogenic opal over the last glacial cycle in sediments from the Scotia Sea (Sprenk et al., 2013). The glacial-to-interglacial cyclicity of b* reveals high-amplitude variations since the Mid-Brunhes Transition (MBT) around ~0.43 Ma, thus following a global pattern of higher amplitude climate variability post MBT (Barth et al., 2018) above ~90 mbsf. b* shows medium-amplitude variability between ~90 and 181 mbsf (~0.43 and 1.1 Ma), and low-amplitude, higher frequency variability below that back to 3.5 Ma.

The combination of robust biomagnetostratigraphy and high-resolution records of MS, GRA, NGR, and b* is used to assign glacial and interglacial periods, providing a strong time-stratigraphic framework for this site. Furthermore, MS, a presumed dust proxy in the sites from Iceberg Alley (Weber et al., 2012, 2018) shows distinct 100 ky peaks representing glacial periods that can be correlated in great detail to the dust record of Antarctic ice cores (e.g., to the Epica Dome C record of Lambert et al., [2008]) over the last 800 ky.

An excellent late Pliocene to middle Pleistocene section was recovered that will allow in-depth study of the impact of the initiation of Northern Hemisphere glaciation on the Southern Ocean. An extended record of the early Pleistocene will allow us to assess the provenance and flux of IRD prior to the Mid-Pleistocene Transition. While there is limited carbonate material to work with, the rich record of IRD and biosiliceous fossils combined with an excellent magnetostratigraphy should make this sequence suitable for in-depth paleoceanographic studies. Although discontinuously cored and heavily disturbed, the Miocene sequence should also provide an important window into the earlier glaciation history of Antarctica.

A continuous spliced record was constructed from Holes U1536A–U1536C for the top 243 m composite depth (mcd). Three intervals appear to contain slumped sediment. Two occur at ~40–50 mbsf and 95–100 mbsf, and one below the splice at about 299–301 mbsf.

Downhole logging in Hole U1536E used a quad combo tool string to obtain as much data as possible in a single tool string run because of deteriorating sea conditions and the risk of icebergs. The logging tools measured MS, gamma ray spectra, electrical resistivity, *P*- and *S*-wave velocities, and density. These in situ measurements successfully covered data gaps in core recovery and complement the core measurements made in the laboratory. Both core and downhole density and *P*-wave velocity values generally increased with depth, reflecting downhole sediment compaction.

Integrating the core stratigraphy with the seismic profiles using the core and log velocity data to transform depths to two-way traveltimes, we identified Reflector B at ~365 mbsf in Core U1536E-4R. This reflector corresponds to relative low values in PWL and GRA. We were also able to identify Reflector C, a central objective of the expedition, at ~530 mbsf in Core U1536E-22R. It is characterized by a sharp increase in PWL values. Determining ages for these basin-wide reflectors will be important in the assessment of the geodynamic history of the Scotia Sea.

References

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