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

Site U1541 Summary

Background and Objectives

Site U1541 is located in the central South Pacific at 54°12.756′S, 125°25.540′W, ~1830 nmi west of the Magellan Strait at 3604 m below sea level. The site sits at the western flank of the southernmost East Pacific Rise (EPR), ~50 nmi north of the Tharp Fracture Zone and ~160 nmi west from the modern seafloor spreading axis, and is underlain by oceanic crust formed at the EPR ~6–8 Ma. Assuming overall constant seafloor half spreading rates of ~4.5 cm, the plate tectonic backtrack path of Site U1541 moves the site eastward, placing it ~100 nmi closer to the crest of the EPR at a water depth shallower by several hundred meters in the early Pliocene. At a smaller scale, the site is located in a ~4 nmi wide trough oriented north-northeast–south-southwest, paralleling the orientation of the EPR. The adjacent ridges rise up to ~3400 m water depth to the southeast, and up to ~3500 m water depth to the northwest of the site.

Site U1541 is located on multichannel seismic (MCS) profile AWI-201000014 at the intersection with AWI-2010000016. The seismic crosslines indicate ~180 m thick sediments above oceanic basement. Sediments are mostly well stratified, with flat laying, slightly irregular reflectors. Low to moderately reflecting layers become stronger below ~120–140 m below seafloor (mbsf). Sediment echo sound (Parasound) profiles indicate moderate penetration (~80 m) with distinct layering suggesting a succession of fine-grained soft sediments with varying lithological composition.

Site U1541 lies in the pathway of the Subantarctic Pacific Antarctic Circumpolar Current (ACC), ~100 nmi north of the modern mean position of the Subantarctic Front (SAF). In this sector of the ACC, the associated fronts are strongly steered by the topography of seafloor spreading systems (Udintsev and Eltanin-Tharp Fracture Zone systems).

Sea surface temperatures (SSTs) seasonally vary between ~3°C (July to September) and ~7°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 3604 m places Site U1541 within Lower Circumpolar Deep Water (LCDW).

The main objectives at Site U1541 were:

- Recover a moderate resolution Subantarctic Miocene–Quaternary sediment record close to the Subantarctic Front;
- Investigate the sequencing of calcareous and siliceous oozes allowing for a wide range of paleoceanographic reconstructions;
- Reconstruct high amplitude subantarctic SSTs based on multiple proxies;

- Investigate long-term changes in dust input;
- Provide a record of lowermost Circumpolar Deep Water (CDW) and potential influence of Antarctic Bottom Water (AABW) during glacial periods;
- Reconstruct productivity (opal versus carbonate), nutrient distribution, and dust-productivity coupling;
- Recover a potential far-field record of West Antarctic Ice Sheet (WAIS) variability.

Operations

During the transit to Site U1541, rough weather systems moved in, causing high seas at the site location. Therefore, upon reaching the site coordinates at ~2300 h on 15 June 2019, the vessel continued at reduced speed on a 245° weather avoidance course for another ~100 nmi past the site. At 2105 h on 16 June, the sea state had sufficiently calmed down to turn the ship around and head back. We completed the sea voyage and arrived at Site U1541 at 0736 h on 17 June. We lowered the thrusters and the vessel was placed over the site coordinates and on dynamic positioning mode by 0820 h. Soon after, the drill crew started to build the advanced piston corer/extended core barrel (APC/XCB) bottom-hole assembly, and they began lowering the drill string to the seafloor.

By 1815 h on June 17, the drill bit had been lowered to 3597 m below rig floor (mbrf), 5 m above the seafloor depth calculated by the onboard precision depth recorder (PDR). We attempted to start Hole U1541A, but the first core came up empty. Three more attempts followed with the bit at 3602, 3607, and 3617 mbrf before we successfully recovered any sediment. Finally, we spudded Hole U1541A at 2330 h on 17 June. Core U1541A-1H recovered 9.5 m of sediment, indicating a missed mudline, and we ended the hole at that point.

The bit was raised to 3612.0 mbrf and Hole U1541B was spudded at 0055 h on 18 June. Based on the recovery in Core U1541B-1H, the seafloor was calculated at 3614.4 mbrf (or 3603.7 m below sea level [mbsl]). Coring continued without incident until a partial stroke was recorded on Core 15H. When the core was recovered, the advanced piston corer temperature tool (APCT-3) cutting shoe showed damage, and the driller pulled back the next APC core barrel before it arrived at the bottom. An XCB core barrel was dropped to attempt Core 16X. After drilling for 45 min and advancing only 0.5 m, the barrel was pulled back aboard. Core U1541B-16X retrieved three large pebble-sized basalt pieces (2–5 cm in diameter) in the core catcher. The bit was pulled out of the hole, clearing the seafloor at 0100 h and ending Hole U1541B.

A total of 16 cores were taken in Hole U1541B. The APC system was used for 15 of these, reaching a depth of 138.0 mbsf before APC refusal and recovering 129.3 m (94%). The XCB system was used for one core, advancing 0.5 m and recovering 0.06 m of basalt (12%). The APCT-3 was used on Cores U1541B-4H, 7H, 11H, and 15H. Misfires were recorded on Cores

1H, 4H, and 6H, and a partial stroke was registered on Core 15H. Twenty-five hours were spent on Hole U1541B.

The vessel was offset 20 m to the east of Hole U1541B, the bit was raised to 3608.0 mbrf, and Hole U1541C was spudded at 0325 h on 19 June. The hole was deepened with the APC system to 118.1 mbsf (Cores 1H to 13H) before coring was terminated at 1805 h on 19 June to allow the vessel to evade approaching heavy weather.

The drill pipe was retrieved and the rig floor was secured for transit at 0204 h on 20 June, ending Hole U1541C and Site U1541. A total of 13 APC cores were taken over a 118.1 m interval with a recovery of 100.4 m (85%).

In summary, three holes were cored at Site U1541 using the full-length APC coring system: Hole U1541A was cored to 9.5 mbsf (9.67 m recovered; 101.8%); Hole U1541B was cored to 138.5 mbsf (129.27 m recovered; 93.3%); and Hole U1541C was cored to 118.1 mbsf (100.37 m recovered; 85%).

Principal Results

A ~145 m spliced sedimentary sequence of Holocene–Miocene age was recovered at Site U1541 from Holes U1541A–U1541C. The sedimentary sequence comprises four lithofacies, namely carbonate-bearing to carbonate-rich diatom ooze (lithofacies 2), diatom-bearing to diatom-rich nannofossil/calcareous ooze (lithofacies 3), nearly pure nannofossil ooze (lithofacies 4), and clay-bearing to clayey biogenic ooze (lithofacies 6). Based on the distribution and co-occurrence of the defined lithofacies, we have divided the Site U1541 sedimentary sequence into three lithostratigraphic units. The youngest Unit I is subdivided into two subunits: Subunit IA down to ~25 mbsf (~27 m core composite depth below seafloor, CCSF-A) and Subunit IB from ~25 to ~63 mbsf (~66 m CCSF-A). The subunit boundary is determined by a transition from frequent and marked changes between lithofacies 2, 3 and 4 to a dominance of lithofacies 3. Unit II spans from ~63 to ~95 mbsf (~66 to ~98 m CCSF-A) and differs from Unit I above by an absence of diatom ooze (lithofacies 2) resulting in a dominance of different varieties of nannofossil ooze (i.e., lithofacies 3 and 4). Subunit IIIA, from ~95 to ~119 mbsf (~99 to ~127 m CCSF-A), can be distinguished from Unit II above by a distinct color change within lithofacies 3 and 4, from white and light greenish gray to very pale brown and pale orange yellow, as well as an increased contribution from lithofacies 3. Subunit IIIB spans from ~119 to ~137 mbsf (~127 to ~145 m CCSF-A), and shows a dominance of lithofacies 4 in contrast to Subunit IIIA. The presence of basalt rock and volcanic glass fragments at the base of Hole U1541B, in Sections U1541B-15H-5 and 16X-CC, suggests the complete recovery of the pelagic sediment sequence above oceanic basement at this site.

All microfossil groups studied aboard (diatoms, radiolarians, silicoflagellates, benthic and planktonic foraminifers, nannofossils, and ostracods) were present at the site. The preservation of diatoms is moderate overall. Radiolarians are generally very well preserved except for a few samples. Silicoflagellates are rare to barren throughout the core except for four samples in which they were common to abundant. Calcareous nannofossils are present in all the samples. They are common to abundant except for few samples, and become dominant in specific nannofossil ooze intervals. Planktonic and benthic foraminifers and ostracods show good to moderate preservation in the upper part of Hole U1541B, and moderate preservation in the lowermost core catcher samples. Ostracods are particularly abundant in Sample U1541B-9H-CC.

The biostratigraphic age model at Site U1541 was mainly based on analyses from Hole U1541B, with additional samples analyzed for diatoms and nannofossils in Hole U1541C. Split-core samples were taken in both holes to refine the stratigraphy in the lower half of the site. In total, 117 biostratigraphic events were recognized and indicate an estimated age of ~7.7 Ma at the bottom of both holes. The integrated biostratigraphy of diatoms, radiolarians, calcareous nannofossils, and planktonic foraminifers showed no major hiatuses at Site U1541, suggesting a continuous sequence of Late Miocene to Holocene sediments.

Paleomagnetic measurements indicate a number of polarity changes, which are best illustrated by downhole changes in inclination. These capture a series of apparent polarity reversals, which are consistent between Holes U1541B and U1541C where they overlap and together provide a long and almost continuous (see Stratigraphic Correlation) record of polarity change over the past 8 Ma. The Matuyama/Brunhes and upper and lower Jaramillo polarity boundaries that define the upper part of the Matuyama Chron (C1r.1r and .1n) are observed. Most reversal boundaries from the Olduvai Chron (C2n) to C4r.1n (8.254 Ma) are generally well characterized**.** The record of inclination and intensity after 20 mT peak alternating field demagnetization for the splice composite record allows polarity interpretations and correlation to the geomagnetic polarity timescale (GPTS). Only the boundaries associated with the reversed polarity intervals of the Gauss (C2An) (Kaena and Mountain) and the short normal polarity subchron C3BR.2n that spans from 7.454 to 7.485 Ma are not clearly recognized over the 8.5 Ma interval.

We analyzed samples for headspace gas, interstitial water chemistry, and bulk sediment chemistry at a resolution of one 5 cm^3 sample per core at Holes U1541A, U1541B, and U1541C. Methane concentrations are low at this site overall, never exceeding 3.47 ppmv. Ethane and propane remain below detection limit throughout the entire hole.

Alkalinity and pH show a decrease starting around 80 mbsf and pore water iron concentrations below 86 mbsf drop below detection limits, while pore water Mn concentrations drop below detection limits below 105.05 mbsf.

Calcium carbonate content is relatively high in this site, never falling below 21.6 wt% and with a downhole average content of 68.6 wt%. The calcium carbonate content shows a good correlation with L* and RGB blue data. Total organic carbon contributes a maximum of 0.8 wt% to the total

carbon pool throughout this site, and shows no clear correlation with $CaCO_3$ content. Total nitrogen is very low at this site, never exceeding 0.06 wt%.

The bulk sediment elemental composition shows marked increase in concentrations towards the bottom at 135.85 mbsf, indicating interaction between basement rocks and the sediment. Oxide contents of Mg, K, Fe, Si, and Ti co-vary strongly with Al oxides, suggesting that these elements are present primarily in clay minerals. High coherency between the downhole Ca and Sr concentrations patterns suggests that Sr is incorporated in biogenic carbonate.

Physical properties data acquired from whole-round measurements are generally in good agreement with those from split-core measurements for magnetic susceptibility (MS) loop and point measurements. Gamma ray attenuation (GRA) density and *P*-wave logger velocity values indicate shorter term variations in Unit I and the top of Unit II, with the shortest term variations at the top of Unit II and in Subunit IB probably linked to 40 ky cycles in the Early Pleistocene. MS shows both high amplitude and large timescale variability all along the record. GRA density shows higher values in Unit II and Subunit IIIB corresponding to a higher fraction of carbonate/nannofossils compared to diatoms, whereas MS and natural gamma radiation show higher values within Subunit IIIA, likely linked to higher terrigenous content.

Downhole changes in physical properties characteristics overall are in good agreement with the defined lithofacies but show different relationships with one another compared to Sites U1539 and U1540 within intervals of low diatom content.

Correlations between holes at Site U1541 were accomplished using Correlator software (version 3.0). Tie points were established mostly using the core image RGB blue channel but in many cases a combination of measurements was used. We constructed a splice from 0 to 127.254 m CCSF-A using three holes; however, due to some disturbed cores or cores that were too short to be used, the splice contains two gaps. Because Hole U1541B was drilled deeper than either of the other holes, the last two cores in Hole U1541B were appended to the bottom of the splice.

We constructed a preliminary age model based on biostratigraphic and paleomagnetic age markers. These data suggest that the sedimentary sequence recovered at Site U1541 covers the past ~8 Ma. Though substantially lower than at Site U1539 and U1540, sedimentation rates at Site U1541 average 2.7 cm/ky down to ~3 Ma and decrease to ~1.3 cm/ky during most of the Pliocene and Late Miocene. This age model is generally consistent with preliminary stratigraphic tuning performed onboard, based on physical properties data such as color measurements (RGB Blue) and GRA bulk density.

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

timescales back into the Late Miocene. Site U1541 will hence provide a crucial Miocene-to-present perspective on the evolution of the ACC system, and its climate impact, and will complement higher resolution paleoclimate reconstructions based on Sites U1539 and U1540 that cover the period from the Pliocene to present.