IODP Expedition 383: Dynamics of the Pacific Antarctic Circumpolar Current (DYNAPACC)

Site U1539 Summary

Background and Objectives

International Ocean Discovery Program (IODP) Site U1539 (proposed Site CSP-2B) is located in the central South Pacific at 56°9.0655′S, 115°8.038′W, ~1600 nmi west of the Magellan Strait at 4070 m water depth. The site sits at the eastern flank of the southernmost East Pacific Rise (EPR), ~220 nmi from the modern seafloor spreading axis, and is underlain by oceanic crust formed at the EPR ~10–12 Ma. Assuming a constant seafloor half-spreading rate of ~4.5 cm, the plate tectonic backtrack path of Site U1539 moves the site westward. This translates in an early Pliocene position ~100 nmi closer to the crest of the EPR at a water depth shallower by several hundred meters. At a smaller scale, the site is located in a northeast–southwest oriented, ~5 nmi wide trough that parallels the orientation of the EPR. The adjacent ridges rise up to ~3000 m water depth to the northwest of the site and up to ~3500 m water depth to the southeast.

Site U1539 is located on multichannel seismic (MCS) profile AWI-201000013 close to the intersection with AWI-2010000011. The seismic crosslines indicate ~650 m thick sediments above oceanic basement. Sediments are mostly well stratified, with flat-lying reflectors. Low to moderately reflecting layers become stronger below ~100–120 m sediment depth. Sediment echosound (Parasound) profiles reveal excellent penetration (>150 m) with distinct layering suggesting a succession of fine-grained soft sediments with varying lithological composition.

Site U1539 lies in the pathway of the Subantarctic Pacific Antarctic Circumpolar Current (ACC), ~100 nmi north of the modern average Subantarctic Front (SAF), in a zonal transition zone of the ACC. To the west of the site, the ACC and the associated fronts are strongly steered by the topography of seafloor spreading systems (Udintsev and Eltanin-Tharp Fracture Zone systems), whereas to the east the vast Amundsen Sea basin does not influence the ACC strongly.

Sea surface temperatures seasonally vary between ~2°C (July to September) and ~6.5°C (January to March). The area is located west of the main Antarctic Intermediate and Mode Water formation regions in the Southeast Pacific. The water depth of 4070 m places Site U1539 within Lower Circumpolar Deep Water (LCDW). This hydrographic setting makes it ideal to evaluate past changes in frontal position, associated export production, ACC current speed and position, as well as aeolian dust and ice-rafted debris (IRD) input during the Pleistocene.

The main objectives at Site U1539 were:

- Recover a moderate to high resolution Subantarctic Pliocene–Quaternary sediment record close to the Subantarctic Front;

- Investigate the sequencing of siliceous and calcareous oozes, allowing for a wide range of paleoceanographic reconstructions;
- Reconstruct high amplitude subantarctic sea-surface temperatures (SSTs) and sea-ice variations;
- Provide a record of lowermost CDW and glacial Antarctic Bottom Water (AABW);
- Reconstruct productivity (opal versus carbonate), nutrient distribution, and dust-productivity coupling; and
- Recover a potential far-field record of West Antarctic Ice Sheet (WAIS) variability.

Operations

The first core of Expedition 383 was taken at Hole U1539A at 0445 h on 1 June 2019 from a water depth of 4071.1 m below sea level (mbsl). We used the advanced piston corer (APC) to penetrate from the seafloor to 107.6 m below seafloor (mbsf) (Cores 1H to 12H) and recover 104.75 m of core (97%). The hole was terminated after Core 12H due to rough weather and sea conditions. Shattered liners were recorded on Cores 5H and 11H. Shear pins were sheared prematurely on Cores 1H, 11H, and 12H.

After 27 h of waiting on weather (WOW), Hole U1539B was spudded at 0540 h on 3 June. Cores 1H to 3H recovered 21.9 m (78% recovery), but Cores 2H and 3H were misfires, so we decided to terminate the hole and wait for seas to improve further before continuing operations.

By 1245 h, heave had fallen to 3.0 m and we resumed coring. Hole U1539C was started with Core 1H returning a full 9.7 m core barrel. This allowed us to determine a seafloor depth of 4070.2 mbsl. Full length APC coring continued to refusal at a depth of 240.1 mbsf (Core 26H). Half-length APC (HLAPC) coring was then used to deepen the hole with coring terminated after Core 32F at 268.1 mbsf. A total of 32 cores were taken in this hole using the APC and HLAPC coring tools. Formation temperature measurements were taken with Cores 4H, 13H, and 16H. Partial strokes were recorded on Cores 24H through 27F, with high overpull on Cores 17H through 26H. A misfire was recorded on Core 31F.

Hole U1539D was spot cored to fill in coring gaps from the previous holes. The hole was spudded at 1405 h on 5 June and drilled ahead without recovery to 47.5 mbsf, when coring began, and continued to 198 mbsf with seven drilled intervals totaling 68.7 m. A total of 14 APC cores were taken over the 129.3 m cored interval with a recovery of 128.15 m (99%). The hole reached its maximum depth at 1500 h on 6 June and the drill string was recovered, ending the hole and Site U1539. Misfires were recorded on Cores 2H, 3H, 6H, 8H, and 9H, and a partial stroke was recorded on Core 18H. No temperature or orientation measurements were taken in this hole. After recovering the drill string, the rig floor was secured for transit at 0130 h. The thrusters were raised and the sea voyage to Site U1540 (proposed Site CSP-7A) began at 0224 h on 7 June.

Principal Results

At Site U1539, a 268.1 m thick continuous sequence of Holocene to early Pleistocene sediment was recovered with a bottom-hole age of ~1.3 Ma and a mean sedimentation rate of ~20.6 cm/ky. Hole U1539C recovered the deepest cored sediments at 268.1 mbsf. The recovered 247.50 m of core spans one lithologic unit with two subunits consisting of interbedded calcareous and siliceous biogenic ooze. Site U1539 sediments can be divided broadly into two categories: diatom ooze with varying amounts of calcareous and biosiliceous components, or biogenic carbonate ooze with varying amounts of biosiliceous and other calcareous components. Siliceous microfossils show relatively good preservation and are abundant throughout the record. Preservation of calcareous microfossils varies from moderate to good.

Five primary lithofacies were identified, and these mostly differ in their proportions of calcareous and biosiliceous components. Secondary defining attributes include degree of diagenetic alteration, bioturbation, and in the case of lithofacies 5, microfossil size and sedimentary structure. Lithofacies 1 is comprised of distinct centimeter-scale diatom mats in a biogenic ooze matrix. This facies can be distinguished from lithofacies 2, which is characterized by sequences of more pronounced and stacked diatom mats with a near absence of diatom ooze matrix. Lithofacies 3 is the dominant lithofacies at Site U1539 and consists of light greenish gray to gray carbonate-bearing or carbonate-rich diatomaceous ooze that exhibits moderate to heavy bioturbation. Lithofacies 4 consists of white to light gray diatom-bearing to diatom-rich nannofossil or calcareous oozes that occur as thin beds generally <3 m thick with moderate to heavy bioturbation. Lithofacies 5 corresponds to foraminiferal oozes and sands that occur sporadically as centimeter- to decimeter-scale layers that are characterized by a sharp basal contact and distinct cross-bedding observable in X-ray images.

We have subdivided the Site U1539 stratigraphic sequence into Subunits IA and IB based on the relative abundance of the five defined lithofacies. With the exception of lithofacies 5 in Subunit IB, all lithofacies are present in both subunits, but the thickness, frequency, and overall occurrence differs between the two. Subunit IA is characterized by the frequent occurrence of ~1.5 m thick beds of calcareous and nannofossil ooze (lithofacies 4) and limited occurrence of diatom mats (lithofacies 2). In contrast, Subunit IB has only a few occurrences of lithofacies 4 and is largely dominated by beds of thick and continuous diatom mats. Carbonate-bearing and carbonate-rich diatomaceous ooze (lithofacies 3) is the dominant lithofacies in both subunits and does not provide a useful means to subdivide the stratigraphy due to its widespread occurrence. The prominent white to light gray calcareous beds associated with lithofacies 4 drive the high-amplitude variations in RGB Blue and L* values. In general, we observe high-amplitude, low-frequency variations above the 125 m core composite depth below seafloor (CCSF-A) subunit boundary and more frequent low-amplitude variations below it.

Biostratigraphic age assignments are consistent with each other and are mainly derived from diatom, radiolarian, and calcareous nannofossil datums. Diatom, radiolarian, and nannofossil biostratigraphy detected no major hiatuses, indicating that a continuous sediment sequence from the early Pleistocene through the Holocene was recovered at this site.

We could not observe unambiguous evidence for geomagnetic reversals at any of the holes at Site U1539. This is probably due to low natural remanent magnetization (NRM) intensities that could be related to the high diatom content of the sediments. Therefore, the paleomagnetic record cannot be used to contribute to the age model of Site U1539.

We analyzed samples for headspace gas, interstitial water chemistry, and bulk sediment chemistry at a resolution of approximately one 5 cm^3 sample per core from Hole U1539A (2.99–105.57 mbsf) and Hole U1539C (81.98–266.41 mbsf). Headspace samples were not collected from HLAPC cores. Methane concentrations were low at this site overall. Methane concentrations gradually increased downhole, averaging 12.3 ppmv and never exceeding 18.4 ppmv. Ethane and propane remained below detection limit throughout the entire hole. Alkalinity increases in the top 10.6 mbsf to ~5 mM, likely caused by anaerobic organic matter remineralization. pH values also increase from 7.7 at the surface to ~8 at 2.94 mbsf and remain constant with depth. Magnesium and lithium concentrations appear conservative throughout the sediment column. Manganese concentration increases sharply from below detection limit in the mudline sample to a maximum of 60 µM at 7.57 mbsf, indicating anaerobic, reductive dissolution of Mn oxides within the top 3 m of sediment.

The composite carbonate record of Site U1539 (Holes U1539A and U1539C) shows a downhole variability ranging from 2.9 to 92.8 wt%, and a strong correlation with RGB Blue and reflectance L* measurements and gamma ray attenuation (GRA) bulk density. Total organic carbon (TOC) concentrations have a mean value of 0.40 wt%, and values range between a minimum of 0.16 wt% at 148.09 m CCSF-A and a maximum of 0.78 wt% in the uppermost core. At Site U1539, the mean value of TOC/TN is above 10 in the upper portion of the hole from 115.2 to 0.8 m CCSF-A, suggesting that the location of Site U1539 received a fraction of terrestrial organic matter input across these depths.

Physical properties measurements at Site U1539 comprised nondestructive whole-round measurements of GRA bulk density, magnetic susceptibility (MS), Whole-Round Multisensor Logger (WRMSL) *P*-wave velocity, and natural gamma radiation (NGR) on core sections from Holes U1539A to U1539D. Additional physical properties collected include thermal conductivity (TCon) on whole-round cores from all holes. Downhole changes in physical properties characteristics overall are in good agreement with the lithofacies defined based on sedimentologic characteristics. In general, diatom ooze lithofacies (lithostratigraphic facies 1 and 2) correspond to high MS, low bulk density, and high porosity. The lowest densities and highest porosities occur in diatom mats within diatom ooze, which is the recurring dominant lithofacies 2. In contrast, intervals that are predominantly calcareous nannofossil ooze (lithofacies 4 and 5) correspond with decreased NGR, high bulk density, low *P*-wave velocity, low to moderate MS, and low to moderate porosity. Over most of the record, GRA bulk density shows an anticorrelation with the NGR derived K concentrations and MS. The NGR record also exhibits 10–15 m scale cyclicity, particularly in the interval from ~10 to 135 m CSF-A. NGR data also imply that total counts and the derived K concentrations can be used as a semiquantitative proxy for the abundance of terrigenous material delivered by dust or sea ice and iceberg transport.

Correlations between holes at Site U1539 were accomplished using the Correlator software (version 3.0). We constructed a splice for the upper portion of the site (from 0 to 219.80 m CCSF-A) using Holes U1539A, U1539B, U1539C, and U1539D. However, the splice contains several gaps, as detailed below. Below 219.80 m CCSF-A, only a single hole (Hole U1539C) was drilled; thus, Cores U1539C-22H through 32F were appended to the splice with gaps set between each core to the bottom of the hole. The composite depth scale is anchored to the "mudline" of Core U1539A-1H, which is assigned the depth of 0 m CCSF-A.

We constructed a preliminary age model based on biostratigraphic results, mainly including diatom and nannofossil age markers. These data suggest that the sedimentary sequence recovered at Site U1539 covers the past ~1.3 Ma. For a pelagic setting, sedimentation rates are extraordinarily high, reaching on average 17 cm/ky in the upper ~0.9 Ma and even higher values of ~30 cm/ky from ~0.9 to 1.3 Ma. This biostratigraphic age model is generally consistent with preliminary stratigraphic tuning performed aboard, based on physical properties data such as color measurements (RGB Blue) and GRA bulk density.

The combination of nearly continuous recovery, very high sedimentation rates driven by high diatom productivity and potential sediment focusing, clear patterns in physical properties and sediment color, and a rich array of well-preserved diatoms combined with calcareous microfossils will provide unprecedented opportunities for improving our understanding of the dynamics of the ACC and its link to global carbon cycle changes at orbital and suborbital timescales.