IODP Expedition 390: South Atlantic Transect 1

Site U1559 Summary

Background and Objectives

Site U1559 is in the central South Atlantic Ocean, ~130 km west of the Mid-Atlantic Ridge at a water depth of ~3050 m. Site U1559 was previously occupied during engineering Expedition 390C, during which the complete sediment succession and uppermost ~2 m of basement were cored with the advanced piston corer/extended core barrel (APC/XCB) system in Hole U1559A and a reentry system was installed in Hole U1559B to within ~10 m of basement. The main objectives of revisiting Site U1559 during Expedition 390 were: (1) to core two to three holes with the APC/XCB system to recover the complete sediment succession and sample the sediment/basement interface to collect samples that address the microbiological, geochemical, and paleoceanographic objectives of the South Atlantic Transect (SAT); (2) to core 250 m into the basement with the rotary core barrel system in Hole U1559B to collect material that addresses the petrological, geochemical, and microbiological objectives of the SAT; and (3) to collect wireline geophysical logging data through the basement sections.

The basement at Site U1559 is predicted to have formed at ~6.6 Ma at a half-spreading rate of ~17.0 mm/y. This site was selected as the young crustal end-member of the SAT and will be compared to older crustal material cored at sites further west. The mineralogy and extent of alteration of the basement rocks at Site U1559 change in physical properties such as porosity. The composition of the microbial communities will be compared to the same characteristics at the other sites along the transect to investigate the development of hydrothermal circulation and the crustal aging of the upper oceanic crust formed at slow to intermediate spreading rate mid-ocean ridges. Additionally, the site is similar in age to Hole 504B in the eastern equatorial Pacific (6.9 Ma) that formed at an intermediate (36 mm/y) half-spreading rate and is covered by 275 m of sediment, as well as Hole 395A and Sites U1382–U1383 in the North Atlantic (8.1 Ma) that formed at a slow (~17 mm/y) half-spreading rate. As such, material from Site U1559 will allow comparison of how alteration progresses at different spreading centers and with different thicknesses of overlying sediment and sedimentation histories. Overlying sediment from Site U1559 is primarily carbonate ooze, and will be used in palaeoceanographic and microbiological studies.

Operations

Expedition 390C

Site U1559 was first visited during Expedition 390C, an engineering leg with the goal of coring a single APC/XCB hole to the basement for gas safety monitoring and to install a reentry system with casing. These activities were successful, with a single APC/XCB hole (Hole U1559A)

cored to 66.2 meters below seafloor (mbsf), contacting a hard layer at 64.0 mbsf, and a reentry system and casing installed in Hole U1559B to a depth of 55.31 m, ~9 m above basement.

Expedition 390

Hole U1559C, located 30 m south of Hole U1559B, was spudded on 22 May 2022 using the APC/XCB system in a water depth of 3058.0 m. Cores U1559C-1H to 6H advanced to 51.8 mbsf, recovering 52.08 m (100%). As we expected to penetrate basement in the next core, we transitioned to using the XCB system. Core 7X encountered a hard layer at ~59 mbsf that was assumed to be the sediment/basement contact. However, no basement material was recovered in the core, only 4.82 m of sediment out of the 9.1 m advance (57%). We ended coring in Hole U1559C and pulled out of the hole to the seafloor at 1545 h, aiming for better recovery of the sediment/basement interface in Hole U1559D. All Hole U1559C APC cores were oriented, and advanced piston corer temperature tool formation temperature measurements were made in Cores 4H, 5H, and 6H. For Hole U1559D, the vessel was offset 20 m south. Cores U1559D-1H to 6H advanced to a depth of 49.9 mbsf and recovered 42.01 m of sediment (84%). During drilling of Core 7X, we contacted a hard layer and recovered some small rubbly pieces of basement. Core 8X advanced 2 m to a final hole depth of 59.4 mbsf and recovered 0.37 m of material (18%). All Hole U1559C APC cores were oriented, and the perfluorocarbon microbial contamination tracer was pumped during circulation of drill fluid. In total, 2.0 d of expedition time was spent coring at Site U1559.

During the pipe trip back to the surface after finishing operations in Hole U1559D, the bearings failed on the forward electromagnetic drawworks brake. The brake was disconnected from the drawworks and isolated. Tripping back to the surface was finished using the single remaining brake. However, it was not possible to continue operations at Site U1559 and the decision was made to end operations for Expedition 390.

Principal Results

Sedimentology

In the three APC/XCB holes cored at Site U1559 during Expeditions 390C and 390, lithology is composed almost entirely of biogenic deposits of calcareous nannofossil ooze with foraminifera. Due to the consistent composition, only member-like subunits are defined. Subunit definitions are based on relatively small changes in color, sedimentary structures, bioturbation, and general appearance, combined with microscopic examination of smear slides, bulk mineralogical analysis by X-ray diffraction, and physical properties data including magnetic susceptibility (MS) and color spectral observations. Subunit IA consists of pale brown calcareous nannofossil ooze with trace siliciclastic material; Subunit IB is similar but has a high foraminifera content (>25% bulk sediment volume). Both date to the Pleistocene. Subunits IC and ID are reversed in age, with Subunit IC consisting of white calcareous nannofossil ooze with foraminifera dating to

the early Pliocene, and Subunit ID consisting of a very pale brown ooze dating to the late Pliocene. Subunit IE is Messinian to late Pliocene in age and consists of a very pale brown calcareous nannofossil ooze with foraminifera enriched in *Discoaster* sp. Differences in mineral assemblages are relatively small downhole; all sample have a ~95 wt% carbonate composition. Below the sediment/basement interface in Holes U1559A and U1559D, a transitional unit comprises a mix of micritic limestone (lithified ooze) and basalt clasts.

Igneous Petrology

Igneous basement was recovered in Holes U1559A and U1559D at Site U1559, although recovery of basement material was low. The rocks represent a portion of the sediment/basement interface and include clasts of both basalt and pelagic sediment, of which some pieces preserve contact relationships between the two lithologies. The textural relationship is similar to that seen in breccias from Sites U1556 and U1557 and is consistent with an origin as a sedimentary breccia. However, given the limited recovery at Site U1559, we have not formally ascribed the rocks to such an origin. The basalts recovered are gray (GLEY 1 5/N) and aphyric, although very sparse plagioclase macrocrysts exhibiting sieve textures are observed. Seven samples from Site U1559 were analyzed by the portable X-ray fluorescence spectrometer. The data yield $[Zr/Ti]_N$ values typical of mid-ocean ridge basalts (0.97 ± 0.04; $n = 7$, 1σ).

Biostratigraphy and Age Model and Mass Accumulation Rate

The 50.95–62.47 m thick sedimentary succession at Site U1559 contains a Recent to latest Miocene sequence of pelagic ooze. Calcareous nannoplankton and planktic and benthic foraminifera are diverse and abundant throughout, although preservation decreases directly above the basement. A coherent late Miocene assemblage within an otherwise Late Pleistocene sequence of samples in Holes U1559A and U1559C marks the presence of a 6–8 m thick slump or sequence of slumps in Holes U1559A and U1559C (~8–14 m cored depth below seafloor, method B [CSF-B] in Hole U1559A, and ~6–14 m CSF-B in Hole U1559C). These out-of-place Miocene samples occur within an interval of noticeably lighter colors in the core and a coincident shift in physical properties (particularly *P*-wave velocity) that delimit the full extent of the slump(s) and allow the same interval to be identified in Hole U1559D (~8–14 m CSF-B). The Pleistocene extends well below the slumped interval to roughly 32 m CSF-B in both Holes U1559A and U1559C. Below this level, multiple calcareous nannoplankton and planktic foraminifer datums occur within the same samples, indicating either very slow sedimentation or a series of short unconformities spanning the Pliocene, which require higher sampling resolution postexpedition to confirm.

The sediment/basement interface was recovered in Holes U1559A and U1559D and is inferred in Hole U1559C based on very slow XCB drilling rates, although no basalt was recovered. The depth of basement varies by more than 5 m between these three holes; in the shallower holes, biostratigraphic markers indicate a latest Miocene age of ~6.0 Ma, whereas the deepest hole contains datums that indicate that the sediment/basement interface there must be older than

6.8 Ma (in line with the projected basement age of 6.9 Ma for this site). Sedimentation rates are high (1.97 cm/ky) in the Pleistocene at Site U1559 (and still 1.43 cm/ky when the 6–8 m slump is removed from the calculation). Assuming that the Pliocene is condensed and not truncated by hiatuses, sedimentation rates in the bottom of the hole are around 0.56 cm/ky. Benthic foraminifera indicate gradual subsidence below abyssal depths from the Miocene to the Recent.

Paleomagnetism

Paleomagnetic investigation of Site U1559 sediments was comprised of remanence analysis of cores split during engineering Expedition 390C, alongside Expedition 390 analyses of the archive halves of Cores U1559C-1H to 7X-4 and Cores U1559D-1H to 7X-1. Discrete sediment samples were taken from Sections U1559A-8X-2 and 4, as well as from Holes U1559C and U1559D, cored during Expedition 390 (26 samples total). Here we use these data to establish a magnetostratigraphy for the sediment package at Site U1559, which will be refined with additional analysis postexpedition. All discrete sediment cubes were alternating field demagnetized, in instances up to 190 mT. By demagnetizing the samples in a stepwise fashion, we determine the characteristic remanent magnetization (ChRM) of the sample, which reflects the magnetic field direction at or soon after sediment deposition and aids in the magnetostratigraphic interpretation. Additionally, this demagnetization process helps to characterize, to a first order, the dominant magnetic mineral assemblage. Isothermal remanent magnetization (IRM) experiments contribute additional background information on the magnetic minerals present, such as coercivity, by "unmixing" the signal and using qualitative relationships between intensities at various field values.

The inclinations after 20 mT demagnetization measured from Holes U1559A, U1559C, and U1559D are bimodal, although histograms indicate significant contributions from inclinations between the two "peaks." For Hole U1559A, inclinations cluster around −53° and 43°. Inclinations for Hole U1559C cluster around −41° and 37° and are the shallowest inclinations at this site. Hole U1559D inclinations cluster around −53° and 34°. Except for the two negative modal inclinations in Holes U1559A and U1559D, most of these inclinations are much shallower than that expected for a geocentric axial dipole at this latitude (±49.1° at 30°S). A small number of the discrete sediment samples display noisy orthogonal vector plots (OVPs); of the 26 sediment samples, 20 had OVPs "clean" enough to contribute to defining the ChRM. Only 16 of these samples gave maximum angular deviation angles <15°, typically considered the cutoff for reliable magnetic field directions.

Because inclination data depicts a clear polarity sequence for most intervals, the magnetostratigraphy for each hole can be confidently determined. Considering the estimated age of the basement (6.6 Ma) and the pattern of the polarity sequence retrieved at Site U1559, which mainly derives from Hole U1559C, a tie to the geomagnetic polarity timescale (GPTS) is proposed. The proposed correlation of the normal polarities at the base of Holes U1559A and U1559C to the Miocene chron C3An is compatible with the crustal age of the basement. Median destructive fields, considered the field at which half of the natural remanent magnetization

intensity remains, and IRM up to 1.2 T and backfield IRM experiments both suggest that stable single domain or fine pseudo-single domain magnetite/titanomagnetite is the predominant magnetic mineral.

Physical Properties and Downhole Measurements

Physical properties characterization of Site U1559 is based on cores and in situ downhole measurements from Holes U1559A, U1559C, and U1559D. Whole-round core-based measurements include natural gamma radiation (NGR), bulk density from gamma ray attenuation, MS and *P*-wave velocity. Split core section measurements include point-contact magnetic susceptibility, *P*-wave velocity, moisture and density, thermal conductivity, and sediment shear and compressional strength.

NGR is relatively low throughout the carbonate-dominated sediments. MS records high frequency but low amplitude variability, between 1 and 25 instrument units, reflecting only minor differences in the concentration of magnetic minerals within the carbonates from seafloor to the sediment/basement interface. The bulk density increases from ~1.3–1.4 g/cm^3 at the seafloor to ~1.7–1.8 g/cm^3 at the sediment/basement interface, with punctuated intervals of low bulk density, likely a reflection of dislocated slumped sediments or slurries caused by drilling disturbance. *P*-wave velocity corresponds with bulk density, and both are likely associated with porosity changes downhole. Shear strength increases downhole, whereas compressional strength remains relatively constant with depth. Thermal conductivity varies between 1.091 and 1.284 W/(m·K) with no downhole trend, which is expected given the uniformity of the carbonate lithology observed in all three sediment holes. From downhole temperature and thermal conductivity measurements, a geothermal gradient of 6.3°C/km and a heat flow of 7.73 mW/m^2 through the sediments is calculated. A heat flow of 7.73 mW/m^2 is low for 6.6 Ma crust, which may suggest substantial advective heat loss via hydrothermal circulation.

Minor variability in MS and color reflectance data are used to correlate stratigraphy between holes, resulting in an almost continuous spliced record to the sediment/basement interface at 71.4 m core composite depth below seafloor (CCSF). Three gaps exist within the shipboard splice where core gaps from all three holes coincide. Proximal to the sediment/basement interface, there is excellent correspondence in the stratigraphy resulting in a robust alignment of the holes.

Geochemistry

At Site U1559, two whole-round samples per core in addition to a mudline water sample were collected for interstitial water (IW) squeezing and geochemical analyses from Holes U1559A (15 samples) and U1559D (13 samples). Rhizon samples were also taken for postexpedition research at an approximate frequency of 1 per section prior to core splitting on cores from Holes U1559C and U1559D. Intervals with drilling disturbance visible through the core liner were not sampled with Rhizons. Shipboard analyses of the squeezed IW from Holes U1559A and U1559D include pH, salinity, alkalinity, major cations and anions using ion chromatography, major and minor

elements using inductively coupled plasma–atomic emission spectrometry (ICP-AES), and nutrients (phosphate and ammonium) using a spectrophotometer. Carbonate and total organic carbon measurements were conducted on squeeze cakes (Holes U1559A and U1559D) and discrete samples from the working half (Holes U1559C and U1559D). Porewater oxygen was measured in cores from Holes U1559C and U1559D using Presens optical oxygen sensors, with a resolution of ~1.5 m. Pore water oxygen declines to zero between ~10 and 35 mbsf, coincident with elevated dissolved Mn concentrations. This finding suggests Mn oxide reduction coupled to organic carbon respiration after depletion of pore water oxygen. Sulfate concentrations decrease immediately across the sediment/water interface; however, downcore concentrations are highly variable and do not indicate substantial sulfate reduction. Major cation (e.g., calcium [Ca], magnesium [Mg], potassium [K], and strontium [Sr]) concentrations are stable throughout the hole, but Ca and Sr show a gradual decline near the sediment/basement interface that coincides with a Si increase. Sediment carbonate varies between ~86 and ~96 wt%, reflecting the calcareous nannofossil ooze lithology of all three holes, whereas the organic carbon content is low (<0.5 wt%).

Microbiology

The microbiology team collected sediment samples in Hole U1559D (Cores U1559D-1H to 7X). The team processed all samples destined for experiments testing physiology in the anaerobic chamber in the walk-in cold room, while samples destined for postexpedition cell counts and nucleic acid analysis were conducted at room temperature between two KOACH units to mitigate contamination. This dual setup allowed faster sample processing in the collected sediment sections compared to processing time at Site U1556. To test for microbial contamination of whole-round core samples from drilling fluid, we collected sediment samples containing perfluorocarbon tracer (perfluoromethyldecalin [PFMD]) from each microbiology whole round. PFMD analyses demonstrate successful delivery of the tracer to the core exterior and limited penetration of tracer into core interiors, indicating minimal or no contamination during the coring process.