**IODP Expedition 395: Reykjanes Mantle Convection and Climate**

**Site U1554 Summary**

## Background and Objectives

International Ocean Discovery Program (IODP) Site U1554 (proposed Site REYK-6A of Expedition 395) is located in the North Atlantic Ocean along the Reykjanes Ridge south of Iceland and on Björn 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. Site U1554 is located in V-shaped trough (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 Björn Drift, which is expected to offer millennial-scale climate records. The sedimentation rate of this drift can serve as a proxy for deepwater current strength, providing information on vertical oceanic gateway motions and their potential ties to pulsing behavior of the Iceland mantle plume.

Cores and data from this site will address all three of the primary science objectives of Expedition 395: (1) crustal accretion and mantle behavior; (2) ocean circulation, gateways, and sedimentation; and (3) time-dependent hydrothermal alteration of oceanic crust.

## Operations

Site U1554 (proposed Site REYK-6A, 60°07.5060′N, 26°42.0960′W) consists of eight holes drilled during Expeditions 384, 395C, and 395. Holes U1554A through U1554D were cored during Expedition 384 in July 2020. These holes ranged in depth from 23.5 to 76.0 meters drilled depth below seafloor (m DSF). The recovered cores were used to create a stratigraphic splice of the section. Holes U1554E and U1554F were cored and logged during Expedition 395C in 2021. The depth of these holes extended to 647.7 and 779.9 m DSF, respectively. Finally, Holes U1554G and U1554H were cored to ~355 m DSF each during Expedition 395.

The sediments and basalts recovered on Expeditions 384 and 395C were sampled for select shipboard measurements during the cruises. Cores from these two expeditions were described postcruise at a core description party held at the Gulf Coast Repository in College Station, Texas, USA in May 2022.

A total of 194 cores were recovered for Site U1554. These cores collected 1611.82 m of sediment and basalt over a 1683.9 m cored interval (96%).

The total time spent at Holes U1554A to U1554F was 21.78 d: 2.02 d during Expedition 384, 16.26 d during Expedition 395C, and 3.5 d during Expedition 395.

Below we summarize operations and scientific results from all three expeditions.

**Expedition 384**

*Hole U1554A*

The vessel arrived at Site U1554 at 0600 h on 27 July 2020. The thrusters were lowered and the ship switched to dynamic positioning (DP) mode at 0629 h, ending the 1100 nmi transit from Kristiansand, Norway. An advanced piston corer/extended core barrel (APC/XCB) bottom-hole assembly (BHA) was made up and deployed at 1445 h. Hole U1554A (60°07.5038′N, 26°42.0955′W; 1869.7 m below sea level [mbsl]) was spudded at 2300 h. Cores 1H to 8H advanced to a depth of 72.2 m DSF. Following Core 8H, the pipe was pulled up and the bit cleared the seafloor at 0625 on 28 July, ending Hole U1554A. A total of eight APC cores with 74.71 m of core were recovered from a 72.2 m interval (104% recovery).

*Hole U1554B*

The vessel was offset 20 m east of Hole U1554A, and Hole U1554B (60°07.5058′N, 26°42.0748′W; 1871.0 mbsl) was spudded at 0735 h on 28 July 2020. Cores U1554B-1H to 8H recovered 76.77 m of core over the 76.0 m cored interval (101%). Hole U1554B ended at 1500 h on 28 July when the bit cleared the seafloor.

*Hole U1554C*

The ship was offset 20 m south of Hole U1554B. Hole U1554C (60°07.4950′N, 26°42.0747′W; 1869.0 mbsl) was spudded at 1600 h on 28 July 2020. Cores 1H to 8H were collected over a 75.0 m interval with 77.03 m of core recovered (103%). The drill pipe was pulled from the hole and the bit cleared the seafloor at 2345 h on 28 July, ending Hole U1554C.

*Hole U1554D*

The vessel was offset 20 m west of Hole U1554C. Hole U1554D (60°07.4941′N, 26°42.0968′W; 1869.0 mbsl) was spudded at 0055 h on 29 July 2020. The hole was washed down to 14 m DSF and Core U1554D-2H was collected from 14.0 to 23.5 m DSF with 9.72 m of sediment recovered (102%). This core was collected for the future testing of the shipboard track systems and was not curated or included as part of the Expedition 395/395C project.

Following coring operations, the drill pipe was pulled out of the hole with the bit clearing the seafloor at 0140 h and the rotary table at 0715 h on 29 July. The drill string and BHA were broken down and the vessel was secured for transit at 0820 h. The thrusters were raised and the ship began the transit to Site U1555 at 0900 h on 29 July, ending operations at Site U1554 during Expedition 384.

**Expedition 395C**

*Hole U1554E*

Following a 54 nmi transit from Site U1555, the vessel arrived at Site U1554 early on 24 June 2021. At 0754 h, Hole U1554E (60°7.5235′N, 26°42.1324′W; 1869.8 mbsl) was spudded using the APC/XCB system and drilled without recovery to 66.3 m DSF. Coring using the APC system progressed from 66.3 to 218.3 m DSF (Cores U1554E-2H to 17H) with 157.92 m of sediment recovered (104%). Cores 18X to 62X (218.3 to 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%).

The drill string was pulled up to 72.8 m DSF for downhole logging. Two runs each with the triple combo and the Formation MicroScanner (FMS)-sonic tool strings were completed for the length of the borehole. 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; 1869.7 mbsl), ~25 m southeast of Hole U1554E, and the rig floor crew began assembling the casing and reentry system. 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, and the casing was drilled into the hole to a depth of 602 m DSF. The drill string was pulled from the hole with the bit clearing the seafloor at 1610 h on 1 July 2021.

The drill string was assembled with a rotary core barrel (RCB) BHA and Hole U1554F was reentered at 1057 h on 2 July. The drill string advanced to the base of the casing. Hole U1554F was then drilled without recovery to 620 m DSF. Two drilled intervals were recorded for the hole. 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 recovery of Core 20R, the drill string was pulled from the hole to change the drill bit. The bit cleared the seafloor at 1840 h and the rotary table at 2210 h on 5 July 2021. The drill string reentered Hole U1554F at 0405 h on 6 July. RCB coring resumed from 721.7 to 779.9 m DSF with the recovery of Cores U1554F-21R to 32R.

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

Following coring operations, the hole was conditioned for downhole wireline logging. The drill pipe was pulled out of the hole and the subsea camera was 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. The bit was released at 0756 h, and at 0955 h the pipe reentered Hole U1554F. The drill string was 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 the base of the casing string (at a depth of 602 m DSF) 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, completing two passes of the borehole. The Ultrasonic Borehole Imager (UBI) tool string was then made up and deployed to the bottom of the hole with two logging passes. The drill pipe was pulled up from a depth of 588 m DSF to 69 m DSF in preparation of running the Versatile Seismic Imager (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 (PSO) protocols. At daybreak, 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. The drill pipe was pulled up, and it cleared the seafloor at 0755 h on 10 July, ending Hole U1554F.

The vessel returned to Hole U1554F on 21 July 2021 to attempt 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 drill string reentered Hole U1554F at 0930 h and the pipe was run to a depth of 68.5 m DSF within the casing string, in preparation for downhole logging with the VSI tool. Fog had formed around the vessel and after waiting until 1250 h, the VSI was deployed to the base of the casing string. 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 PSO 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 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 on 21 July. The rig floor was secured for transit and the thrusters were raised. The vessel began the 39 nmi transit to Site U1563 at 2236 h, ending operations at Hole U1554F and Site U1554 during Expedition 395C.

**Expedition 395**

*Hole U1554G*

Following a 104 nmi transit from Site U1564, the ship arrived at Site U1554 at 1800 h on 27 June 2023. The thrusters were lowered, and the vessel switched to DP mode, beginning Hole U1554G (60°7.5037′N, 26°42.1129′W; 1868.7 mbsl) at 1842 h. Hole U1554G was spudded at

0340 h on 28 June and recovered 5.43 m of sediment. Cores U1554G-1H through 31H were advanced to a depth of 288.4 m DSF. After reaching refusal of the APC system, the half-length APC (HLAPC) was deployed for Cores 32F to 34F (288.4–302.5 m DSF).

XCB coring advanced the hole from 302.5 to 355.0 m DSF, recovering Cores 35X to 40X. The target depth of the hole was achieved, and the drill string was pulled out of the hole with the bit clearing the seafloor at 1745 h on 29 June, marking the end of Hole U1554G. A total of 40 cores were taken in Hole U1554G over the 355.0 m cored interval. Core recovery was 102% and 362.3 m of sediment was collected.

*Hole U1554H*

The ship was offset 20 m south of Hole U1554G. At 2135 h on 29 June 2023, Hole U1554H (60°7.4952′N, 26°42.1188′W; 1866.7 mbsl) was spudded with Core U1554H-1H recovering 9.4 m. Cores 1H to 30H advanced to 280.1 m DSF.

The decision was made to switch to the XCB system when the overpull on the core barrels increased and Cores U1554H-31X to 38X (280.1–354.9 m DSF) were collected. After reaching the target depth, the drill string was pulled out of the hole. The drill bit cleared the seafloor at 0640 h on 1 July, ending Hole U1554H and operations at Site U1564. The vessel began the transit in DP mode to Site U1562. A total of 38 cores were recorded for Hole U1554H, with 370.1 m of core recovered across a 354.9 m interval (104%).

## Principal Results

*Sedimentology*

The Holocene to middle Miocene sediments cored at Site U1554 are relatively homogenous, primarily composed of silty clay with varying but minor amounts of siliceous and carbonate microfossils, as well as minor proportions of sand. Near the sediment/basement interface, the sediments transition to nannofossil chalk. Core recovery through the sedimentary sequence is near continuous in the upper 475 m. Based on the observations of sediment composition along with the attenuation pattern of natural gamma ray (NGR), magnetic susceptibility (MS), and calcium carbonate ($CaCO_3$), Site U1554 is divided into four lithostratigraphic Units (I–IV). Units I, II, and IV include two subunits. The measured $CaCO_3$ varies from 0.26 to 84.76 wt%. Features of note include glass layers, bands of variable color at unit or subunit boundaries, basaltic and metamorphic clasts, shell fragments, and halo/pyritized and silt-filled burrows.

*Igneous Petrology*

The cores from Hole 395C-U1554F are dominated by slightly to moderately altered basalt. An additional meter of basalt was also recovered in Hole 395C-U1554E. The contact between the basalt and overlying sedimentary strata was partly recovered across Cores U1554F-4R to 6R. In

Hole 395C-U1554F, detailed core and thin section observations reveal a sequence of intercalated sheet flows and pillow lavas. The sheet flows consist of hypocrystalline aphyric olivine basalt. Flow boundaries and fractures generally show brown alteration halos, especially in the upper third of the hole, and vesicles are often filled. The pillow lavas are highly fragmented with glass rinds, chilled margins, and vesicle bands. In the upper 40 m of the basement, thin sedimentary and volcanoclastic horizons are common, consisting of calcareous mudstone conglomerate layers and peperites. The peperites become increasingly baked and crystalline downhole. Thin section examination reveals fine-grained aphyric or sparsely olivine phyric basalts with low to moderate alteration. They contain abundant olivine microphenocrysts, as well as some large olivine phenocrysts with occasional spinel inclusions. The groundmass contains acicular and skeletal swallowtail plagioclase laths, rare clinopyroxene microcrystals, opaque oxides, and altered glass. The inferred volcanic stratigraphy consists of a sequence of interbedded extrusive sheet flows and pillow lavas with minor evidence of sediment deposition.

*Alteration Petrology*

Basalt at Site U1554 (Holes 395C-U1554E and U1554F) predominantly contains background-type alteration, which is spread throughout the basalt, though localized alteration in the form of halos around fractures is present to a lesser degree. The alteration assemblage is chlorite+Fe-oxide/oxyhydroxides+clay with minor carbonate. In thin section, saponite and chlorite dominate the alteration assemblage and disseminated magnetite is observed. Vesicles are commonly filled with celadonite, and to a lesser extent chlorite, Fe-oxide/oxyhydroxides, carbonate, zeolite, and rare sulfides. Basalt fragments in peperite intervals are variably altered to palagonite material. Vesicle fill is commonly mineralogically zoned with multiple minerals in each, including clay (saponite), celadonite, chlorite, Fe-oxide/oxyhydroxides, carbonate, and zeolite.

Fracture density at Site U1554 is ~28 fractures/m and is uniform with depth. Fracture mineral fill is dominantly Fe-oxide/oxyhydroxide+carbonate±chlorite with occasional clay and celadonite. Some fractures are filled with carbonate sediment in intervals where sediment and peperites are common. Alteration halos are observed around some fractures with colors including gray, brown, and brown with a gray border.

*Micropaleontology*

At Site U1554, a 647 m interval of upper Miocene to upper Pleistocene silty clay and nannofossil chalk was recovered across multiple holes. Micropaleontological analyses were undertaken on sediment samples down to 647.7 m cored depth below seafloor, method A (CSF-A) in Hole 395C-U1554E, and to 354.97 m CSF-A in Hole 395-U1554G. Biohorizons used in the age model are based on calcareous nannoplankton, planktonic foraminifers, and bolboforms. Calcareous nannofossils and planktonic foraminifera are present with varying abundances, from barren or nearly barren samples to those with very high abundances. Bolboforms, when present, are always rare or few.

A total of 11 calcareous nannofossil Pleistocene biohorizons are identified within the top 234.96 m CSF-A of Hole U1554G, representing ages of 0.09 to 1.71 Ma. Four nannofossil biohorizons are identified through the upper Miocene to Pliocene, including the biohorizon Top *Coccolithus miopelagicus*, which constrains the bottom of the hole to be older than 11.04 Ma. A total of five Pleistocene, two Pliocene, and three Miocene planktonic foraminifer biohorizons were recognized, with an estimated age of the base of the sediment section to be between 10.54 and 11.76 Ma. Four upper Miocene bolboform biohorizons are recognised with calibrated ages between 5.60 and 10.20 Ma. In the interval ~530 to 630 m CSF-A, glauconite is abundant in foraminifer sample residues and corresponds to a marked change in sedimentation rate of between 13 and 17 cm/ky in the Pleistocene succession to 1 cm/ky in the Pliocene and upper Miocene sequence.

*Physical Properties*

At Site U1554, bulk density broadly shows an increase from 1.4 to ~1.8 g/cm$^3$ from seafloor to 450 m CSF-A with noticeable increases and decreases superimposed on this trend. Both MS and NGR suggest similar oscillatory behavior to that observed in the bulk density. These variations become more pronounced below ~450 m CSF-A. Poor core recovery in Hole 395C-U1554E between 470 and 570 m CSF-A causes more detailed interpretations for physical properties to be challenging in this interval. The bottom ~80 m of Hole U1554E (570–647 m CSF-A) is characterized by variations in bulk density, a trend also expressed by the MS, color records, and more variable lithology. The limestone in the bottom two cores (U1554E-61X and 62X) shows higher bulk densities (>1.8 g/cm$^3$), lower MS, lower NGR, and lighter colors compared to the overlaying sediments.

*Stratigraphic Correlation*

A ~0 to 70 m splice for Holes 384-U1554A to U1554C was previously constructed during Expedition 384. In the full splice, the upper 80 m composite cored depth below seafloor (CCSF) interval is very similar to that produced during Expedition 384, and includes Holes 384-U1554A through U1554C. From Core 395C-U1554E-2H, tied to Core 384-U1554A-7H from the initial splice, through Core 395-U1554H-23H, a continuous splice was constructed using only Holes 395C-U1554E and 395-U1554H. Between 225 and 345 m CCSF several gaps are unavoidable.

*Paleomagnetism*

Natural remanent magnetization (NRM) was measured for sedimentary cores recovered from Holes 384-U1554A to U1554C, 395C-U1554E and U1554F, and 395-U1554G to U1554H. The cores were demagnetized with a stepwise alternating field cleaning protocol, with the exceptions of Hole 395-U1554G and the upper part of Hole 395-U1554H. The resolution of these measurements varies from 1 to 5 cm. The demagnetization step at 20 mT from Hole 395C-U1554E was used to establish an age-depth trend for the upper 400 m CSF-A in Site U1554. Between 400 m CSF-A and the bottom of Core U1554E-61X at 645 m CSF-A, apparent gaps in sediment deposition hampered interpretation of the magnetostratigraphy.

NRM was measured for basalt cores recovered in Hole 395C-U1554F. The basalts in Hole 395C-U1554F do not fully demagnetize at 25 mT, but the drilling overprint is removed. The demagnetization reveals mostly normal polarities and one of two behaviors: (1) 80% magnetization loss before 25 mT, or (2) no significant loss of magnetization by 25 mT. The variations in MS coincide with those in NRM intensity before and after demagnetization at 25 mT.

*Geochemistry*

Cores taken from Expeditions 384 (Hole U1554A), 395C (Holes U1554E and U1554F), and 395 (Holes U1554G and U1554H) were analyzed for headspace gas, interstitial water (IW) chemistry, and bulk sediment geochemistry. Headspace gas analyses were conducted at Holes 384-U1554A and 395C-U1554E; methane concentrations are variable and range from 0 to ~12,000 ppmv. Ethane was absent in all holes. Holes 395C-U1554E and 395-U1554G were analyzed for IW chemistry and bulk sediment geochemistry. Calcium ion ($Ca^{2+}$) and magnesium ion ($Mg^{2+}$) concentrations display similar trends with depth. Sulfate ion ($SO_4^{2-}$) concentrations display a bimodal distribution with seawater-like values at the top and bottom of the sediment column. $CaCO_3$ wt% generally decreases downhole, trending from ~30 wt% at the top to ~17 wt% near the sediment/basement interface. Bulk sediment generally has low total organic carbon (TOC), total nitrogen (TN), and total sulfur (TS) content. Dissolved oxygen measurements were conducted on whole-round cores from Hole 395-U1554G down to ~347 m CSF-A (Core U1554G-40X).

*Downhole Logging*

Logging operations were undertaken at Hole 395C-U1554E (~0 to 640 m wireline depth below seafloor [WSF]) and Hole 395C-U1554F (~604 to 770 m WSF). Hole 395C-U1554E was logged with the triple combo and FMS-sonic tool strings, while Hole 395C-U1554F was logged with the triple combo, FMS-sonic, and UBI tool strings. Logging responses at Site U1554 define five logging units, with subunits in Logging Units 1, 2, and 4. Logging Subunit 1a (0–75 m WSF) is defined by gamma log measurements collected through the drill pipe, and Logging Subunit 1b (75 to 108 m WSF) is characterized by low density and low NGR. Logging Unit 2 (108–440 m WSF) is characterized by cyclic, 1 to 10 m long fluctuations in NGR, the peaks of which are dominated by high thorium counts. MS data shows a similar cyclic pattern in this logging unit. The cyclic gamma and MS logging responses occur at shorter wavelengths in Logging Subunit 2a (108–375 m WSF) than in Logging Subunit 2b (375–440 m WSF). Logging Unit 3 (440–495 m WSF) is marked by relatively lower NGR and longer wavelength fluctuations in MS, while the density (~1.8 g/cm$^3$) and porosity (~0.6) in this unit are remarkably invariant. Logging Unit 4 (495–647 m WSF) is marked by relatively high NGR, and can be divided into three subunits: Logging Subunit 4a (495–535 m WSF) shows invariant $V_P$ and $V_S$ values, while Logging Subunit 4b (535–635 m WSF) shows relatively high $V_P$ and $V_S$ (up to ≤2615 m/s and 850 m/s, respectively). Logging Subunit 4c (635–647 m WSF) contains the lowermost sediment and the top of the sediment/basement transition zone, the top of which is marked by an abrupt decrease

in density and increase in porosity. FMS borehole images for the sedimentary section of Site U1554 show decimeter-scale, shallow dipping, alternating conductive and resistive layers. Logging Unit 5 denotes the basaltic basement of Site U1554, with an increase in resistivity and density. The FMS and UBI borehole images show clear layering within the basalt basement, some of which contain numerous features that may represent fractures and basaltic pillow margins.

*Age Model*

Age model tie points at Site U1554 are based upon paleomagnetic and paleontologic constraints. From the seafloor down to the base of Matuyama Chron at 402.34 m CSF-A, the age model is based on magnetostratigraphic reversals complemented by calcareous nannofossil and planktonic foraminifer biostratigraphy. Below that level, a succession of magnetic polarity reversals is recorded, but their magnetostratigraphic interpretation is highly uncertain because of gaps in the record, so the age model relies on biostratigraphy alone, which is based on calcareous nannofossils, planktonic foraminifers, and bolboforms. The age at the sediment/basement interface is extrapolated at ~12.15 Ma.