IODP Expedition 395C: Reykjanes Mantle Convection and Climate: Crustal Objectives

Site U1554 Summary

Background and Objectives

International Ocean Discovery Program (IODP) Site U1554 (proposed Site REYK-6A) is located in the North Atlantic Ocean along the Reykjanes Ridge south of Iceland and on Bjorn Drift. Site U1554 is located on seismic line JC50-1 (CMP 41740), near the intersection with line JC50-C3 (CMP 1005), both obtained in 2010 during RRS *James Cook* Cruise JC50.

Diachronous V-shaped features visible in bathymetry and gravity data, termed V-shaped ridges (VSR) and V-shaped troughs (VST), straddle the Reykjanes Ridge and may provide evidence of varying behavior of the Iceland mantle plume and its interaction with the Mid-Atlantic Ridge through time. Basalt samples from the VSRs and VSTs will test hypotheses relating to the formation of these crustal features. Site U1554 is located in VST-2b with an estimated basement age of 12.7 Ma. Another target for Site U1554 is to obtain a continuous sedimentary record of the Bjorn Drift, which will offer millennial-scale climate records. The sedimentation rate of this drift can serve as a proxy for deep water current strength, providing information on oceanic gateways and their potential ties to mantle plume pulses.

Cores and data from this site will address all three of the primary science objectives: (1) crustal accretion and mantle behavior; (2) ocean circulation, gateways, and sedimentation; and (3) time-dependent hydrothermal alteration of oceanic crust.

The operational objectives for this site were to core the sedimentary section using the advanced piston corer/extended core barrel (APC/XCB) system to the sediment/basement interface, install a reentry system with casing and use the rotary core barrel (RCB) system to core ~130 m into the basement, and use downhole wireline tools to log the borehole. All of the planned operations are in support of Expedition 395, which was postponed twice due to the COVID-19 pandemic.

Operations at Site U1554 first occurred in July 2020 during IODP Expedition 384. Holes U1554A–U1554D ranged in depth from 23.5 to 76.0 m drilling depth below seafloor (DSF). The recovered cores were used to create a stratigraphic splice of the section. Paleomagnetic data from these cores were used to test and resolve issues with the Icefield MI-5 core orientation tools.

Operations

Hole U1554E

Following a 54 nmi transit from Site U1555 (proposed Site REYK-13A), the vessel arrived at Site U1554 early on 24 June 2021. The ship's thrusters were lowered at 0124 h and the vessel switched to dynamic positioning (DP) mode at 0136 h. The APC/XCB bottom-hole assembly

(BHA) and drill string were made up and run to the seafloor (1870 m below sea level [mbsl]). At 0754 h, Hole U1554E (60°7.5235′N, 26°42.1324′W) was spudded and drilled without recovery to 66.3 m DSF. Coring during Expedition 384 recovered three copies of the uppermost ~75 m DSF, and coring this interval was not required for safety monitoring. Coring using the APC progressed from 66.3 to 218.3 m DSF (Cores U1554E-2H to 17H) with 157.92 m of sediment recovered (104%). The cores expanded upon arrival on the core receiving platform. When taking Core 17H, the core barrel could not be pulled out of the sediment using the core winch line. The barrel was drilled over using the drill string to free the core.

Formation temperature measurements using the third-generation advanced piston corer temperature (APCT-3) tool were collected on Cores 2H, 5H, 8H, and 11H. All APC cores were oriented and collected using nonmagnetic core barrels.

The XCB was deployed following Core 17H. Cores 18X to 62X (218.3–647.7 m DSF) were collected with 383.15 m of core recovered (89%). The basement was encountered at ~647 m DSF while drilling Core 62X; the core contained 1 m of basalt interlayered with carbonate sediment. The final hole depth was 647.7 m DSF.

A total of 61 cores were collected at Hole U1554E, with 541.07 m of core collected over a 581.4 m interval (93%).

Following coring operations, the hole was cleaned and displaced with heavy mud and the drill string pulled up to 72.8 m DSF. The triple combo logging tool string was made up and run in the hole at 2100 h on 27 June. The tool string was able to descend to the base of the hole (~647 m DSF) and the triple combo made two passes of the borehole. The first attempt to pull the triple combo through the bit and into the drill pipe occurred at 0115 h on 28 June. The lockable float valve (LFV) at the bit had closed, preventing the tool string from reentering the pipe. After several hours of pumping seawater and rotating the drill string, the triple combo was pulled past the LFV and the tools reached the surface at 0845 h. The Formation MicroScanner (FMS)-sonic string was assembled and deployed at 1120 h. A go-devil was attached to the top of the tool string to lock open the LFV. After two passes of the borehole, the FMS-sonic was unable to pass through the LFV and reenter the pipe. After additional pumping, the tools were successfully recovered and the FMS-sonic tool string reached the rig floor at 2055 h. Based on the caliper results from the triple combo, which showed that the borehole was washed out to >14 inch diameter for the majority of the hole, the decision was made not to run the Versatile Seismic Imager (VSI). Following logging operations, the drill string was pulled out of the hole with the bit clearing the seafloor at 2210 h on 28 June. At 0245 h on 29 June the bit cleared the rotary table, ending the hole.

Hole U1554F

The ship was positioned over the Hole U1554F coordinates (60°7.5136′N, 26°42.1140′W), ~25 m southeast of Hole U1554E, and the rig floor crew began assembling the casing and reentry system. The mud skirt of the reentry system was moved over the moonpool and the

hydraulic release tool (HRT) was made up and racked in the derrick. A 602.3 m long casing string, composed of 52 joints of 10¾ inch casing, was assembled. The HRT running tool was attached to the casing and lowered to the mud skirt. The HRT running tool was then detached and put back into the derrick. The mud motor, underreamer, and bit were assembled and tested. The first mud motor rotated too freely and was replaced with a second mud motor. After a successful test, the crew made up the BHA with the HRT running tool assembly and the reentry cone. At 0638 h on 30 June, the HRT reentry system was deployed through the moonpool. The casing and drill string were run to a depth of 1552 mbsl and the subsea camera system was deployed to observe the casing operations. Hole U1554F was spudded at 1345 h at a water depth of 1870 mbsl, and the casing was drilled in to a depth of 602 m DSF. Once the casing and reentry system were in place, a go-devil was pumped down the pipe to activate the HRT running tool and release the drill string from the casing. The drill string, including the HRT running tool assembly, was pulled from the hole with the bit clearing the seafloor at 1610 h on 1 July. The rig floor crew broke down the HRT running tool assembly.

An RCB BHA, with a C-4 RCB bit, and the drill pipe were made up and run to a depth of 1836.5 mbsl. The subsea camera, along with the Conductivity-Temperature-Depth (CTD) sonde, was run to the end of the drill string to observe the bit reenter Hole U1554F. The bit entered Hole U1554F at 1057 h on 2 July. The subsea camera was retrieved and the drill string advanced to the base of the casing string (602 m DSF). The center bit was dropped into the RCB bit and Hole U1554F was drilled without recovery to 620 m DSF. Two drilled intervals, U1554F-1-1 (0–606.3 m DSF) and 2-1 (606.3–620 m DSF), were recorded for the hole. The center bit was retrieved and an RCB core barrel was deployed. Cores U1554F-3R to 5R advanced from 620 to 649.1 m DSF with 19.86 m of core recovered (68%). Core 5R contained the sediment/basement interface at ~647 m DSF. Cores 6R to 20R advanced from 649.1 to 721.7 m DSF with 45.91 m of basalt recovered (63%).

Following Core 20R, the drill bit had reached 50 rotating hours. The drill string was pulled from the hole to change the drill bit and the bit cleared the seafloor at 1840 h and rotary table at 2210 h on 5 July 2021. A new C-7 RCB drill bit was made up to the BHA. The drill string was assembled and the subsea camera, along with the CTD sonde, was deployed for the reentry. The bit reentered Hole U1554F at 0405 h on 6 July. The subsea camera was recovered and the drill string advanced to 721.7 m DSF. RCB coring resumed from 721.7 to 779.9 m DSF with the recovery of Cores U1554F-21R to 32R.

In total, 30 cores were recovered from Hole U1554F over an interval of 159.9 m. The core recovery for this hole was 100.15 m (63%). The basement cores advanced at an average rate of 1.76 m/h.

Following coring operations, the hole was conditioned for downhole wireline logging with a 50-barrel high-viscosity mud sweep. The drill pipe was pulled out of the hole and the subsea camera deployed to observe operations. The drill bit cleared the seafloor at 0643 h on 8 July and the ship was offset 20 m to the northeast. A rotary shifting tool was run to release the drill bit and allow the logging tools to exit the drill pipe. The bit was released at 0756 h and at 0955 h the pipe

reentered Hole U1554F. The subsea camera was recovered and the drill string deployed to a depth of 589.2 m DSF, inside the casing string. The triple combo logging tool string was made up and run for two passes of the borehole from a depth of 602 m DSF, the base of the casing string, to the bottom of the hole at 779 m DSF. At 2010 h, the triple combo tool string reached the drill floor and was broken down. The FMS-sonic tool string was made up and run at 0410 h on 9 July. After making two logging passes, the FMS-sonic tool string was recovered to the rig floor, disassembled, and laid out. The Ultrasonic Borehole Imager (UBI) tool string was then made up and deployed to the bottom of the hole. The UBI made two logging passes, taking 360° images of the borehole wall. The UBI tool string was recovered and laid out at 1425 h. The drill pipe was pulled up from a depth of 588 m DSF to 69 m DSF in preparation of running the VSI from the base of the hole up through the casing string. However, foggy conditions throughout the afternoon and evening inhibited visibility and prevented the start of the protected species observation protocols. At day break, visibility had worsened and conditions were not forecasted to improve until evening. Because of the time already allocated to Site U1554, the decision was made to abandon the VSI logging run and begin operations at Site U1562 (proposed Site REYK-3B). The drill pipe was pulled up and cleared the seafloor at 0755 h on 10 July, ending Hole U1554F.

The vessel returned to Hole U1554F on 21 July to complete the VSI logging operations. The ship completed the 6.1 nmi transit in DP mode from Site U1562 to Hole U1554F at 0730 h. The subsea camera was deployed and the drill pipe was lowered to 1836 mbsl. The drill pipe was positioned over the reentry cone and reentered Hole U1554F at 0930 h. The subsea camera was retrieved and pipe was run to a depth of 68.5 m DSF, within the casing string, in preparation for downhole logging with the VSI tool. At ~1030 h, fog had formed around the vessel and reduced visibility. The vessel waited on the fog to clear and at 1250 h the VSI was deployed to the base of the casing string (602 m DSF), the air guns were set in the water, and the protected species observation protocols were initiated. Nearly immediately whales were spotted within the exclusion zone, which delayed the start of the VSI operations. After 2 h of tracking whales in the vicinity of the vessel, foggy conditions reduced visibility prohibiting the continuation of protected species observation watch. With the fog forecasted to worsen throughout the evening and into the next day, the planned VSI operations were cancelled at 1600 h in favor of coring at the next site. The VSI was pulled from the drill pipe and the tool reached the rig floor at 1700 h. While retrieving the tool string, visibility briefly improved only to reveal that the whales had come closer to the ship. The drill pipe was pulled out of the hole and the end of the pipe cleared the seafloor at 1840 h and the rig floor at 2210 h. The rig floor was secured for transit and the thrusters were raised. The vessel began the 39 nmi transit to Site U1563 (proposed Site REYK-11A) at 2236 h, ending Hole U1554F and Site U1554.

Principal Results

The JRSO technical staff processed all cores and samples in the laboratories, following the measurement and sampling plan constructed by the shore-based Expedition 395C Co-Chief

Scientists and science party. Data interpretation, core description, and biostratigraphic analyses will take place postexpedition.

Sediment cores obtained from Holes U1554E and U1554F (Cores U1554E-2H to 60X, 66.3–645.23 m core depth below seafloor [m CSF-A]; U1554F-3R to 4R, 620.0–636.9 m CSF-A) were run through the whole-round (WR) physical properties tracks, which include magnetic susceptibility (MS), gamma ray attenuation (GRA) bulk density, *P*-wave velocity, and natural gamma radiation (NGR) measurements. WR core sections near the sediment/basement interface (Cores U1554E-56X to 61X) were imaged using the X-Ray Imager (XRI). The split section halves were imaged, measured for point magnetic susceptibility (MSP) and color reflectance, and scanned for magnetic remanence using the superconducting rock magnetometer (SRM). Thermal conductivity measurements and moisture and density samples were collected at a resolution of one per core.

Samples were collected on the catwalk and at the sample table for shipboard and shore-based interstitial water (IW), gas, microbiology, and micropaleontology analyses. Headspace gas samples for shipboard hydrocarbon safety analysis and postcruise research were collected every core and the resolution increased to two samples per core ~30 m above the sediment/basement interface. Samples for postcruise biostratigraphy were collected from each core catcher, and additional split core samples were collected from 500 to 645 m CSF-A at 3 to 4 m resolution. Catwalk sampling for IW analysis and microbiology began at Core U1554E-31X (~350 m CSF-A). The overlying sedimentary section will be sampled for IW chemistry and microbiology during Expedition 395 when the section is re-cored and a sailing science party is available to assist with the measurements. IW samples, 10 cm in length, were collected in each core below 350 m CSF-A and three per core were collected in the ~20 m above the sediment/basement interface. Microbiology samples were extracted using a sterile syringe, with 4 cm^3 of sediment frozen in the syringe and 1 cm^3 of sediment added to a glycol solution and flash frozen using liquid nitrogen. The microbiology samples were paired with the IW samples. X-ray diffraction and carbonate samples were subsampled from the IW squeeze cake sediment residues. Additional carbonate samples were collected beginning ~30 m above the sediment/basement interface.

RCB Cores U1554F-5R to 32R (639.4–778.8 m CSF-A) were run through the WR tracks to collect the same physical properties measurements as Hole U1554E, with the exception of *P*-wave velocity, which was not recorded because the space between the liner and the core for RCB cores prevents meaningful measurements. The split section halves were imaged, measured for MSP and color reflectance, thermal conductivity, *P*-wave velocity using the caliper, and scanned for magnetic remanence using the SRM. Section halves from Cores U1554F-3R to 5R (620–642.4 m CSF-A) were imaged using the XRI. Each basalt core section was scanned using the portable X-ray fluorescence spectrometer device. WR samples of basalt for postcruise microbiology studies were collected immediately after the core was received from the rig floor at a resolution of one sample per ~10 m. Samples for inductively coupled plasma–atomic emission

spectroscopy (ICP-AES) and thin sections were selected by the shore-based petrologists using core photos, also at a resolution of ~10 m.

The lithology of the sedimentary cores changes downhole, with terrigenous sediment dominating the majority of the section and transitions to biogenic carbonate at the base of the drift. Cores U1554E-2H to 14H contain clay and silt that alternate between dark gray, light gray, and light greenish gray intervals. These cores display mottling and bioturbation. Cores U1554E-15H to 55X are dark gray and do not display the color changes observed in the upper section of the hole. These cores contain gastropod shells, some of which are pyritized. Foraminifers and biogenic silica can be seen in the split core sections using a hand lens, and dropstones of varying composition are occasionally observed. The XCB cores have prevalent biscuiting from the coring process.

Core U1554E-56X records a lithology change to lighter material with soft sediment deformation and erosional surfaces. Cores U1554E-57X to 60X and U1554F-3R contain sediments that alternate between light green to dark gray with varying amounts of calcium carbonate (32–54 wt%) and clay content. Sharp, erosional contacts and burrows are observed in these cores. Core U1554E-61X transitions from the dark gray material to a light green and white nannofossil chalk with higher carbonate content (66–85 wt%). Chalk was also recovered in Cores U1554F-4R and 5R.

The sediment/basement interface was recovered in Cores U1554E-62X and U1554F-5R. The uppermost basement is composed of basalt alternating with carbonate beds. Cores 6R–10R consist of basalt that is interlayered with thin beds of carbonate. The basalt contains glass and shows varying degrees of alteration with several veins present. Some of the carbonate intervals contain brecciated basalt clasts. Cores U1554F-11R to 32R (673.5–778.8 m CSF-A) are composed of basalt that contains glass and has varying degrees of alteration that includes calcite veins, infilled vesicles, and staining. The shore-based petrology group provided sampling intervals for ICP-AES measurements and thin sections.

The physical properties of the cores primarily reflect changes in lithology. MS and NGR show cyclic patterns from 66 to ~450 m CSF-A. At ~450 m CSF-A, the values of both properties decrease and remain reduced to the base of the sediment section in Hole U1554E. The MS values of the basalts in Hole U1554F average ~200 instrument units (IU), with a peak value of over 2300 IU. The NGR values of the basalt average ~3.5 counts/s. Red, green, and blue (RGB) color shows the most variance between 66–200 m CSF-A and RGB and color reflectance increase from 520 to 646 m CSF-A. The average porosity of samples collected between Cores 31X and 61X (344.4 to 645.23 m CSF-A) is 62%.

The collection of measurements downhole at Site U1554 was successful. Four formation temperature measurements from 75.8 to 161.3 m DSF linearly increase from 5.6° to 8.3°C. The triple combo logging tool collected good measurements of porosity, density, NGR, resistivity, and MS throughout the sediment and basement sections. The FMS-sonic collected resistivity

images for the entire length of the cored section, and the UBI collected 360° images of the basement.

Core sections were run through the SRM, which measured natural remanent magnetization before and after alternating field demagnetization. The sediment cores were demagnetized up to 25 or 35 mT and the basalt cores up to 25 mT. The magnetic inclination displays strong changes in polarity, which will be used to construct a magnetostratigraphy postcruise.

The Chemistry Laboratory measured hydrocarbon concentrations in gas samples, as well as sediment and pore water geochemistry. Methane concentrations increase from 3 ppmv at the top of the hole to 11,000 ppmv at a depth of 205 m CSF-A. From 205 to 301 m CSF-A, the values plateau before decreasing to 0 ppmv at the sediment/basement interface (646 m CSF-A). Pore water sulfate is less than 2 mM from 350 to 400 m CSF-A and then linearly increases to 27 mM at 646 m CSF-A. Alkalinity decreases from 12.5 mM at ~350 m CSF-A to 2.3 mM at the base of Hole U1554E. Dissolved Ca, Mg, K, and Sr increase downhole while B decreases downhole. Br and Si fluctuate over the sampled interval. Li concentration peaks at 492.8 m CSF-A with a value of 41 mM. Mn has a local peak of 7.4 mM at 510 m CSF-A and increases to 12.7 mM at the base of Hole U1554E. Sulfate, phosphate, and ammonium were measured on the spectrophotometer. Ammonium and phosphate decrease downhole while sulfate increases downhole. Carbonate results from sediments in Hole U1554E show an increase in calcium carbonate at the base of the hole. Cores U1554E-31X to 51X have an average calcium carbonate concentration of 5.4 wt%. Below Core U1554E-51X (~550 m CSF-A), carbonate concentrations increase steadily to a maximum value of 85 wt% at the base of the sedimentary section (646 m CSF-A). Total organic carbon values average 0.47 wt% and show a slight increase downhole.