IODP Expedition 390C: South Atlantic Transect Reentry Systems

Site U1558 Summary

Background and Objectives

International Ocean Discovery Program (IODP) Site U1558 (proposed Site SATL-43A) is in the central South Atlantic Ocean, ~1067 km west of the Mid-Atlantic Ridge. The objective for Expedition 390C was to core one hole with the advanced piston corer/extended core barrel (APC/XCB) system to basement for gas safety monitoring, and to install a reentry system with casing through the sediment to ~5 m above basement in a second hole, to expedite basement drilling during South Atlantic Transect Expeditions 390 and 393.

Site U1558 is located on seismic line CREST1B/C at position CDP 3252 near the CREST04 crossing line. A reflector at ~5.9 s two-way traveltime (TWT) was interpreted as the top of basement and estimated to be at 148 m below seafloor (mbsf). Basement is predicted to be 49.2 Ma in age and was formed at a half spreading rate of ~19.5 mm/y. Oceanic crust at this site is the second oldest crust that will be drilled as part of the South Atlantic Transect expeditions and will be compared to older and younger crustal material recovered along the transect. Overlying sediment from Site U1558 is expected to be primarily carbonate ooze, and will be used in palaeoceanographic and microbiological studies.

Operations

Hole U1558A

The *JOIDES Resolution* arrived at Site U1558 on 12 November 2020 after a 92 nmi transit from Site U1557 at an average speed of 11.7 kt and switched into dynamic positioning (DP) mode at 1724 h. No acoustic beacon was deployed. The drill string with the APC/XCB bottom-hole assembly (BHA) and a nonmagnetic drill collar was lowered and the bit was spaced out to 4326.7 m below sea level (mbsl) based on the precision depth recorder (PDR) seafloor depth of 4331.6 mbsl. The first mudline core attempted came back empty. The bit was lowered 4 m and the core was reshot. Hole U1558A was spudded at 0700 h on 13 November and recovered 3.46 m, which established a water depth of 4336.8 m. APC Cores U1558A-1H through 11H advanced to 94.9 mbsf and recovered 87.87 m (92%). Core 2H experienced low recovery, as at Sites U1556 and U1557, suggesting that there are also one or more hard layers in surface sediment at this site. Core 9H was a partial stroke, advancing only 6 m. Core 10H experienced a strong overpull (70,000 lb) and was drilled over in order to release it from the formation. However, as Core 10H was a full stroke, the decision was made to attempt another APC core. Core 11H was a full stroke, but also experienced a strong overpull and had to be drilled over. The decision was made to switch to the XCB system with the polycrystalline diamond compact (PDC) cutting shoe. Cores 1H to 11H were oriented with the Icefield MI-5 core orientation tool using a nonmagnetic core barrel, following new procedures to identify any rotation relative to the core barrel during deployment. Formation temperatures were measured using the advanced piston corer temperature (APCT-3) tool on Cores 4H, 7H, and 10H.

XCB Cores 12X to 19X advanced from 94.9 to 163.9 mbsf and recovered 50.82 m (74%). Core 12X had a broken liner and was pumped out of the core barrel. A hard layer was encountered at 158.9 mbsf in Core 18X and is tentatively interpreted as the top of basement. Core 18X advanced 2.6 m into the hard layer but recovered almost none of it, aside from ~10 cm of material in the core catcher. Core 19X advanced an additional 2.4 m and recovered 2.62 m of basalt (109%), making overall recovery of hard rock material 52%. After Core 19X, we began the process of pulling the drill string back to the surface in order to prepare for casing and reentry system installation at this site. The bit cleared the rig floor at 0710 h on 15 November, ending Hole U1558A. The XCB PDC cutting shoe was examined and found to be in good condition, again performing exceptionally well in altered basalt material. Overall, coring in Hole U1558A recovered 138.69 m out of the 163.9 m advance (85%) and took 2.6 d of operational time.

Hole U1558B

The ship was offset 20 m east and preparations for casing and reentry system installation began. The Dril-Quip running tool stand was made up and the upper guide horn (UGH) was removed. A casing string of 13⅜ inch casing was made up, followed by a crossover and the 16 inch casing hanger needed to latch into the reentry system. The first three joints were locked and welded. Sea conditions were unfavorable and one of the joints was cross-threaded during assembly and had to be removed from the string. A replacement casing joint was added, which shortened the casing string slightly to 159.3 m. The plan was for the casing to extend slightly into basement and allow for a second 10¾ inch casing string to be added in the future. We paused operations to wait on weather at 2300 h on 15 November. The reentry cone was lifted off the moonpool doors and the area secured for rough seas. Operations resumed at ~0630 h on 16 November. The casing string was lowered and landed in the reentry cone in the moonpool. The bit, mud motor, and underreamer were made up with the underreamer arms set to open to a diameter of 15½ inch. We conducted a test to determine the pump rate required to open the arms of the underreamer (40 strokes/min and 400 lb/inch^2). Then, the rest of the stinger BHA was made up with the Dril-Quip running tool on top. The running tool was latched into the reentry cone and the driller lifted the complete assembly to measure the weight of the system and check the engagement of the running tool. Finally, the moonpool doors were opened, and the reentry system was lowered through the splash zone at 1220 h. Drill pipe was tripped to the seafloor, pausing to fill pipe with water every ten stands to ensure equalized pressure.

Hole U1558B was spudded at 0120 h on 17 November and the process of drilling in the reentry cone and 13⅜ inch casing began. The subsea camera system was deployed after the drill-in process began, to limit the amount of time that the camera was at depth and avoid a pressure-related failure as occurred at Site U1557. The camera system with the conductivity-temperature-depth (CTD) sensor strapped to the frame was deployed through the moonpool at 0700 h and was lowered rapidly toward the seafloor. At 0830 h and a depth of ~3700 mbsl, the video feed failed first on the entry camera and then on the survey camera. The camera system was brought back up to a depth of 300 mbsl and kept there so that drilling in the casing could continue without interruption. At 155.9 mbsf, the rate of penetration decreased substantially, indicating that we were now drilling into hard rock material. Basement at Hole U1558B was encountered 3 m shallower than expected based on Hole U1558A (158.9 mbsf). The shallower basement required a longer drilling time than anticipated. We progressed at a rate of ~1 m/h until 1415 h and a depth 161.1 mbsf, when an increase in the measured weight on bit indicated that the reentry cone had landed on the seafloor.

We then spent several hours trying to disconnect the drill string from the reentry system, applying torque to the drill string and attempting to rotate the Dril-Quip running tool 3.5 turns. At 1600 h on 17 November, we were still unable to disengage the running tool and we decided to bring the camera back on deck to conduct emergency repairs. While the camera system was being repaired, we continued to attempt to disconnect from the reentry cone without being able to observe it. The ship was moved in a 50 m grid pattern, and then a 100 m grid pattern, in an attempt to find a position and angle that might allow the tool to release from the reentry cone.

The issue with the subsea camera system was determined to be with the connector between the junction box and telemetry pod, as with the two previous failures. With no remaining spare connectors and clear evidence that the connectors cannot handle pressure, an alternative solution was found. New fiber and power connections were independently terminated at the junction box and telemetry pod. This solution reduced functionality, but did provide light and a single video feed. The camera repairs were completed just before midnight on 17 November, and the repaired camera system was deployed through the moonpool at ~0010 h on 18 November. It was lowered rapidly to the seafloor without incident and allowed us to view the reentry cone and drill string, although the Dril-Quip running tool itself was obscured by suspended sediment and cuttings. Even with the assistance of the camera, we were unable to disconnect the running tool. It appeared that torque applied to the drill string caused rotation of the entire reentry system and mudskirt, not just the running tool. At 0230 h, after a total of 12 h trying to disengage from the reentry system, we made the decision to pull the entire drill string back to the surface, diagnose the issue, and attempt to drill in the casing again in Hole U1558C. The subsea camera was recovered and secured at 0500 h. The next ~12 h were spent tripping pipe back to the surface.

The reentry system was pulled up through the splash zone at 1600 h on 18 November and set onto the moonpool doors. We observed that the Dril-Quip running tool was not easily able to move along the length of the slots in order to achieve the neutral position required to disengage it. Nonetheless, we were able to rotate and disengage the tool. The tool was lifted to the rig floor and examined. Once on the rig floor, it was able to move freely and there was nothing obviously wrong with it. The underreamer and bit were also examined and found to be in good condition. The bit cleared the rig floor at 2000 h on 18 November, ending Hole U1558B. Hole U1558B used 3.5 d of operational time.

Hole U1558C

The Dril-Quip running tool was exchanged for a spare, newly inspected and overhauled one and the process of redeploying the reentry system began. We again tested the mud motor and underreamer to confirm the pump rate required for rotation and to open the underreamer arms. The stinger was then reassembled, removing a 1 m drill collar pup joint from the original assembly to decrease the distance between the bit and the casing and reduce drilling time in basement. The ship was moved back toward Hole U1558A instead of following the standard offset pattern, with the expectation that we would encounter hard rock at ~158.9 mbsf instead of the shallower 155.9 mbsf basement depth found in Hole U1558B, and thus spend less time drilling in hard rock. The stinger with the mud motor, underreamer, and bit was lowered through the reentry cone and casing, and the running tool at the top of the stinger engaged with the reentry cone. Then, we opened the moonpool doors and the reentry cone was lowered through the splash zone at 0245 h on 19 November. We tripped pipe down to the seafloor, filling the drill pipe with water every ten stands. When the bit was near the seafloor, we paused operations to perform a routine slip and cut of the drilling line. We then picked up the top drive and spudded Hole U1558C at 1635 h.

Drilling in the casing continued smoothly through the sediment column. We contacted hard rock at 158.9 mbsf. The subsea camera was deployed just before contact with basement at 0100 h, so that we could observe the release of the Dril-Quip running tool from the reentry system. Drilling continued until a decrease in hook load indicated that the reentry cone had landed on the seafloor. We slowly transferred the weight of the reentry system with casing to the seafloor while trying to maintain weight on bit. We reached a final hole depth of 162.7 mbsf where we expected that the weight of the reentry system was entirely supported by the seafloor. The next 12 h were spent attempting to disconnect the running tool from the reentry system. As with the Hole U1558B attempt, the ship was moved in a grid pattern in an attempt to find a position and angle that might allow the tool to release from the reentry cone. We also stopped circulation of drill fluids for several hours so that the formation might collapse around the casing and take the weight of the casing string. We were ultimately unable to disconnect, despite the installation modifications we had made after the first failed attempt. At 1700 h on 20 November, in consultation with the Expedition 390 and 393 Co-Chief Scientists, we made the decision to abandon Hole U1558C and pull the reentry system back to the surface. The subsea camera was recovered at 1800 h, and the process of tripping drill pipe back to the surface began. The bit cleared the seafloor at 1850 h.

The reentry system was raised to just below the ship at ~0600 h on 21 November. We opened the moonpool doors but had zero visibility in the dark and were unable to determine the orientation of the reentry cone base. We paused operations until daylight when we could safely recover the reentry system. At 0800 h we reopened the moonpool doors, oriented the base, and recovered the reentry system. We observed that three out of four load-bearing plates on the mudskirt had fallen off during the attempted redeployment. As with our first attempt at Hole U1558B, the Dril-Quip running tool was easily disconnected from the reentry system once at the surface despite our inability to disconnect it while on the seafloor. The running tool, underreamer, and bit were raised to the rig floor and inspected. The underreamer was found to be in excellent condition. The bit cleared the rotary table at 1056 h on 21 November, ending Hole U1558C. Hole U1558C used 2.6 d of operational time.

Hole U1558D

After two failed attempts to install casing and a reentry system at Site U1558, we determined that our inability to disengage the Dril-Quip running tool from the reentry system when on the seafloor was due to hard rock inhibiting the complete transfer of weight off the tool. The assembly from where the bit sits in hard rock to the running tool is too rigid. As such, the only option for installing a casing and reentry system at Site U1558 was to remove a joint of casing so that the casing shoe landed in sediment above the hard rock contact. We decided to make a final attempt to install this shorter casing string and reentry system. The 16 inch casing hanger was released at 1320 h on 21 November by screwing releasing bolts into the snap ring that holds the hanger in place in the reentry cone, after some initial difficulty with compressing the snap ring caused by debris caught in the ring. The hanger was raised to the rig floor and swapped out for a spare. We shortened the casing string by removing a single joint and had reassembled it with a length of 146.1 m by 1745 h. The running tool was then latched into the casing hanger and the hanger landed in the reentry cone. We picked up the mud motor, underreamer, and bit and tested them to determine the pump rates required for rotation and for the underreamer arms to open up. Finally, the casing stinger was lowered to 150 m below rig floor and the running tool engaged with the reentry cone. New plates were welded onto the mud skirt to replace the ones that were lost.

We opened the moonpool doors and started to lower the reentry cone through the splash zone at ~0245 h on 22 November. On the first attempt, the reentry cone and base slipped out of the bottom snap ring groove, catching on the upper one. We recovered the system, reset the casing hanger snap ring, and attempted a second deployment with the same result. After recovering the system and resetting the snap ring again, we decided to proceed with the deployment. Changing out the reentry system at this stage would require breaking down and then remaking all of the casing, using up the remainder of our operational time. The reentry cone was lowered through the splash zone at 0335 h and we began the process of tripping drill pipe towards seafloor. Drill pipe was filled with water every ten stands. We closely monitored the weight of the drill string as an indicator of whether the reentry cone was still attached. However, ship heave generated noisy hook load data that made it difficult to track weight changes on the order of the reentry cone (8,800 lb). At 0600 h, the vessel was moved into position over our proposed location for Hole U1558D (30 m east of Hole U1558A, near U1558B). Prior to the move, the vessel was in an offset position 40 m west and 20 m south of Hole U1558A.

The subsea camera system was deployed at 1200 h on 22 November and lowered towards the seafloor. When the camera caught up with the running tool at 3957.6 mbsl, we observed that the reentry cone had slipped and fallen off the casing, which was still attached to the drill string via the running tool. We then initiated a search for the reentry cone on the seafloor. If it could be located and had landed in proper orientation, we would be able to reenter and drill in the casing as planned. We pulled the subsea camera system back to the surface so that we could remove the drill pipe insert and install a door that enlarges the opening of the camera frame. The camera was redeployed at 1545 h and lowered over the running tool to the bottom of the casing string, just above seafloor. Visibility was good despite the fact that the repaired camera system only had a single functional camera and light. We searched for the reentry cone by moving the ship in an expanding grid pattern, starting at the offset position 40 m west and 20 m south of Hole U1558A. Our best estimate from the hook load data was that the reentry cone had fallen off early in the tripping process, before the ship was positioned over the intended location of Hole U1558D. Ultimately, however, we located the reentry cone and mudskirt at 2223 h, sitting upright on the seafloor in the vicinity of Holes U1558A–U1558C and near its intended position. This location implies that the reentry cone fell off later, after the ship had moved. We picked up the top drive and prepared to spud Hole U1558D.

The cone was reentered at 0056 h on 23 November and Hole U1558D was spudded at 0059 h. The drill-in process proceeded smoothly, with the bit achieving a maximum depth of 150.0 mbsf at 0745 h. The length of the shortened casing string is 146.1 m. Basement is estimated to be at ~155.9 mbsf in Hole U1558D. After landing the casing hanger in the reentry system, the Dril-Quip running tool rotated easily and disengaged from the casing and reentry cone at 0750 h. We began pulling the subsea camera and drill string back to the surface and recovered the camera at 0945 h. For the next ~8 h, we pulled the remaining drill pipe to the surface. The running tool was recovered at 1800 h and the rest of the BHA was pulled up to the rig floor and laid out. The UGH was reinstalled and the rig floor secured for transit to Site U1559 (proposed Site SATL-13A) at 2356 h, ending Hole U1558D. The vessel switched out of DP mode at 0003 h and was underway at full speed by 0018 h. Hole U1558D used 2.5 d of operational time.

Principal results

Basement at Site U1558 was determined to be only slightly deeper than estimated from seismic data, at 158.9 mbsf in Holes U1558A and U1558C and at 155.9 mbsf in Hole U1558B, relative to the estimated 148 mbsf. Video footage acquired from the subsea camera during the survey for the reentry cone at Hole U1558D indicates that Holes U1558A and U1558C are <10 m apart, suggesting that there is substantial basement topography within short lateral distances.

Cores U1558A-1H to 18X were measured on the whole-round (WR) and split-core track systems. Core 19X sections, containing hard rock material, were measured on the WR tracks but were not split, and were instead preserved in nitrogen gas-flushed bags for description and analysis during Expeditions 390 and 393. The sediment/basement interface occurs in the Core 18X core catcher, which was accidentally split before we realized that the interface was present in that section. The core catcher section halves were subsequently vacuum sealed and stored in D-tubes. Core catcher samples from Cores 1H to 17X were collected for postexpedition biostratigraphic dating. In addition, we collected one sample per core for headspace gas analysis as well as 1–2 WR samples per core for chemical analysis of interstitial water (IW). Starting with Core 16X, we collected 10 cm instead of 5 cm WR samples to ensure enough water was available for standard analyses. No systematic core description took place during Expedition 390C. Sediment lithology consists primarily of carbonate ooze, aside from the first two cores. Core 1H is predominantly clay, with a calcium carbonate content of 24.1 wt%. Core 2H contains alternating 0.5–1 m thick, clay- and carbonate-rich layers, with a calcium carbonate content of 47.1 wt% at 7.825 mbsf. Below that depth, calcium carbonate content averages 80.1 wt%. Physical properties such as magnetic susceptibility (MS) and counts of natural gamma radiation (NGR) generally correlate with lithology, with higher MS values and NGR counts in the clay layers and in the hard rock sections. *P*-wave velocity and gamma ray attenuation (GRA) density increase downhole, with a significant increase in GRA density values in basement Core 19X. *P*-wave velocity was not measured in that core.

Data acquired from analysis of IW in Hole U1558A do not show as clear downhole trends as observed at Sites U1556 and U1557. Alkalinity shows a very narrow range in concentration (from 2.28 to 2.56 mM) and concentrations are generally lower than those found at Sites U1556 and U1557. Total dissolved sulfur concentrations, as measured by inductively coupled plasma–atomic emission spectroscopy of IW samples, are relatively constant throughout the sediment column. A maximum concentration of 29.3 mM occurs in the mudline sample, with downhole concentrations averaging 27.9 ± 0.9 mM. Dissolved manganese (Mn) concentrations increase downhole, reaching a maximum value of 3.02 µM at ~126 mbsf and then decreasing towards basement. Mn concentrations are significantly lower than at Sites U1556 and U1557, where peak Mn concentrations are >100 µM. The peak in dissolved Mn at ~126 mbsf is followed by a sharp peak in ammonium (reaching 213.4 µM at ~130 mbsf) and then a sharp decline in sulfur to a minimum of 24.5 mM at ~137 mbsf. These respective maximum and minimum values are only present in 1–2 samples and will need to be confirmed through higher resolution sampling during Expeditions 390 and 393. Combined, however, the data suggest a deep redox horizon and that the upper sediment column may be oxygenated. This hypothesis can be verified with direct measurements of dissolved oxygen during Expeditions 390 and 393. Dissolved iron was below the detection limit, likely because it reoxidized and precipitated during the WR squeezing process.

Dissolved calcium and strontium concentrations increase downhole before decreasing again just above basement, with the inflection point at ~140 m. Their concentrations in IW are overall lower than at Sites U1556 and U1557. Conversely, dissolved magnesium and potassium concentrations decrease slightly with depth and do not show a near-basement reversal in the trend. Dissolved silicon concentrations decrease from the surface until ~25 mbsf and then remain relatively constant with depth. Boron concentrations decrease initially but increase again at ~115 mbsf. The two elements do not have the close inverse correlation observed at Sites U1556 and U1557.

All cores excluding the unsplit basement sections were measured on the superconducting rock magnetometer (SRM) for natural remanent magnetization (NRM) and then at alternating field demagnetization levels of 5, 10, and 20 mT. Vertical drilling overprints were ubiquitous but were generally removed by the 5 mT demagnetization step. Many samples appeared to show a characteristic remanent magnetization (ChRM) after 20 mT demagnetization, although some likely have a higher coercivity component that will need to be examined during postexpedition research.

The CTD sensor was deployed along with the subsea camera system at Hole U1558B. It successfully logged water column data.