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

Site U1542 Summary

Background and Objectives

Site U1542 (proposed Site CHI-4B) is located at the Chilean continental margin in the eastern South Pacific at 52°42.2917′S, 75°35.76915′W, ~30 nmi west of the entrance of the Magellan Strait, at 1100 m water depth. North of ~53°S, subduction in the Chile trench is more orthogonal and results in a steep slope incised by canyons that run perpendicular to the trench axis. Recent sediment cover is minor at the lower slope but a relatively small-scale sediment depo-center ("sediment drift") has been identified at the upper continental slope where Site U1542 is located.

Site U1542 is located on multichannel seismic (MCS) profile AWI-20160511 ~1 nmi north of the intersection with profile AWI-20160513. The seismic cross profiles indicate up to ~700 m thick sediments above continental basement. Although the basement age of the drift is unknown, a maximum age of ~10 Ma can be derived from the end of the tectonic erosion and start of subsidence at the continental margin. Sediments are mostly well stratified, with slightly irregular reflectors. Low to moderately reflecting layers become stronger below ~350 m sediment depth. Sediment echo sounder (Parasound) profiles reveal moderate penetration (~50 m) with distinct layering suggesting a succession of fine- to medium-grained sediments with varying lithological composition.

Site U1542 is located underneath the southward flowing Cape Horn Current (CHC), a northern branch of the Antarctic Circumpolar Current (ACC) that continues towards the Drake Passage and provides a major fraction of the present day northern Drake Passage transport. Satellite-tracked surface drifters reveal that, after crossing the East Pacific Rise, Subantarctic Surface water of the ACC is transported northeastward across the Southeast Pacific towards the Chilean coast at ~45°S, 75°W. Here, presently only a minor part of ACC water is deflected northward into the Humboldt Current System, whereas the major fraction deviates southward towards the Drake Passage. The CHC thus transports a significant amount of northern ACC water towards the Drake Passage within a narrow belt of ~100–150 km width along the coast. Modern surface current velocities within the CHC reach up to 35 cm/s and high flow speeds of ~20 cm/s extend to mid-depths.

At a water depth of 1100 m, Site U1542 is located at the lower boundary of Antarctic Intermediate Water (AAIW), and the site lies close to or within the major modern AAIW formation area in the Southeast Pacific. Circumpolar Deep Water (CDW) underlies AAIW in this region. The area off the Strait of Magellan is located ~5° north of the present Subantarctic Front. Modern mean annual sea-surface temperature (SST) in this area is ~8°C, and the seasonal range is 6° to 9°C.

The main objectives at Site U1542 were:

- Recover Pleistocene paleoceanographic records over the past several glacial/interglacial cycles at suborbital-scale resolution;
- Reconstruct the strength of the CHC (Subantarctic ACC) before entering the Drake Passage;
- Investigate AAIW and CDW water mass properties;
- Investigate changes of continental paleoclimate;
- Recover a potential near-field record of Patagonian ice sheet variability.

Operations

We arrived at Site U1542 at 1948 h on 3 July 2019. As soon as the vessel was positioned over the site coordinates in dynamic positioning (DP) mode, an advanced piston corer/extended core barrel (APC/XCB) bottom-hole assembly (BHA) was made up and lowered to the seafloor. Based on a precision depth recorder (PDR) reading of 1111.4 m below rig floor (mbrf), an APC shooting depth of 1108.4 mbrf was chosen and Hole U1542A was started at 0215 h on 4 July. Core U1542A-1H retrieved 7.1 m of sediment, which determined the seafloor depth at 1110.8 mbrf, or 1099.8 m below sea level (mbsl).

APC coring continued until 165.6 mbsf (Cores U1542A-1H to 19H) when the core barrel became detached from the sinker bars during retrieval. The core barrel fell ~50 m through the pipe back to the landing seat. Three attempts were needed to finally retrieve the barrel. Once at the surface, we found that only 1.05 m of core was recovered, and we decided to switch to the half-length advanced piston corer (HLAPC) to deepen the hole. The HLAPC was used for only one core, recording a partial stroke and recovering 3.91 m before the hole was abandoned due to high seas and winds. The bit was raised to 1033 mbrf, clearing the seafloor at 2359 h on 4 July, and ending Hole U1542A. A total of 20 APC and HLAPC cores were taken over a 169.5 m interval, recovering 181.74 m (107.2%).

We waited on the seas and winds to calm from 0030 h to 1545 h on 5 July with the bit set at 1033 mbrf. Once sea conditions had improved, the vessel was offset 20 m east of Hole U1542A, the bit was lowered to 1104.0 mbrf, and Hole U1542B was spudded at 1745 h on 5 July. Core U1542B-1H recovered only 1.46 m of sediment; because of the low recovery and quality of the core, we decided to abandon the hole in favor of obtaining a better mudline core.

The vessel stayed at the same coordinates and the bit was lowered to 1105.0 mbrf. Hole U1542C was spudded at 1830 h on 5 July. Based on the 3.3 m recovery from Core U1542C-1H, the seafloor was calculated at 1111.2 mbrf (1100.2 mbsl). APC coring continued to 169.3 mbsf with Core 20H. While running in with the core barrel for Core 21H, operations were once again

stopped due to high currents and winds. When the core barrel was retrieved, it was found that the pins had sheared and 3.57 m of core had been retrieved for an advance of 3.0 m.

At 0900 h on 6 July, the bit was pulled to 71.8 mbsf and the top drive set back to wait on weather with the bit in the hole. The crew continued to wait on weather until the seas subsided at 1630 h. The top drive was picked up, the hole washed to the bottom by 1815 h, and coring continued with Cores U1542C-22H through 28H to 226.0 mbsf. A total of 26 cores were taken over a 217.0 m interval with two 4.5 m drilled intervals (9 m drilled in total). A total of 228.91 m was recovered (106% recovery).

The vessel was offset 20 m south of Hole U1542C and the bit was spaced out to 1107 mbrf. Hole U1542D was spudded at 0600 h on 7 July. Based on the 7 m recovery from Core U1542D-1H, the seafloor was calculated at 1111.7 mbsf (1100.7 mbrf). The hole then was cored to 213.7 mbsf using the APC system, with three drilled intervals without recovery over a total of 11.0 m to help eliminate gaps in core coverage between the holes. A total of 24 cores were taken over a 202.7 m interval in Hole U1542D with 205.4 m of recovery (101.2%). The bit was recovered to the surface, clearing the seafloor at 0245 h and the rotary table at 0545 h on 8 July. The BHA was racked back in the derrick and the rig floor was secured for transit at 0555 h. The vessel was switched from DP to cruise mode at 0558 h, ending Hole U1542D and Site U1542.

Principal Results

A ~249 m core composite depth below seafloor (CCSF-A) spliced sedimentary sequence of middle Pleistocene–Holocene age was recovered at Site U1542 from all four holes and comprises five lithofacies, of which one was identified at previous Expedition 383 sites in the central South Pacific (nannofossil ooze lithofacies 4). New lithofacies include clayey silt to silty clay (lithofacies 8); carbonate- and/or sand-bearing clayey to sandy silt (lithofacies 9); foraminifer-, sand- and/or clay-bearing silty nannofossil ooze (lithofacies 10); and sand (lithofacies 11). Site U1542 is characterized by exceptionally high sedimentation rates that exceed 30 cm/ky. The entire recovered sedimentary sequence can be described as one lithostratigraphic unit (Unit I), which covers the middle Pleistocene to Holocene interval. Sediments at Site U1542 are predominantly of siliciclastic nature. The sedimentary sequence at this site is dominated by dark gray to dark greenish gray clayey silts or silty clays, while thin beds of light greenish gray to light gray nannofossil ooze occur infrequently. Below 50 m CCSF-A, up to 3 m thick intervals of interbedded clayey silt and sand appear recurrently. In addition, thin, light gray, foraminifer-bearing calcareous ooze, clay-bearing silty nannofossil ooze, or foraminifer-rich nannofossil ooze have been observed below 95 mbsf.

Diatoms and radiolarians are rare throughout the sediment succession, silicoflagellates are absent, nannofossils are few to barren, benthic and planktonic foraminifers are abundant, and ostracods are sparsely present in some intervals at the site. The biostratigraphic age model at Site

U1542 is mainly based on biostratigraphic analyses of core catcher and split-core samples from Holes U1542A (0–169 mbsf) and the bottom of U1542C (172.3–234.0 mbsf). In total, eight biostratigraphic events were recognized, which indicate an estimated age of ~0.7 Ma at the bottom of Hole U1542C. The preliminary age model, based on the biostratigraphic age markers, provides an average sedimentation rate of 37 cm/ky.

The natural remanent magnetization (NRM) of the archive-half core sections was measured before and after alternating field (AF) demagnetization at 2 cm increments. After demagnetization, the intensity correlates with neither magnetic susceptibility (MS) nor intensity prior to demagnetization, suggesting that the large drill string overprint has been successfully removed and a geomagnetic signal is recovered. Inclinations are steep and positive prior to demagnetization and steep and negative after, suggesting, as with the intensity data, that the vertical drill string magnetic overprint was removed, revealing a primary remanence that varies around the expected direction (–69°) for the site latitude during normal polarity. The NRM after 15 mT shows no evidence for reversed polarity, suggesting that Site U1542 sediments are younger than 0.781 Ma. Shore-based studies will verify these interpretations and allow us to further develop these sediments as geomagnetic recorders, providing information on the field intensity and directional variability, while facilitating the next iteration in magnetic stratigraphy.

Organic matter remineralization in sediment is one of the primary controls of pore water geochemistry. Close to the sediment water interface, where oxygen is available, aerobic respiration is the primary mechanism of organic matter remineralization. As oxygen is depleted, nitrate, Mn, and Fe serve as terminal electron acceptors in organic carbon oxidation. Sulfate reduction occurs as other electron acceptors become consumed/unavailable and, once sulfate is completely consumed, methanogenesis becomes the primary remineralization pathway. At this site, sulfate reduction predominates in the shallow sediment and the sulfate–methane transition zone likely occurs at ~9 mbsf. This is not unusual for continental margin sediments, and is probably a result of the fact that Site U1542 lies within a high productivity zone supported by abundant supply of nutrients via continental runoff.

Calcium carbonate content is very low in this site, with the exception of two distinct peaks of $CaCO_3$ of 39.2 and 80.0 wt% at 97.22 and 125.57 mbsf, respectively. The carbonate record shows no correlation with L* and RGB blue data. Organic carbon contributes a maximum of 0.67 wt% to the total carbon pool at this site. Total nitrogen is very low at this site, never exceeding 0.05 wt%, and low concentrations yield poor reproducibility of samples, as a result of the detection limit of the instrument. The TOC:TN ratio ranges between 0.82 and 18.56, suggesting a predominance of marine derived organic matter. However, the very high values of TOC:TN are likely artefacts caused by the extremely low values and poor reproducibility of TN measurements.

Physical properties data acquired from whole-round measurements are generally in good agreement with those from split-core measurements. However, considerable offsets in many

individual section depths exist in all holes, due to ongoing expansion of the sediment between when the whole-round and the split-core measurements were made. These differences will have to be corrected with further onshore measurements such as high-resolution X-ray fluorescence (XRF) scanning and manual inspection of MS parameters before sampling. The applied manual processing for cores from all holes, based on the Whole-Round Multisensor Logger/Special Task Multisensor Logger (WRMSL/STMSL) whole-round log sheets, provided sufficiently "clean" data for gamma ray attenuation (GRA) density, MS, and natural gamma ray (NGR) data, but resulted in data loss of about 8%–15%, depending on hole and data category. *P*-wave velocity measurements largely failed at Site U1542 due to core expansion and related cracking of the sediment.

At this site, the downhole changes in physical properties only partly follow the defined lithofacies based on sedimentological characteristics. The higher MS and GRA density values, compared to previous Expedition 383 sites, match the hemipelagic composition and the higher lithogenic input to the sedimentary matrix.

The physical properties at Site 1542 reflect the higher complexity of this hemipelagic site in terms of sediment delivery mechanisms. The predominantly terrigenous sediment supply likely reflects multiple processes, such as ice and glacial meltwater transport as well as dust, current-induced lateral material transport, and sorting after deposition, all influenced by various forcings such as climate and glacier mass balance changes, associated sea level changes, and dynamic changes in mid-depth ocean circulation that affect the transport direction and strength on both orbital and short (sub)millennial timescales.

The combination of nearly continuous recovery, very high sedimentation rates in a sediment drift primarily driven by siliciclastic sediment input during glacial intervals, and (although diluted) a rich array of calcareous microfossils combined with diatoms, will provide unprecedented opportunities for improving our understanding of the dynamics of the northern ACC before entering the Drake Passage, variations of the Cape Horn Current, intermediate water mass circulation, and Patagonian ice sheet variability.