**IODP Expedition 393: South Atlantic Transect 2**

**Site U1560 Summary**

## Background and Objectives

International Ocean Discovery Program (IODP) Site U1560 (proposed Site SATL-25A) is located ~315 km west of the Mid-Atlantic Ridge at 30°24.2057′S, 16°55.3702′W in 3724 m of water. The basement at Site U1560 was predicted to have formed at ~15.2 Ma at a half spreading rate of 25.5 mm/y (Kardell et al., 2019), which is the highest spreading rate in the study region. The site is located on the north–south-trending (356) CREST 02 seismic crossing line at common depth point (CDP) 12770 about 0.4 km south of the main east–west (085) CREST 1D/E seismic line where a reflector at ~5.07 s two-way traveltime (TWT) was interpreted to be the top of basement and estimated to be 104 meters below seafloor (mbsf).

Site U1560 was previously occupied in April 2021 during Expedition 395E with objectives to confirm the depth to basement by coring, conduct gas safety measurements, and set a reentry system consisting of a reentry cone and 10¾ inch casing (Williams et al., 2021). Hole U1560A was cored by advanced piston corer/extended core barrel (APC/XCB) to 122.5 mbsf, finding the sediment/basement contact at 120.2 mbsf. The drill bit and casing assembly was drilled into Hole U1560B, setting the casing shoe at 122.0 msbf and the base of the hole at 124.0 mbsf. Although the drill bit showed signs of wear, the underreamer and casing were in excellent condition and consequently the top of basement in Hole U1560B was defined to be between those depths (~123 mbsf). Ten barrels of 15 ppg cement were pumped with the intention to fill the base of the hole, and pipe was run to ~100 mbsf. Hole U1560C, drilled on Expedition 393, encountered volcanic rocks at 129 mbsf indicating significant basement topography over ~10 m.

The original operational objectives of Expedition 393 at Site U1560 were to core a single APC/XCB hole to basement (Hole 393-U1560C) and to core and log ~250 m of basement volcanic rocks in Hole U1560B.

At 15.2 Ma, Site U1560 is the second-to-youngest location on the South Atlantic Transect and will be compared to older and younger crustal material cored at Expedition 390/393 sites. Site U1560 is of similar age but contrasting environment to the deep drilling at the *Superfast* Site 1256 (Wilson et al., 2006; Teagle et al., 2006; Teagle et al., 2012) on crust that formed at the East Pacific Rise during an episode of superfast spreading rate in a region of high pelagic productivity and rapid sedimentation (Wilson, Teagle, Acton et al., 2003).

Science objectives at Site U1560 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 Ocean through key Cenozoic intervals of elevated atmospheric $CO_2$ and rapid climate change.

## Operations

*Transit*

The ship completed the 187 nmi voyage from Site U1583 to Site U1560 in 16 h at an average speed of 11.3 kt, arriving at 0130 h on 19 July 2022.

*Hole U1560B*

At 0130 h on 19 July we lowered the thrusters and started operations in Hole U1560B. We assembled the rotary core barrel (RCB) bottom-hole assembly (BHA) with a new C-7 bit and lowered it down to 3714 meters below sea level (mbsl). Guided by the subsea camera images, we reentered Hole U1560B at 0920 h on 19 July and lowered the bit down to 124 mbsf, the base of the existing hole. No cement was found by drilling except for a small 5 cm roller at the top of Core 393-U1560B-2R. A turbid greenish cloud issued from the reentry cone on reentry.

We started coring in Hole U1560B at 1215 h on 19 July. Cores U1560B-2R to 21R penetrated volcanic basement from 124.0 to 219.2 mbsf, recovering 38.4 m (40%). Ship heave reached over 4 m at times and up to 4 m of soft hole fill was reported between cores. Mud sweeps of 30–60 barrels were made after most cores to flush out cuttings and fill. All cores were half-length (4.8–4.9 m). After cutting Core U1560B-21R, the bit had 52.3 h of drilling time. It was still cutting in-gauge cores with good recovery, but would not last to the intended target depth, so at 2325 h on 22 July we started to raise the pipe to change to a new bit. There was 5,000–10,000 lb overpull at 128 mbsf (~5 m subbasement), so the drillers rotated through this area to clear the tight spot. We deployed the subsea camera to observe the BHA coming out of the reentry cone, and the bit cleared the seafloor at 0250 h on 23 July. The BHA was racked in the derrick and the used bit and mechanical bit release (MBR) were removed, and a new MBR with a new C-7 bit and BHA were made up. At 1030 h we started lowering the new bit down to the seafloor.

We redeployed the subsea camera and reentered Hole U1560B at 1955 h. We found 1 m of soft fill and at 0030 h on 24 July we restarted coring from 219.2 mbsf. Cores U1560B-22R to 41R penetrated from 219.2 to 316.2 mbsf and recovered 36.35 m (37%). There were no problems with torque and a 30–60 barrel mud sweep was run after every core to flush out any cuttings. At 2320 h on 26 July, the decision was made to stop coring to leave time for downhole logging and to core a sediment hole at this site.

With ship heave increasing through the day to an extent where it would have not only posed problems for the downhole logging tools but also provide poor quality data, it was decided not to

drop the RCB bit on the seafloor for logging. Instead, we decided to change to an APC/XCB polycrystalline diamond compact (PDC) bit and log through that, to give time for the heavy seas to subside as forecasted. The narrower diameter of the PDC bit at 9⅞ inch compared to 11$^{7}/_{16}$ inch for a typical APC/XCB roller-cone bit would allow the bit to reenter casing at Hole U1560B for downhole logging. The lockable float valve (LFV) would be locked open to allow the logging tools to pass through. The RCB bit was raised to the ship, clearing the seafloor at 0225 h on 27 July and the rig floor at 0905 h. The bit, MBR, and RCB parts of the BHA were removed and replaced with an APC/XCB BHA. The RCB bit had been used for 42.5 drilling hours and had some wear to the inner teeth but was otherwise in good condition.

From 1115 h we lowered the bit to the seafloor and deployed the subsea camera to guide reentry. At 1755 h we reentered Hole U1560B and set the bit at 27.7 mbsf in the casing for downhole logging. From 2025 h we assembled the triple combo downhole logging tool string, consisting of magnetic susceptibility, electrical resistivity, density, neutron porosity, and natural gamma tools. During drilling, hole conditions had not caused excessive torque and no tight spots were encountered while raising the RCB bit, so the hole seemed to be in good condition for logging. Therefore, the density tool source and the magnetic susceptibility tool were included in the tool string, unlike operations in Hole U1583F. We lowered the triple combo down the pipe and it reached the base of the hole, 316 mbsf, recording logging data down from the seafloor. The tool string completed one upward pass in open hole (316 to 122 mbsf) and a second pass from 316 mbsf through the open hole and casing to the seafloor. The triple combo was raised back to the ship and the Formation MicroScanner (FMS)-sonic tool string was assembled. At 0645 h on 28 July we started to lower it down the pipe. The bottom of the tool was kept 5 m off the bottom of the hole (311 mbsf) to prevent damage to the bottom part of the FMS tool. The tool made two upward passes in the open hole. After the second pass, one of the caliper arms would not fully close, remaining open by 0.2 inch and causing difficulty at first to bring the tool into the base of the BHA. However, after pumping to clear hole and tool of potential debris we were able to bring the tool string to the surface without damage. We assembled the Ultrasonic Borehole Imager (UBI) tool string, and at 1545 h we lowered it down the pipe. This tool string also reached 311 mbsf and made two upward passes in the open hole, and was back on the rig floor at 2245 h. We rigged down the Schlumberger logging equipment and started pulling the bit out of Hole U1560B, clearing the seafloor at 2355 h.

In summary, Cores U1560B-2R to 41R penetrated from 124.0 to 316.2 mbsf (192.2 m of basement rocks), recovering 74.8 m (39%). Of the two C-7 RCB bits deployed in Hole U1560B, bit number one drilled for 52.3 h over a 95.2 m interval with 38.44 m of recovery (40%), and bit two drilled for 42.5 h over a 97.0 m interval recovering 36.35 m of basalt (38%). A total of 9.9 days (238.5 h) were spent on operations in Hole U1560B.

*Hole U1560C*

The ship was offset 10 m to the north in preparation for coring Hole U1560C. An XCB core barrel was deployed to close the LFV in the BHA, which had been set open for the previous day's downhole logging. The bit was set at 3721.7 mbsl and at 0245 h on 29 July we started Hole U1560C. Core U1560C-1H recovered 6.5 m of sediment, placing the mudline depth at 3724.7 mbsl. To correct the stratigraphic overlap with cores from Hole U1560A, cored in April 2021 on Expedition 395E, we drilled ahead by 2.0 m from 16.0 mbsf (drilled Interval U1560C-3-1). Advanced piston corer temperature (APCT-3) tool measurements were made on Cores U1560C-5H, 8H, and 11H. While taking the Core 11H APCT-3 measurement, the APC core barrel became stuck in the formation, and it required three drillover attempts and 160,000 lb overpull to free it. The APC piston rods had twisted during the process and as a result we switched over to half-length advanced piston corer (HLAPC) coring from Core U1560C-12F. The drill crew worked between cores to straighten the piston rods for the full-length tool.

After Core U1560C-16F reached 117.5 mbsf we switched to the XCB coring system in anticipation of reaching basement at approximately the depth it was found in Holes U1560A (120.2 mbsf) and U1560B (~123 mbsf). Basement was eencountered at 129.0 mbsf in Hole U1560C, 9.8 m deeper than in Hole U1560A. The two holes are only 10 m lateral distance apart, and the difference in basement depth reflects the rugged basement surface topography that is typical of slow/intermediate spreading rate ridges. Core U1560C-17X drilled a further 0.3 m into the basement and recovered two ~5 cm pieces of basalt. It was the last core of the expedition. Cores U1560C-1H to 17X cored from seafloor to 129.3 mbsf and recovered 122.75 m (96%). Nonmagnetic core barrels were used on all APC and HLAPC cores, and all full-length APC cores were oriented using the Icefield orientation tool.

From 0530 h on 29 July, the rig floor team coated the core line and then raised the bit to the ship, clearing the seafloor at 0900 h and the rig floor at 1655 h. The BHA was disassembled and stowed for transit and 115 ft of drill line was slipped and cut. We raised the thrusters and started the transit to Cape Town at 1930 h.

## Principal Results

Site U1560 targeted 15.2 Ma upper oceanic crust along the South Atlantic Transect. A complete sedimentary sequence comprising nannofossil ooze with varying amounts of clay and foraminifers was recovered from both Holes U1560A and U1560C, and uppermost basement rocks were recovered in both holes as well as in Hole U1560B. Hole U1560B advanced 192.2 m into basement and recovered a volcanic sequence of moderately to sparsely plagioclase ± olivine phyric pillow lavas and sheet and massive flows. Most of the lavas show positive magnetic inclinations, but negative inclinations for rocks from igneous Units 1 and 2 occur, hinting at a younger age for these flows. Core U1560B-7R directly beneath the fine-grained basalt massive flow of Unit 2 was without recovery. Preliminary wireline logs hint at elevated natural gamma

readings suggesting the presence of strongly altered basalts that enjoyed prolonged direct exposure to ocean bottom waters at the southern Mid-Atlantic Ridge. The lowermost lavas in Hole U1560B are highly plagioclase-olivine-clinopyroxene phyric basalt lavas that include two zones of sedimentary breccias comprising altered basalt and glass clasts in a matrix of indurated calcareous sediment, hyaloclastite and zeolite.

*Sediments*

Sedimentology

Biogenic and minor amounts of siliciclastic sediments were recovered from Holes 395E-U1560A and 393-U1560C. Biogenic sediments consist primarily of nannofossil ooze with varying amounts of clay and foraminifers. Intervals with siliciclastic sediments include rare to common clays with variable nannofossil and foraminifer content. A single sedimentary lithologic Unit I was defined at Site U1560 and was divided into five subunits. Unit IA extends from the top of the hole to 49.5 m core depth below seafloor, Method A (CSF-A) in Hole U1560A and to 51.3 m CSF-A in Hole U1560C. It is Pleistocene to Late Miocene pinkish-white, pink, light brown, and rarely light reddish-brown nannofossil ooze with variable amounts of clay and foraminifers. Subunit IB is Late Miocene and extends from 49.5 to 61.0 m CSF-A in Hole U1560A and from 51.3 to 61.2 m in CSF-A in Hole U1560C, and comprises pink, pale brown, light brown to dark brown nannofossil ooze with clay interbedded with 10–30 cm thick beds of pinkish-white, pink, and pinkish-gray nannofossil ooze. Subunit IC extends from 61.0 to 85.4 m CSF-A in Hole U1560A and from 61.2 to 89.3 m in CSF-A in Hole U1560C and consists of Late Miocene pink to light brown nannofossil ooze with varying foraminifer content interbedded with light brown to reddish-yellow and light brown nannofossil ooze with clay. Subunit ID extends from 85.4 to 96.4 m CSF-A in Hole U1560A and from 89.3 to 98.9 m CSF-A in Hole U1560C. It consists of Late to Middle Miocene pink, light brown, and brown nannofossil ooze with clay interbedded with medium-thick beds of brown clayey nannofossil ooze. Subunit IE extends from 96.4 and 98.9 m CSF-A in Holes U1560A and U1560C, respectively, down to the sediment/basement interface. It consists of the Middle Miocene pink, light brown, and brown nannofossil ooze with foraminifers and variable amounts of clay interbedded with brown to dark brown organic carbon bearing nannofossil ooze with clay, brown to dark brown clayey organic carbon bearing nannofossil ooze, and 10–30 cm thick beds of pink nannofossil ooze.

Biostratigraphy and Age-Depth Model

Calcareous nannofossil and planktic foraminifer biostratigraphy was performed primarily on core catcher samples recovered from Holes 395E-U1560A and Hole 393-U1560C, examined both onshore and onboard the *JOIDES Resolution*. The mudline sample in Hole U1560C contains Late Pleistocene to Recent planktic foraminifers, but ages based on nannofossils could not be determined due to contamination. Biostratigraphic analyses indicate that the Pliocene/Pleistocene boundary occurs above 42.65 m core depth below seafloor, Method-B (CSF-B) in Hole U1560A and above 43.24 m CSF-B in Hole U1560C, with the Pliocene/Pleistocene boundary located at

20.42 m CSF-B in Hole U1560A and at 20.56 m CSF-B in Hole U1560C. The Miocene/Pliocene boundary could not be determined precisely because index taxa were not observed for either nannofossils or foraminifers. However, the position of this boundary is approximated by a nearby nannofossil bioevent, base of *Ceratolithus cristatus* (5.08 Ma), which occurs at 42.65 m CSF-B in Hole U1560A and at 43.24 m CSF-B in Hole U1560C. Combined nannofossil and planktic foraminifer biostratigraphy indicates the presence of Early to Middle Miocene sediments below 45.80 m CSF-B in Hole U1560A and below 46.45 m CSF-B in Hole U1560C.

The most refined estimate for the age of basement comes from the micropaleontological analysis of the thin section (Sample 393-U1560B-2R-1, 83–85 cm) taken from indurated calcareous inter-pillow sediments. The sample contained preserved planktic foraminifer tests and amongst the identified taxa were *Orbulina* spp., *Praeorbulina* spp., and *Trilobatus sicanus*. This provides narrow 14.4–15.1 Ma age constraints, which agree with the projected crustal age of ~15.2 Ma for Site U1560.

Calcareous nannofossil and planktic foraminifer bioevents, in conjunction with paleomagnetic data, allowed for comprehensive hole age-depth models and calculation of linear sedimentation rates (LSRs). Linear sedimentation rates range from 0.43 cm/ky to 2.01 cm/ky in Hole U1560A, and from 0.29 cm/ky to 2.24 cm/ky in Hole U1560C. In both holes, the highest LSRs occur throughout the Miocene–Pliocene interval, with values ranging from 0.43 to 2.01 cm/ky in Hole U1560A, and from 0.49 to 2.16 cm/ky in Hole U1560C, whereas the lowest LSRs are recorded in the Pleistocene.

Sedimentary and Pore Water Geochemistry

Samples from Holes U1560A and U1560C were analyzed for interstitial water (IW) and sediment geochemistry. In addition, headspace gas was measured in Hole U1560A during Expedition 395E. IW geochemical data from Holes U1560A and U1560C show an increase in Na, Cl, and Br in the upper ~20 m, remain uniform downhole for most of the section, and decrease to near seawater values in the lowermost ~25 m of subunit IE. Measured pH is mostly uniform in both holes and remains within the range of local bottom seawater (7.6 to 7.8), with the exception of the upper ~40 m in Hole U1560A (pH varies from 7.7 to 7.8). Alkalinity profiles are mostly indistinguishable between the two holes and values remain uniformly higher than seawater between ~25 and 90 m CSF-A (~2.8–2.9 mM) before decreasing gradually towards near seawater values at the sediment/basement interface. In contrast to the small changes in the Ca and Mg porewater profiles, Sr concentrations and consequently Sr/Ca ratios vary significantly in both holes (~90 to 190 μM and ~8 to 17 μM/mM, respectively), consistent with carbonate dissolution and recrystallization within the sediments. Increases in concentration relative to the mudline are observed for B (11%–13%), Li (2%–4%), Si (179%–215%), and K (7%–9%) at Site U1560, and all profiles behave similarly between Holes U1560A and U1560C. Silicate diagenesis within the sediment column, as well as chemical exchanges between sediment and basement, are likely responsible for the downhole variability observed in these elements.

Sulfate concentrations in both holes show some variability in Subunit IA (~27 to 28 mM) but remain uniform below ~40 m CSF-A. Ammonium concentrations vary significantly between Holes U1560A (3.5 to 40.6 μM) and U1560C (7.5 to 20.3 μM), whereas Mn profiles are mostly similar (0.13 to 3.67 μM). Oxygen concentrations in Hole U1560C decrease in Subunit IA to near anoxic for much of the hole before increasing again to reach ~260 μM at the sediment/basement interface. Calcium carbonate is generally high in both holes, with lowest values in the lowermost ~10 m of each hole. Total organic carbon (TOC) values in Hole U1560A are fairly uniform downhole (0.3 wt%), but concentrations in Hole U1560C are higher overall and gradually increase with depth (up to ~1.4 wt% near the top of subunit IE). In Hole U1560C, TOC are low in the lowermost ~20 m of the sediment cover.

Paleomagnetism

Paleomagnetic measurements were conducted at 2 cm resolution on sediment archive-half sections from Holes U1560A and U1560C using the superconducting rock magnetometer (SRM). Remanent magnetization was measured before and after alternating field (AF) demagnetization steps at 5, 10, and 20 mT. Discrete measurements including anisotropy of magnetic susceptibility (AMS) and AF demagnetization were conducted on a total of 26 samples. Isothermal remanent magnetization (IRM) acquisition experiments were performed on ten selected samples, at least once per lithological subunit. Paleomagnetic measurements were used to construct the magnetostratigraphy for the sediment package at Site U1560.

A single remanent magnetization component could be defined after cleaning the drilling overprint with the 5 mT AF demagnetization step. The distribution of the 20 mT inclination is generally bimodal in both holes. The values are clustered around ±46° in Hole U1560A, whereas clusters centered at +43° and −45° were measured in Hole U1560C. Despite the presence of few intervals with shallow inclinations, generally clear positive and negative polarities can be detected, allowing good preliminary correlation to polarity Chrons in the geomagnetic polarity timescale (GPTS). AF demagnetization of discrete samples up to a maximum of 160 mT allow us to isolate the characteristic remanent magnetization (ChRM) with maximum angular deviation (MAD) angles ranging from 2.1° to 14.0°. Inclinations from ChRM calculated for discrete samples confirm the values measured from the SRM used to construct the magnetostratigraphy. Preliminary ties to the GPTS reveals the Brunhes, Matuyama, and Jaramillo Chrons in the uppermost sediment column down to ~8 m CSF-A in both Holes U1560A and U1560C. The Pliocene/Pleistocene boundary is identified in Unit IA at ~20 m CSF-A, and the Miocene/Pliocene boundary at the bottom of Unit IA in both holes. The base of the sediment column was placed in the Chron C5ADn (14.163–14.609 Ma, Gradstein et al., 2020), which agrees with the estimated basement age of ~15.2 Ma (Kardell et al., 2019).

Rock magnetic experiments were conducted on one to two samples per each lithological subunit, revealing the dominance of low-coercivity minerals in the cores with no significant variations with depth or sediment type. AMS measurements reveal a well-defined oblate magnetic fabric

characterized by a steeply inclined magnetic foliation, which might reveal deposition on a steep slope or subsequent tectonic tilting.

Physical Properties

Characterization of the sediment physical properties at Site U1560 was primarily based on cores from Hole U1560C, with additional information from Hole 395E-U1560A. A correlation framework and splice were developed for the site that considers natural gamma radiation (NGR), gamma ray attenuation (GRA) bulk density, magnetic susceptibility (MS), and magnetic inclination from each hole. The correlation resulted in an almost continuous spliced record to 138 m core composite depth below seafloor (CCSF), with a total core gap of ~4 m.

Whole-round measurements of NGR range between 1 and 52 counts/s but are mostly lower than 10 counts/s throughout Hole U1560C (mean of 5 ± 4 counts/s). A few peaks (10 and 20 counts/s) stand out in the middle portion of the sequence (within Unit IB and at the boundary between Unit IC and ID). In particular, peaks in Unit IB reflect the clayey nannofossil ooze lithology. In both holes, the elemental concentrations of K and Th display trends that are similar to the NGR total counts. U shows the lowest concentration of the radioactive components. These well-defined features were used as tie points for stratigraphic correlation.

MS from Whole-Round Multisensor Logger (WRMSL) mimics the NGR trends, ranging from 1 to 60 instrument units (IU), although it is scattered towards higher values in the lower Unit IE, likely due to drilling disturbance caused by the XCB system. Discrete point contact MS shows a downhole trend similar to the WRMSL record, with some higher peaks in the upper Unit IA. For both MS measurements, the lower values are consistent with the nannofossil ooze. Bulk density based on GRA ranges from 1.4 to 1.9 g/cm$^3$ over the interval measured and is uniform with depth. The highest density interval is recorded in the upper Unit IC (60 to 65 m CSF-A), up to 1.9 g/cm$^3$, which also corresponds to a peak in *P*-wave velocity.

Moisture and density (MAD) analyses were performed on 25 discrete samples to measure porosity and density. Porosity shows a decreasing trend from ~70% to ~60% within the first 15 m, but stays relatively constant at ~60% to the bottom of Hole U1560C. There is a small interval with 45% porosity that corresponds to the highest bulk density at 106 m CSF-A but the sedimentological cause remains unclear. *P*-wave velocity data range from 1.5 km/s to 1.6 km/s with a mean of 1.53 ± 0.02 km/s and is invariant downhole, other than an increase from 1.55 to 1.6 km/s in the uppermost 15 m.

Shear strength is relatively uniform in lower Unit IA and Units IC, ID, and IE around values of 8–10 kN/cm$^2$, whereas it shows higher values in the upper Unit IA and its highest value in Unit IB (30 kN/cm$^2$). Compressional strength decreases from the seafloor to ~75 mbsf from 2.0 kg/cm$^2$ to 0.1 kg/cm$^2$ (mean 1.1 ± 0.5 kg/cm$^2$), below which it shows a scattered trend around 1 kg/cm$^2$ down to the sediment/basement interface. Most samples have a thermal conductivity of ~1.2 W/(m·K) with the highest measurements from Unit IC (1.34 ± 0.02 W/[m·K]). Using the

thermal conductivity data and formation temperature measurements from Holes U1560A and U1560C, the vertical conductive heat flow for Site U1560 is estimated to be 22 $mW/m^2$.

Microbiology

Microbiology sampling in sediments at Site U1560 during Expedition 393 occurred in Hole U1560C and was focused on exploring evidence for microbial life in the sediments using microscopy, culture-based, and culture-independent approaches. From Hole U1560C, one microbiology whole-round sample (between 5–10 cm long) was collected from each 9.5 m core. Fourteen routine whole-round samples were subsampled for different ship- and shore-based scientists. An additional 35 personal whole-round cores for specialized shore-based analyses were also taken.

Multiple microbiology analyses were started shipboard during Expedition 393 on sediment samples from Site U1560. To study the extent of viral activity and dynamics between viruses and other microbial life (Bacteria and Archaea), virus-induced microbial mortality and prophage induction experiments were performed on subsamples taken from five microbiology whole-round samples throughout the sediment column. To study the microbial activity at the sediment/basement interface, ammonium enrichment incubation experiments were started with samples from the deepest sediment cores in Hole U1560C, along with the uppermost basement samples.

*Volcanic Rocks*

Igneous Petrology

Holes 395E-U1560A, 393-U1560B and 393-U1560C all recovered volcanic basement, but only Hole U1560B penetrated deeply into basement. Expedition 393 cored from the Hole 395E-U1560B pilot bit depth at 124 mbsf and advanced a further 192.2 m to 316.2 mbsf, recovering ~75 m of basalt (~39% recovery). This recovery was generally sufficient for unit boundaries, lava types, and volcanic emplacement styles to be determined with confidence throughout most of the hole, although low to zero core recovery in critical parts of the sequence means some important transitions were not recovered (e.g., Core U1560B-7R, 147–153 msbf). Similarly, the extent of sedimentary breccias and other fragile or broken formations from throughout the hole remain uncertain. Some clarification may come from the careful analysis of drilling and wireline logging information and paleomagnetic conglomerate tests.

Hole U1560B recovered a volcanic sequence composed of six main volcanic units, comprising 15 subunits. Unit 1 directly underlies basal sedimentary Unit IE and consists of sparsely to moderately plagioclase-olivine-phyric pillow lavas with some intervening sheet flows and inter-pillow sediments near the interface. Unit 2 is a sparsely plagioclase-olivine-augite-phyric massive flow, with a fine- to medium-grained interior and between 6 to 11 m thick depending on the unrecovered material in Core U1560B-7R. Unit 3 consists mostly of pillow lavas with phenocryst abundances that grade from sparsely phyric to aphyric. Unit 3 is the most primitive of

Hole U1560 in terms of Cr/Ti ratios. Unit 4 consists of sparsely plagioclase-olivine-phyric basalt pillow lavas, with a composition transitional between Unit 3 and Unit 5. Unit 5A and 5C consist of moderately to sparsely plagioclase-olivine-phyric pillow lavas, separated by two to three sheet lava flows (Unit 5B). Basalts in Unit 6 are highly plagioclase-olivine-clinopyroxene-phyric, and may provide a relatively fresh protolith for comparison with other, more strongly altered highly phenocryst-rich basalts recovered at other sites along the South Atlantic Transect. Hole U1560B ends in Unit 6B that contains highly plagioclase-olivine-clinopyroxene phyric lavas with two sedimentary breccias of basalt and glass clasts in a matrix of indurated calcareous sediment and hyaloclastite.

Lava composition assessed by portable X-ray fluorescence spectrometer (pXRF) varies significantly downhole, with geochemical boundaries largely corresponding to the petrologically defined boundaries. Incompatible element concentrations and Zr/Ti ratios are mostly consistent with a normal mid-ocean-ridge basalt (N-MORB)-like composition for the lavas at Site U1560, although higher Zr/Ti in Units 3A and 3B and 6 move towards enriched mid-ocean-ridge basalt (E-MORB) and warrant further investigation. The recurring sequence of chemostratigraphic units, with a central primitive, aphyric lava unit as was noted for Sites U1558 and U1583 is also present at Site U1560.

Alteration Petrology

Hole U1560B records fluid/rock reactions over the range of spatial contexts expected for uppermost basement, albeit with only limited recovery of breccias. The secondary minerals forming (predominantly various clays, carbonate, iron oxyhydroxides, and zeolites) are consistent with reactions at low temperatures with seawater derived fluids. The uppermost 25 m of the igneous rocks in Hole U1560B are characterized by the presence of green clay filling vesicles in the background rocks and alteration halos in the massive flows as well as the low abundance of alteration halos (<20%) and few carbonate veins. From 25–250 meters subbasement (msb), the proportion of halos remains similar, but orange halos dominate the overall halo abundance. This zone in Hole U1560B also hosts the most carbonate veins whereas green clay is restricted to massive flows. From below 250 msb there is a marked increase in the abundance of brown halos of variable alteration intensity. The lowermost part of the hole (below 250 msb) is carbonate vein poor but zeolite veins are more abundant than higher in the section. This overall change in dominant characteristics is in part controlled by the volcanic architecture of the upper crust, such as the association of green clay with massive flow, but also reflects hiatuses in volcanism that exposed parts of the crust to direct contact with seawater for prolonged periods of time as recorded by the brown halo zones.

Igneous Geochemistry

For the Hole U1560B basement cores, representative samples 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. A sample of intercalated

sediments/breccia fill was taken to better understand the basalt/sediment chemical exchanges that occurred as new lavas erupted. Twenty-seven samples were measured for loss on ignition (LOI) and bulk rock geochemical analysis via inductively coupled plasma–mass spectrometry (ICP-AES) and powder pXRF to complement the large number of pXRF analyses taken directly on the split core surface.

Basalt compositions show strong variability downhole that is evident in both the pXRF surface data and in the ICP-AES data. In terms of basaltic rock type, the freshest Site U1560 samples classify as olivine tholeiites per the Yoder and Tilley (1962) normative classification scheme. $TiO_2$ contents vary between 1.3–1.7 wt%, consistent with moderate to large amounts of crystallization before eruption. The Hole U1560B basalts are moderately altered, with elevated abundances of $K_2O$ and Rb, but lower abundances overall than seen at older Sites. $K_2O$ shows only a slight increase downhole, from 0.1 wt% up to 0.33 wt%. K/Zr ratios, a measure of relative K enrichment, range from MORB-like values of 7–9, up to 24.6. MgO shows evidence for Mg removal from the rocks via seafloor weathering. The lowest MgO samples are clustered near unit boundaries, suggesting locally more intensive reactions with seawater.

Paleomagnetism of Volcanic Rocks

Paleomagnetic measurements were conducted on archive halves of basement cores of Hole U1560B using the SRM at 2 cm intervals. Remanent magnetization before and after progressive AF demagnetization at 5, 10, and 20 mT fields were measured on pieces that are longer than 9 cm. Data resolution varied according to the core recovery rate in Hole U1560B (0% to 84%). AF demagnetization and rock magnetic experiments were performed on cube samples, targeting representative levels of both fresh basalts and those with varying degree and type of alteration.

NRM intensity of volcanic rocks at Site U1560 varies between 8.65 and 0.04 A/m, with the highest values detected in volcanic units, and some rocks showing unexpectedly high MS values (8.65 A/m). The SRM results at 20 mT demagnetization step show mean intensity values around 0.95 A/m and mostly positive inclination which agrees with the expected reverse polarity for a 15.2 Ma old basement. However, negative inclinations were also observed at the top of the basement, suggesting a significantly younger age for Unit 1A than Unit 2. Overall, the 20 mT inclination values are clustered around 64°, significantly steeper than the expected values calculated based on the geocentric axial dipole (GAD; ±49.1° at 30°S).

A total of 28 discrete samples were subjected to AF demagnetization up to 190 mT step to isolate the ChRM, which is generally well-defined with MAD between 0.5° and 11.3°. Locally, a secondary component was detected in pillow lava units. Rock magnetic experiments in fresh basalts reveal the dominance of low-coercivity minerals such as magnetite or maghemite. In contrast, heavily altered samples are characterized by a mixture of high- and low-coercivity minerals. These samples also revealed the lowest MS and remanence intensity values. In addition, variations in magnetic mineral grain-size were observed for units associated with different emplacement styles. The magnetic fabric of the volcanic rocks in Hole U1560B is

mostly prolate, showing a subhorizontal magnetic foliation with no visible correlation with the emplacement style.

## Physical Properties

Characterization of the basement physical properties at Site U1560 is primarily based on cores from Hole U1560B, with additional information from Holes U1560A and U1560C, where only the uppermost basement was recovered.-In Hole U1560B, the mean NGR is 2.1 ± 0.7 counts/s (±1σ) and ranges from 0.2 to 5.3 counts/s. The highest NGR is associated with sedimentary breccias, which have a mean NGR of 2.7 ± 1.3 counts/s. Basalts of all flow styles have lower mean NGR between 1.8 and 2.1 counts/s. Point-contact MS ranges from 0 to 2595 IU. Five prominent peaks in MS are associated with relatively fresh, fine-grained holocrystalline massive and sheet basalt flows. These peaks in MS are also apparent in the wireline logging data. Thirty-three discrete samples were used for moisture and density and *P*-wave velocity measurements, and these samples were characterized in terms of their alteration, emplacement style, and groundmass grain size. The bulk density of discrete samples ranges from 2.08 to 2.89 g/cm$^3$, with the lowest densities measured from breccia matrix and pillow lava chilled margins with thin sedimentary intercalations. These samples also display the lowest *P*-wave velocity and the highest porosity. *P*-wave velocity ranges from 3.85 to 5.89 km/s in Hole U1560B and is highest in igneous Units 1 and 6 (mean ~5.7 km/s). Units 2, 3, and 4 have a mean *P*-wave velocity of ~5.4 km/s but the lowest mean velocity measured in Unit 5 (5.0 ± 0.6 km/s). Porosity ranges from 2.0%–35.5%, but basaltic samples that are not associated with a chilled margin generally show porosities <10%. Thermal conductivity in the hole ranges from 1.13 to 1.79 W/(m·K) with a mean of 1.63 ± 0.15 W/(m·K). There is a slight downhole increase in thermal conductivity from ~1.7 W/(m·K) at the top of the basement sequence to ~1.8 W/(m·K) at ~230 mbsf. Thermal conductivity values show two broad oscillations in the lower part of Hole U1560B, with relative minima at ~255 and 288 mbsf. Its overall trend mimics the *P*-wave pattern and is opposite to the porosity profile.

Three different wireline logging tool strings—the triple combo, FMS-sonic, and UBI—were run successfully through the basement section in Hole U1560B, reaching the bottom of the hole at every pass, and indicating overall good hole conditions. Some of the more outstanding features observed in the core measurements, such as high MS values associated with massive flows in Unit 2 and smaller peaks in deeper units, are clearly recognized in the logs, and the generally good agreement between the logs and core measurements provide robust constraints for the stratigraphy of intervals with incomplete recovery. Two full passes each with the FMS-sonic (high resolution resistivity images of the borehole wall) and the UBI (360° acoustic images) may provide a comprehensive frame core log integration.

## Microbiology

Microbiology sampling in volcanic rocks from Hole U1560B focused on exploring evidence for life in the basement, especially at the sediment/basement interface using microscopy, culture-

based, and culture-independent approaches. Eighteen whole-round samples (9–14 cm long) from Hole U1560B were collected for microbiological analyses and they represented all characterized lithostratigraphic units. After the exteriors of whole-round pieces were removed to avoid material contaminated during coring, the remaining material was split into subsamples that were prepared for different microbiology analyses. Experiments were started shipboard to study microbial activity at the sediment/basement interface using ammonium enrichment incubations. These incubations focused on the uppermost basement samples to correspond with the deep sediment column samples described in the sediment section.

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