IODP Expedition 393: South Atlantic Transect 2

Site U1559 Summary

Background and Objectives

International Ocean Discovery Program (IODP) Site U1559 (proposed Site SATL-13A) is located ~130 km west of the Mid-Atlantic Ridge at 30°15.63′S, 15°2.09′W in 3055 m of water. The basement at Site U1559 was predicted to have formed at ~6.6 Ma at a half spreading rate of 17 mm/y. The site is located on seismic line CREST01 at position CDP 11923 between the CREST06 and CREST1E/F crossing lines where a reflector at ~4.15 s two-way traveltime (TWT) was interpreted to be the top of basement and was estimated to be at 50 m below seafloor (mbsf).

Site U1559 was occupied twice before being reoccupied during Expedition 393. In November 2020, Expedition 390C cored Hole U1559A to a depth of 66.2 mbsf, contacting basement rocks at 63.9 mbsf, and drilled in a reentry system with 13⅜ inch casing at Hole U1559B to a depth of 55.3 mbsf, the hole itself extending to 58.9 mbsf. In May 2022, Expedition 390 revisited the site and cored Hole U1559C to 60.9 mbsf and Hole U1559D to 59.4 mbsf. The plan for Expedition 390 was to core 250 m into basement with the rotary core barrel (RCB) system in Hole U1559B and to collect wireline geophysical logging data through the basement. However, a failure of the forward electromagnetic drawworks brake caused operations to be cut short and the ship returned early to Cape Town, South Africa. Instead, the Hole U1559B basement objectives were postponed to the present expedition.

Site U1559 forms the young crustal endmember of the South Atlantic Transect and will be compared to older crustal material cored at Expedition 390/393 sites further from the ridge axis. The site is similar in age to Hole 504B in the eastern equatorial Pacific (6.9 Ma) that formed at an intermediate rate (36 mm/y half spreading rate) and is covered by 275 m of sediment. Science objectives at Site U1559 are: 1) investigate the history of the low temperature hydrothermal interactions between the aging ocean crust and the evolving South Atlantic Ocean and quantify past hydrothermal contributions to global geochemical cycles; 2) collect samples of the sediment- and basalt-hosted deep biosphere beneath the low productivity South Atlantic Gyre which will be used to refine global biomass estimates and investigate microbial ecosystems' responses to variable conditions; and 3) construct paleoceanographic records of carbonate chemistry and deepwater mass properties across the western South Atlantic through key Cenozoic intervals of elevated atmospheric CO_2 and rapid climate change.

IODP Expedition 393 reoccupied Hole U1559B but deepened it only 49.0 m into relatively fresh basaltic lava flows of the upper ocean crust and recovered 12.8 m of hard rock core. Very slow rates of drilling (<0.7 m/h absolute, 0.8 m/h rotational) and low rates of recovery (~26%) may in

part reflect heavy damage to the RCB bit even after a short duration of rotation (52.7 h) and are perhaps displayed in the commonly flared deformation of the basalt cores recovered.

Operations

Previous operations at Holes U1559A and U1559B are described in the Expedition 390C Preliminary Report (Estes et al., 2021), and Expedition 390 operations in Holes U1559C and U1559D are described in the Site U1559 summary from that expedition (https://iodp.tamu.edu/scienceops/sitesumm/390_393/390_ss1559.html).

The *JOIDES Resolution* departed Repair Quay 3 in Cape Town on 11 June 2022, with the last line released at 0949 h. Just outside the harbor we stopped to test the 50 kVA uninterruptible power supply (UPS) system under different levels of electrical load, and then started the sea voyage to Site U1559 at 1455 h. Much of the transit was completed at reduced speed due to rough seas and high winds, and at times the heading had to be adjusted. Sea conditions began to improve on 18 June, allowing the ship to increase to full speed for the final two days of the transit. The ship completed the 1713 nmi voyage in 7 days 23 h, at an average speed of 9 kt. The ship's thrusters were lowered at 1220 h on 19 June, beginning operations in Hole U1559B.

A RCB bottom-hole assembly (BHA) was made up and run to 3031 meters below rig floor (mbrf). The top drive was picked up and a pipe "pig" was pumped through the drill string to clean rust from the inside. The ship maneuvered for reentry into Hole U1559B, which had been established and cased during Expedition 390C in November 2020. We reentered Hole U1559B at 0143 h on 20 June and washed to 58.9 mbsf, the bottom of the existing hole. Cores U1559B-2R to 13R penetrated from 58.9 to 107.9 mbsf and recovered 12.82 m (26.2%). Core 2R had no recovery and drilled very quickly, indicating softer sediment above basalt. While drilling Core 3R, the drillers encountered basement at a depth of approximately 65 mbsf. Coring proceeded through Core 11R with a rate of penetration of about 1 m/h. In Core 12R, penetration slowed to under 0.5 m/h with recovery decreasing. After 9% recovery of distinctively under gauge poor quality core in Core 13R, it was decided to terminate coring and retrieve the bit to the ship. There was significant damage to the core guides and bit cones, some of which had been ground down to the bearings, creating a large 20 cm diameter hemispheroidal void where once were cones and cutting buttons. Similar damage had been seen during recent operations drilling young basalts on IODP Expedition 395C in Holes U1562B and U1554F. Recovery in Hole U1559B was low and penetration was slow, in part because of the fresh and fractured hard young ocean floor basalts being drilled, and in part because the ~65 m of sediment cover meant that the BHA extended ~100 m above seafloor, limiting the weight that could be applied to the bit. However, serious bit damage was clearly an issue, probably for some days. Early diagnosis and identification of warning signs of this style of bit failure require investigation. The ship was secured for transit and switched from dynamic positioning (DP) to cruise mode at 1232 h on 23 June, ending operations at Site U1559.

Covid mitigation protocols were in effect from arrival in Cape Town until 24 June.

Principal Results

Site U1559 targeted ~6.6 Ma upper oceanic crust, the youngest to be drilled along the South Atlantic Transect. Sediments recovered from Site U1559 during engineering Expedition 390C and Expedition 393 are described in the Preliminary Report for IODP Expedition 390 (Coggon et al., 2022) and, until that is published, in the online Expedition 390 Site U1559 summary, https://iodp.tamu.edu/scienceops/sitesumm/390_393/390_ss1559.html. Basal sediments and a few meters of volcanic basement had been recovered from Holes 390C-U1559A and 390-U1559D. Hole 393-U1559B advanced 43 m into basement, reaching a depth of 107.9 mbsf. Core pieces were mostly <10 cm in length.

Basement

Igneous Petrology

Five lithostratigraphic units were identified, comprising four main volcanic units and one thin sedimentary unit. Those four volcanic units were further subdivided into seven subunits based on volcanic emplacement style and subtle changes in phenocryst assemblages. No brecciated rocks were recovered. The uppermost volcanic rocks are aphyric microcrystalline basalt sheet flows with some planar glassy margins and vuggy vesicular patches (Unit 1). These are underlain by sparsely plagioclase-phyric microcrystalline to fine-grained basalt pillow lavas (Unit 2A) with common curved and planar glassy margins. Rare fresh olivine phenocrysts are present from 73.9 mbsf (Unit 2B), and the absence of curved glassy margins from 83.7 mbsf suggest the lowermost lavas of this unit are sheet flows (Unit 2C). Unit 2 basalts are separated from Unit 4 basalts by a thin layer (~10 cm) of hydrothermally altered indurated calcareous sediment (Unit 3) with altered glass impregnated into both the upper and lower contact (~85.5 mbsf). The directly underlying lavas (Unit 4A) are sparsely plagioclase-phyric microcrystalline to fine-grained basalt sheet flows with rare olivine phenocrysts, with the absence of glass and relatively coarse holocrystalline grain size suggesting emplacement as a sheet flow. Unit 5 (~100.7 mbsf) comprises sparsely plagioclase-phyric microcrystalline to fine-grained basalt sheet and pillow flows with rare olivine and clinopyroxene phenocrysts. The relative abundance of olivine over plagioclase phenocrysts in the final recovered pieces distinguishes Subunit 5B (104.34 mbsf). Despite this variation, distinctive sparse macroscopic plagioclase phenocrysts are common to all the volcanic units apart from aphyric Unit 1. Together with only modest differences in geochemistry determined by portable X-ray fluorescence spectrometer (pXRF) analysis, this consistency suggests all of the igneous lithological units at Site U1559 belong to a single co-magmatic sequence of relatively normal mid-ocean-ridge basalt (N-MORB) with subtle internal variations related to fractional crystallization and other magma chamber processes. The

interpretation of significant intervals of sheet flows is somewhat atypical for a slow spreading ridge. However, given the poor recovery, it is possible some sections of pillow basalts or breccia were not recovered. This potentially biased recovery must be carefully considered by subsequent studies seeking to compare hydrothermal exchange between this hole and others along the South Atlantic Transect.

Alteration Petrology

Hydrothermal alteration in Hole U1559B is characterized by pervasive gray background alteration with a variety of different colored alteration halos throughout the cored interval. The short penetration of Hole U1559B precludes the separation of alteration zones with depth, but a downhole evolution in alteration halo types is present and the recovery of a more oxidized pillow lava fragment at the base of the hole indicates that seawater-basalt exchange continues below the bottom of the hole. All alteration is dominated by the formation of yellow-brown clay minerals that replace mesostasis and groundmass. Calcite replaces groundmass in some sections. Three halo types are present and they show a downhole shift from mainly dark gray halos accompanied by orange-light brownish gray halos in the cores down to 92 mbsf, to an increasing abundance of orange-gray halos below 92 mbsf (Igneous Units 1, 2, and uppermost Unit 4). The earliest stage of alteration is the formation of dark gray alteration halos around fractures and veins. This is followed by the formation of the orange-light brownish gray and orange-gray halos. Cross-cutting relationships are rare, and the sequence of later alteration is determined by crack-seal textures in veins that suggest that early clay lined veins are reopened and filled by calcite.

Igneous Geochemistry

Representative samples of basement cores from Hole U1559B were taken from the freshest portions of each lithological subunit to obtain a downhole record of the primary magmatic conditions, along with one sample near the basalt/sediment contact. In addition, two Hole U1559B samples were prepared as matrix-matched check standards for use with direct core pXRF data collection throughout IODP Expedition 393. Eight samples were measured for loss on ignition (LOI) and bulk rock geochemical analysis via inductively coupled plasma–atomic emission spectroscopy (ICP-AES). The unoxidized powders of these samples as well as powders of the reference billets of the two standards were also characterized for elemental abundances via pXRF. The Hole U1559B basalts are exceptionally uniform in their major element compositions, with TiO_2 contents varying between 1.0 and 1.2 wt%, with high Cr (320–390 ppm) and low Ba (<1–6 ppm). In terms of basaltic rock type, they are olivine tholeiites per the Yoder and Tilley (1962) normative classification scheme. K/Zr ratios, which are a crude measure of alteration, are 10–18 in Hole U1559B samples, moderately higher than fresh South Atlantic MORB, which averages 7.4.

Paleomagnetism

Paleomagnetic measurements on basement cores from Hole U1559B were performed to characterize the magnetic signature and retrieve initial information regarding the magnetic mineralogy. Continuous measurements of the remanent magnetization were conducted using the superconducting rock magnetometer (SRM) at 2 cm spacing. To avoid excessive noise and edge effects, we only measured pieces longer than 9 cm. Measurements of remanence were made before and after progressive alternating field (AF) demagnetization at steps of 5, 10, and 20 mT applied field strength. Measurements were also conducted on a total of 11 discrete cubes of 8 cm^3 volume, which is 1–2 per core. Paleomagnetic experiments included anisotropy of magnetic susceptibility (AMS), remanence before and after AF or thermal demagnetization, and isothermal remanent magnetization (IRM) acquisition.

Paleomagnetic SRM results reveal a clear principal component at 20 mT demagnetization. Inclination values of these components are predominantly positive, which indicates a reverse polarity. The distribution of inclinations is approximately Gaussian with mean values around 38°. This is about 11° less than the geocentric axial dipole (GAD; ±49.1°) at 30°S. Discrete sample measurements revealed clear characteristic remanent magnetization (ChRM) that has inclinations similar to the SRM results. Discrete sample results confirm a reversed polarity magnetization, which is in contrast to the normal polarity expected for the 6.6 Ma basement age at Site U1559 based on magnetic data collected during the CREST survey (Kardell et al., 2019). Considering the biostratigraphic datums at the sediment/basement interface, the crustal age is likely placed within the geomagnetic polarity Chron C3Ar (Gradstein et al., 2020), which is slightly older than the expected age for Site U1559. In addition, median destructive fields and IRM acquisition up to 1.2 T suggest that the dominant magnetic carriers are likely low-coercivity minerals (e.g., titanomagnetite and maghemite). AMS measurements indicate a dominant prolate fabric for the majority of samples with a well-defined subhorizontal magnetic foliation perhaps caused by flow emplacement. No systematic changes of the scalar parameters of AMS were found with depth in Hole U1559B.

Physical properties

Characterization of the basement physical properties at Site U1559 is primarily based on cores from Hole U1559B, with additional information from Holes U1559A, U1559C, and U1559D. Whole-round, section-half, and discrete measurements were considered together to characterize the petrophysical signatures for the different volcanic units. In addition to these measurements, all whole-round cores were imaged using an X-Ray imager and ~30% of the recovered material was scanned using the Deutsche Montan Technologie (DMT) core scanner, after identifying oriented core pieces with relatively cylindrical shapes.

Many of the hard rock whole-round measurements are impaired by the small, discontinuous core pieces recovered from Hole U1559B. These measurements therefore often underestimate the true physical properties of the material. The natural gamma radiation (NGR) at Hole U1559B is

relatively low and consistent across units and ranges from 0.2–2.1 counts/s (mean = 1.05 ± 0.36 counts/s, ±1σ). Pass-through magnetic susceptibility (MS) measured on whole-round cores ranges from 1–1054 instrument units (IU) (mean = 68.5 ± 112 IU). Discrete point contact MS measurements from section-halves range from 1–1636 IU (mean = 97.6 ± 199 IU). Peaks in MS are associated with Lithologic Unit 3 (thin indurated calcareous sediment layer), the base of Unit 4 (sheet flow), and Unit 5A (mixed sheet and pillow flows).

Discrete bulk density measurements using moisture and density (MAD) range from 2.79–2.90 g/cm^3. Porosity is variable in Hole U1559B and ranges from 2.6% in the fine-grained sheet and pillow flows of Unit 5A to 5.6% in the microcrystalline sheet flow of Unit 4. *P*-wave velocity ranges from 5.46 km/s in Unit 2A to 5.80 km/s in Unit 1 (mean = 5.63 ± 0.91 km/s). The limited number of discrete samples (n = 11) from Hole U1559B do not show a clear relationship between alteration level and petrophysical parameters. The average thermal conductivity measured in basement samples was 1.78 ± 0.04 W/m·K. Together with heat flow estimates from the overlying sediment, this suggests a temperature gradient of about 40°C/km in the shallow basement at Site U1559 if the thermal regime is mostly conductive.

Microbiology

Microbiology sampling in basement in Hole U1559B was focused on exploring evidence for life in the sediments and underlying volcanic basement, especially at the sediment/basement interface, using microscopy, culture-based approaches, and culture-independent approaches. In total, eight whole-round samples (5–13 cm long) representative of the different rock types and alteration styles that comprise the volcanic basement stratigraphy of Hole U1559B were collected for shipboard and shore-based microbiological analyses. All eight samples were tested for contamination, but no tracer was detected, most likely the result of the too small amount of rock sample in the test vials. To determine the extent of microbial activity, viral production and ammonium enrichments were established that will be analyzed in shoreside laboratories postexpedition.

References

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