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

Site U1544 Summary

Background and Objectives

Site U1544 (proposed Site CHI-1C) is located at the Chilean continental margin in the eastern South Pacific at 55°32.2192′S, 71°35.6194′W, ~30 nmi southwest off the Chilean coast and at a water depth of ~2090 m.

Tectonically, the southern Chile Margin is characterized by a complex geodynamic setting with oblique convergence between plates, transcurrent motion, and tectonic rotation on land. The geodynamic setting of the southernmost Chilean margin is driven by relative movements between three main plates: Antarctica, Scotia, and South America. This complex setting results in a strong segmentation of the southern Chile Margin as clearly visible in bathymetric data and multichannel seismic data. There are two major forearc basins at ~53°–54.5°S and 55°–56.5°S that are characterized by a thick sediment infill of up to ~3 km. Site U1544 is situated close to the axis of the southern forearc basin on continental crust of the Scotia plate. This southern basin most likely formed after the ridge consumption (10–14 Ma ago). When accretion resumed, it contributed to an outer high that provided the barrier for the accumulation of continent-derived sediments. The upper unit in the southern basement, relevant for drilling, shows onlap terminations on both basin flanks.

Site U1544 lies on multichannel seismic (MCS) profile IT95-181, ~3 nmi southeast of the intersection with profile IT95-171. Sediments are mostly well stratified and the sediment cover at the site exceeds 2.5 km. Sediment echo sound (Parasound) profiles reveal poor to moderate penetration (~30 m) with distinct layering and an irregular surface, suggesting a succession of fine- to medium-grained sediments with occasional coarser grained composition.

Site U1544 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 (CHS), whereas the major fraction is deviated 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.

Site U1544 is presently located at the lower limit of Lower Circumpolar Deep Water (LCDW) and might have been affected by Antarctic Bottom Water (AABW) in the past. The site is located ~4° north of the present Subantarctic Front. Modern mean annual sea-surface temperature (SST) in this area is ~8.5°C and the seasonal range is 6° to 9°C.

The main objectives at Site U1544 were:

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

Operations

We arrived at Site U1544 at 1746 h on 14 July 2019. Soon after arrival, the rig floor crew assembled the advanced piston corer/extended core barrel (APC/XCB) bottom-hole assembly (BHA) and deployed the drill string to the seafloor, reaching 2055 m below rig floor (mbrf) by midnight.

The initial attempt to spud Hole U1544A was made at 0015 h on 15 July and resulted in a bent/broken APC core barrel, which made it necessary to pull the bit back to the rig floor and remove the stuck portion of the barrel. The vessel was then moved 50 m southwest at 225° to attempt starting Hole U1544A again. Due to a hard layer below the sediment surface, we used the XCB system to spud the hole and break through the hard layer.

Hole U1544A finally was spudded at 1330 h on 15 July with the first core advancing 7.8 m into a softer formation. When the XCB core barrel was retrieved, we found a ~5 cm granite pebble in the core catcher. We then deployed the APC system and cored to APC refusal at 88.1 m below seafloor (mbsf). The half-length APC (HLAPC) system was used to deepen the hole to the final depth of 106.0 mbsf before coring was terminated due to high seas and winds. The drill string was pulled out of the hole, clearing the seafloor at 0958 h on 16 July and ending Hole U1544A.

The vessel was offset 20 m to the east of Hole U1544A with the bit at 2055 mbrf to wait for the seas to subside, so an attempt could be made to spud Hole U1544B. However, heave was still above 3.5 m at 0630 h on 17 July and operations were terminated. The drill pipe was pulled to the surface and the vessel was secured for transit by 1300 h on 17 July, ending Site U1544. A total of 19 cores were taken over a 103.0 m interval with 89% recovery.

Principal Results

Site U1544 consists of a 91.3 m sedimentary sequence obtained from a single hole. The sedimentary record comprises four lithofacies, all of which were identified at previous Expedition 383 sites. They include fine-grained (biosilica-bearing silty clay [lithofacies 7] and silty clay [lithofacies 8]) and coarse-grained siliciclastic sediments (sand [lithofacies 11]), as well as biogenic sediments (diatom-, clay-, and/or silt-bearing to rich nannofossil or calcareous ooze [lithofacies 10]). The sedimentary sequence in Hole U1544A is dominated by siliciclastic sediments (i.e., lithofacies 7, 8, and 11), with only sporadic layers of calcareous ooze. Sedimentation is characterized by highly variable sedimentation rates of ≥25 cm/ky, with rapidly deposited gravity-driven sedimentation (e.g., turbidities) contributing a significant fraction of the sedimentary sequence. Hole U1544A sediments comprise one lithostratigraphic unit, Unit I (7.7–106.1 mbsf), which spans the Late Pleistocene interval. Unit I largely consists of greenish gray to dark greenish gray silty clay (lithofacies 8) or biosilica-bearing silty clay (lithofacies 7) that frequently alternates with prominent decimeter- to meter-scale, dark gray sand layers that often have normal grading and erosional boundaries to underlying strata. Prominent <1 m thick beds of light gray to light greenish gray silt-bearing and foraminifer-rich nannofossil ooze occur in two intervals at 26–28 and 80.5–82.5 mbsf. Dropstones are rare, while mottling due to diagenetic overprints is minor but frequent. The upper core, Core 2X, retrieved a single hard rock pebble that suggests a rocky and hard substrate close to the seafloor at this site.

A 91.3 m thick sediment sequence of middle to late Pleistocene age was recovered at Site U1544. Diatoms are rare to abundant throughout the sediment succession; radiolarians and silicoflagellates are absent; nannofossils are abundant to barren; benthic and planktonic foraminifers are abundant above ~85 mbsf; and ostracods are sparsely present throughout the sequence but abundant at ~60 and ~101 mbsf. The biostratigraphy of Site U1544 is not well constrained due to the lack of marker species for most fossil groups. Based on the biostratigraphic events recorded, the estimated age is <0.42 Ma at the bottom of Hole U1544A.

The natural remanent magnetization (NRM) of the archive-half core sections was measured before and after alternating field (AF) demagnetization at 2 cm increments. The intensities before and after demagnetization for the upper 140 m of cores recovered from Hole U1544A are generally quite strong, varying around the 10^{-1} to 10^{-2} A/m range. A few discrete intervals have values as low as 10^{-4} A/m and are generally associated with magnetic susceptibility (MS) lows. Below 140 mbsf, intensities are slightly lower on average, falling in the 10^{-2} A/m and below range. Below 240 mbsf, intensities are more variable, with values in the 10^{-3} to 10^{-4} A/m range being much more common. Compared with previous sites, there is little difference in intensity before and after demagnetization at a peak field of 15 mT, suggesting a finer magnetic mineralogy with a higher coercivity that is less susceptible to the drill string overprint. Although a very noisy record, no evidence for reversed polarity is observed, suggesting that Site U1544 sediments are younger than 0.781 Ma.

We constructed a preliminary age model based on biostratigraphic and paleomagnetic age markers. These data suggest that the sedimentary sequence recovered at Site U1544 covers less than ~0.4 Ma. Sedimentation rates are high and average ~25 cm/ky.

The low sampling resolution makes it difficult to interpret pore water profiles from this site. Low sulfate and high methane concentrations suggest that the sulfate–methane transition zone occurs above ~10 mbsf. The high alkalinity indicates that organic matter degradation is dominated by anaerobic processes, and concentrations of pore water Fe suggest that microbial Fe reduction also occurs at this site. Due to limited time, only two samples were analyzed for total nitrogen and carbon, and observed TN values are among the highest among all Expedition 383 sites.

At this site, the downhole changes in physical properties characteristics do not show obvious features aligned with the defined lithofacies based on sedimentologic characteristics. Principally, lower MS and low gamma ray attenuation (GRA) bulk density values match the interval of higher biogenic component, but they do not show a unique relationship with one another throughout the record. Comparing natural gamma radiation (NGR) and MS records could provide indications about the different terrigenous components as they are mainly anti-correlated, similar to shallow water Site U1542.

The close proximity of Site U1544 to the southernmost Chilean margin explains the dominance of terrigenous sediments at this site. Terrigenous sediment is likely delivered to the site by a combination of ice rafting, suspension fallout from glacial meltwater plumes and/or freshwater plumes that originate from nonglaciated catchments, episodic downslope transport from the outer continental shelf, and fine-grained sediments transported by the CHC entering the Drake Passage as the northern branch of the ACC. The large proportion of normally graded sand beds with erosive basal contacts implies that turbidity currents were a transport mechanism to carry sediments from the continental slope and the upper slope during the Middle and Upper Pleistocene. We conservatively estimate the contribution of turbidities as ~40% based on the thickness of sand layers (lithofacies 11). However, it is possible that a certain fraction of the hemipelagic sediments also represents a continuation of the normal graded turbidite deposition sequence; if so, then turbidites may account for a larger proportion of the sequence and sedimentation at Site U1544 was rather discontinuous. Future geochemical and sedimentary analyses will provide crucial insights into the nature and temporal evolution of sedimentation processes at Site U1544.