

IODP Expedition 395: Reykjanes Mantle Convection and Climate

Site U1562 Summary

Background and Objectives

International Ocean Discovery Program (IODP) Site U1562 (proposed Site REYK-3B) is located in the North Atlantic Ocean, east of the Reykjanes Ridge and on Björn contourite drift south of Iceland. Site U1562 is located on seismic line JC50-1 (CMP 39920), near the intersection with line JC50-C2 (CMP 685), both obtained in 2010 during RRS *James Cook* Cruise JC50.

Diachronous V-shaped crustal 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 U1562 is located on VSR-3, and has an estimated basement age of 13.86 Ma. The sediment section at Site U1562 comprises the Björn drift deposit, a thicker section of which was cored at Site U1554.

Cores and data from this site will address all three 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 U1562 (60°06.3006'N, 26°30.1044'W) consists of three holes, 395C-U1562A, 395C-U1562B, and 395-U1562C, completed over the span of two expeditions and ranging in depth from 300.4 to 561.5 m drilled depth below seafloor (DSF). A total of 144 cores were recovered for Site U1562. These cores collected 792.57 m of sediment and basalt over a cored interval of 876.5 m (90% recovery). Downhole wireline logging operations using four logging tools took place at Hole 395C-U1562B. The total time spent at Site U1562 was 12.3 d.

Expedition 395C

Hole U1562A

The vessel began the 6.1 nmi transit from Hole 395C-U1554F to Site U1562 under dynamic positioning (DP) mode on 10 July 2021. At 1306 h on 10 July, the vessel arrived at Site U1562 and the advanced piston corer/extended core barrel (APC/XCB) bottom-hole assembly (BHA) was made up.

Hole 395C-U1562A (60°06.3030'N, 26°30.1245'W; 2003 meters below sea level [mbsl]), located 21 m west of the proposed site coordinates, was spudded at 2115 h on 10 July. Cores U1562A-1H to 21H advanced from 0 to 192.0 m DSF. The half-length APC (HLAPC) core barrels were made up and coring continued from Core 22F to 57F (192.0–361.2 m DSF) with 4.7 m long advances. The XCB was deployed for Cores 58X to 64X (361.2–429.1 m DSF). After recovering Core 64X, the XCB cutting shoe was severely damaged and slightly melted, and the base of the core catcher contained basalt. Another core barrel was deployed and Core 65X was advanced to ensure that the bit had reached basement. The bit advanced 0.7 m over an hour and Core 65X contained 0.68 m of basalt (97% recovery), confirming a basement depth of 429.1 m DSF. The final depth of Hole U1562A was 429.8 m DSF. The drill string was pulled from the hole, with the bit reaching the seafloor at 1535 h on 13 July. Hole U1562A ended when the bit reached the rotary table at 1935 h.

Hole U1562B

Following the end of Hole 395C-U1562A, a rotary core barrel (RCB) BHA with a C-4 RCB bit was made up and the drill string lowered to the seafloor. The ship was offset 21 m east-southeast of Hole U1562A, and Hole 395C-U1562B (60°6.2993'N, 26°30.1026'W; water depth 2003 mbsl) was spudded at 0320 h on 14 July 2021 and advanced without coring to a depth of 408.1 m DSF. The center bit was recovered and an RCB core barrel was deployed. Cores U1562B-2R to 19R advanced from 408.1 to 500.7 m DSF. The sediment/basement interface was recovered in Core 4R at a depth of 429.0 m DSF. While coring Core 19R, the penetration rate dropped to 1 m/h and there was erratic torque on the bit. It was suspected that the drill bit was damaged, and the rig floor crew began pulling the pipe out of the hole. A free-fall funnel (FFF) was deployed at 0220 h on 17 July to allow for the reentry of Hole U1562B. The bit cleared the seafloor at 0312 h and the rotary table at 0708 h. The bit was indeed damaged and a new C-7 RCB coring bit was made up to the BHA and the crew assembled the drill string. The subsea camera, along with the Conductivity-Temperature-Depth (CTD) sonde, was deployed at 1130 h to observe the reentry of Hole U1562B, which occurred at 1450 h. The subsea camera was retrieved and the drill string advanced to 500.7 m DSF. After cleaning the hole with a high-viscosity mud sweep, Cores 20R to 28R advanced from 500.7 to 561.5 m DSF. Coring operations concluded at Hole U1562B after coring 132.5 m into the basement section. The final depth of Hole U1562B was 561.5 m DSF.

Following coring, the rotary shifting tool (RST) was run to release the bit into the bottom of the hole. The drill string was pulled up and end of the pipe was set at a depth of 89 m DSF. The triple combo logging tool string was made up and deployed at 1755 h on 19 July. After completing two successful passes of the entire hole, the tools were retrieved and reached the rig floor at 2310 h. The Formation MicroScanner (FMS)-sonic tool was made up and deployed at 0100 h on 20 July. Following two passes that extended to the base of the hole, the FMS-sonic tool was pulled from the hole and reached the rig floor at 0645 h. The Versatile Seismic Imager (VSI) was lowered to the base of the hole and a total of four depth stations (420.5, 426, 459.9, and 556.6 m DSF) were completed, two within the basement section, one at the sediment/basement interface, and one in the lowermost sediment. The final logging run, using the

Ultrasonic Borehole Imager (UBI) tool, began at 1445 h. The UBI made two passes of the basement section, acquiring 360° borehole images. The UBI was recovered at the rig floor at 2130 h. The drill string was pulled out of the hole to a depth of ~1489 mbsl and the ship began the transit in DP mode to Hole 395C-U1554F at 2355 h on 20 July, ending Site U1562.

Expedition 395

Hole U1562C

The vessel returned to Site U1562 on 1 July 2023. Following a 6.1 nmi transit from Hole 395-U1554H, the vessel was over the site coordinates at 1210 h, marking the start of Hole 395-U1562C (60°6.3015'N, 26°30.0754'W; 2002.7 mbsl), which was spudded at 1500 h. Cores U1562C-1H to 16H advanced the hole to 139.3 m DSF. Refusal of the full-length APC system was reached at 139.3 m DSF and the HLAPC was deployed for the remainder of the hole. Cores U1562C-17F to 53F advanced the hole to 300.4 m DSF. Five short drilled intervals (1.5 to 2 m in length) were used to offset coring gaps between Holes 395C-U1562A and 395-U1562C for stratigraphic correlation. After reaching the target depth of 300 m DSF, the drill pipe was pulled from the hole with the bit clearing the seafloor at 0405 h on 3 July. A total of 48 cores were collected at Hole U1562C, recovering 308.45 m of sediment over a 293.4 m cored interval (105% recovery). The BHA was broken down and the rig secured for transit. At 0900 h the ship was switched from DP to cruise mode, ending operations at Site U1562.

Principal Results

Sedimentology

The sediments at this site include silty clay with variable amounts of carbonate (lithological Units I–III) and nannofossil chalk (Unit IV). Based on smear slide observations, carbonate microfossils are present in amounts ranging from a few to >30%. Siliceous microfossils are present throughout but in minor amounts (<10%). The terrigenous component is dominated by quartz and feldspar, although glauconite and glass are also present. Glass abundance increases from Unit I to Unit II. Immediately below the lithological boundary between Units I and II, there are several sharp contacts. Unit III is defined by an abundance of features consistent with soft sediment deformation, likely caused by a series of slumps. There is a sharp contact between Units III and IV. Weight percent CaCO₃ is variable, but average values increase downhole until the chalk in Unit IV. Small clasts of volcanoclastic material (pumice and scoria) and larger clasts of variable lithology are found throughout the sequence at Site U1562.

Igneous Petrology

Hole 395C-U1562B was drilled 133 m into basement with a recovery of 48%. In addition, glassy lava fragments and the top of a weathered sheet flow were recovered from the base of Hole 395C-U1562A. The sediment/basement contact is poorly defined. Cores from this site consist of sparsely to moderately olivine phyric pillow lavas with a few massive sheet flow intervals up to 5–10 m thick. Fragmented cryptocrystalline pillow lavas are characterized by curved chilled margins, glassy rinds, and abundant vesicles. Sheet flows have chilled weathered tops and medium grained a vesicular interiors. Intercalated peperites and mudstone are common. The peperitic intervals display abundant evidence for lava/sediment mingling, including fragmented basalt clasts with quenched rims and fluidal margins. Thin sections from pillow lavas have abundant groundmass olivine grains, sometimes with dendritic forms suggestive of rapid cooling during the eruptive process. The abundance of sediment-rich material at this site suggests that significant amounts of sediment accumulated between eruptions, with preliminary estimates of eruption hiatuses on the order of $\sim 10^5$ y.

Alteration Petrology

The majority of basalt recovered from Site U1562 is slightly to moderately altered. Intervals of the basalt basement intermixed with carbonate sediment and peperite intervals are highly to completely altered. Alteration is dominantly pervasive, though localized mainly in the form of fracture halos. It occurs throughout the basalts, but more commonly within intervals that contain sediment and peperite material. The alteration assemblage is clay+Fe-oxide/oxyhydroxides and minor chlorite and celadonite. Basalt clasts within peperite intervals are mostly altered to palagonite material. Vesicles are dominantly filled with celadonite, Fe-oxide/oxyhydroxides, and calcite with some saponite and minor zeolite. Vesicle fills are commonly mineralogically zoned with multiple minerals in each. Fracture density in Hole 395C-U1562B is ~ 21 fractures per m and is near constant with depth. Fractures are dominantly ≤ 0.5 mm wide and occur either as isolated, nonconnected fractures or within anastomosing networks. Fracture mineral fills are dominantly carbonate \pm Fe-oxide/oxyhydroxide with minor clay, chlorite, and celadonite. Peperite and altered carbonate sediment intervals contain complex carbonate-filled fracture networks. Fracture alteration halos are up to 2 cm wide from the fracture wall, and are either pale gray, brown, green-gray, or green-brown in color.

Micropaleontology

Micropaleontological analyses were undertaken on samples from all three Site U1562 holes. Calcareous nannofossils and planktonic foraminifers are generally present in moderate to high abundances, with occasional barren or nearly barren samples. Bolboforms, when present, are generally rare or few. Calcareous microfossil preservation is mostly excellent to very good, with occasional intervals of moderate preservation. The Pleistocene succession is well constrained by biostratigraphy, with eight calcareous nannofossil biohorizons identified in Hole 395-U1562C and five planktonic foraminifer biohorizons identified in both Holes 395C-U1562A and 395-

U1562C. No upper Pliocene biohorizons were identified, but one calcareous nannofossil and two planktonic foraminifer biohorizons constrain the lower Pliocene succession. The basal upper Miocene sedimentary succession is also constrained by one calcareous nannofossil and two planktonic foraminifer biohorizons, as well as three bolboform biohorizons. Based on calcareous microfossil biostratigraphy, the bottom of the sedimentary succession is between 11.04 and 11.76 Ma. During the rotary drilling of Hole 395C-U1562B into basement, a substantial interval of sediment (~0.65 m thick) was encountered 45 m into basalt and yielded a well-preserved foraminiferal assemblage that is significantly older than the lowermost sample examined from the sedimentary succession.

Physical Properties

Holes 395C-U1562A and 395-U1562C recovered overlapping stratigraphic sections and, thus, display similar physical properties. Gamma ray attenuation (GRA) bulk density, magnetic susceptibility (MS), and natural gamma radiation (NGR) increase gradually downhole in the upper 130 m core depth below seafloor, method A (CSF-A), with meter-scale oscillations superimposed on this trend. The latter two parameters sharply drop at 130 m CSF-A. Below this depth, bulk density stays relatively constant with small variations around 1.6 g/cm^3 , while MS and NGR show a more variable pattern: large amplitude variations until ~350 m CSF-A after which core recovery is lower and both properties show lower values. The changes in color properties in the sediments of Holes U1562A and U1562C can be subdivided in similar stratigraphic intervals as the whole round property profiles.

In Hole 395C-U1562B, voids and gaps between the basalt cores and liners make the interpretation of their physical properties profile less straightforward. The sedimentary and peperite units in Hole U1562B are apparent in color records, with higher red, green, blue (RGB), a^* , and b^* values.

Caliper measurements of V_p for the sediments from Hole 395C-U1562B are about 1700 m/s, and vary between 4725 and 6053 m/s for the basalt section. Sedimentary V_p values for Hole 395-U1562C average around 1500 m/s. Bulk density values in Hole 395C-U1562A range between 1.370 and 1.673 g/cm^3 . Porosity is around 80 vol% going down to 65 vol%, with an average of 70 vol%. Grain density decreases downhole from 2.85 to 2.60 g/cm^3 with an average value of 2.74 g/cm^3 . Thermal conductivity, K , is typically 0.75–1.20 W/(m·K) for the sediments in Holes 395C-U1562A and 395-U1562C, and 1.40–1.80 W/(m·K) for Hole 395C-U1562B.

Stratigraphic Correlation

Correlation was achieved without gaps from the seafloor through Cores 395C-U1562A-16H and 395-U1562C-17F (155.125 m core composite depth below seafloor, method A [CCSF-A]). Small coring gaps are present below this depth to ~280 m CCSF-A, but cores can still be tied with some confidence based on the broad cyclic patterns and the comparison with wireline logging MS data from Hole 395C-U1562B. Below Core 395C-U1562A-35F, correlation between holes

becomes difficult, probably because of the presence of disrupted sequences (e.g., soft sediment deformation).

Paleomagnetism

The sedimentary rocks of Holes 395C-U1562A, 395C-U1562B, and 395-U1562C were demagnetized with a stepwise alternating field (AF) cleaning protocol. For sediments, an overprint likely induced by the drilling process was removed by application of an AF of 10 mT. The primary characteristic remanent magnetization (ChRM) was successfully isolated by 25 mT and used to create an age-depth plot for the hole. Natural remanent magnetization (NRM) and MS values both show a variable cyclicity between 160 and 350 m CSF-A. For basalts in Hole U1562B, demagnetization revealed 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 and intensity after 25 mT of demagnetization.

Geochemistry

Holes 395C-U1562A and 395C-U1562B were analyzed for headspace gas, interstitial water (IW) chemistry, and bulk sediment geochemistry. Cores collected from Hole 395-U1562C were analyzed for bulk sediment geochemistry. Methane concentrations are low and range from 0 to ~3 ppmv. Ethane is absent in all samples. IW calcium ion (Ca^{2+}) concentrations display a bimodal distribution with highest values near the sediment/water and sediment/basement interfaces. Magnesium ion (Mg^{2+}) concentrations display a generally decreasing trend with depth, with a small increase at the sediment/basement interface. Sulfate ion (SO_4^{2-}) concentrations display a bimodal distribution with seawater-like values at the top and bottom of the sediment column. Calcium carbonate (CaCO_3) wt% generally increases downhole, trending from ~0 to 33 wt% in the top 100 m CSF-A to ~83 wt% near the sediment/basement interface. Bulk sediment generally exhibits low total organic carbon (TOC), total nitrogen (TN), and total sulfur (TS) content.

Downhole Logging

Logging operations were carried out at Hole 395C-U1562B. A full suite of downhole logs was collected with the triple combo (NGR, spectral gamma radiation, resistivity, density, porosity, MS), FMS-sonic, and VSI toolstrings for the sediment and basement sections. The UBI was also deployed in the basement section. Formation temperature measurements were acquired at Hole 395C-U1562A.

The sedimentary section shows three distinct logging units including multiple subunits. Logging Subunit 1a (0–85 m wireline depth below seafloor [WSF]) was collected through the drill pipe and only collected natural and spectral gamma radiation. Logging Subunit 1b (85–136 m WSF) shows an increase in the NGR peaks up to ~25 gAPI, which are dominated by Th counts. The density increases in this interval from ~1.2 to ~1.6 g/cm³. Logging Unit 2 (136–350 m WSF) is characterized by an overall higher cyclic gamma signal (average of 20.5 ± 2.8 gAPI). This cyclic

logging response is also observed in the MS, V_s , and porosity measurements of this logging unit. Logging Subunits 2a (136–305 m WSF) and 2b (305–350 m WSF) are differentiated from each other based on the thickness of these logging response cycles. Logging Unit 3 (350–426 m WSF) shows clearly different logging responses with a sharp drop in NGR and an increase in density with depth from 1.58 to 1.72 g/cm³. MS is very low (average 7.9 SI). The image logs of the sedimentary section show layering as well as mottling patterns; however, the frequent ledges and borehole breakouts are influencing the data quality.

Logging Unit 4 encompasses the entire basement section of the hole (426–560 m WSF). The top of Unit 4 is defined by marked changes in resistivity, density, porosity, V_p , V_s , and MS, rather than the gamma log. All logging responses show variability throughout the basement sequence, with increases in MS correlating to increases in V_p , density, and resistivity, and decreases in porosity, and vice versa. The image logs as well as the wireline data indicate the potential presence of sedimentary layers intercalated with the basaltic basement. Overall, both image logs are of excellent quality in the basement section of the hole.

Age Model

Magnetostratigraphic and biostratigraphic age constraints for the sedimentary succession in Holes 395C-U1562A and 395-U1562C were combined to create a site age model. Thirteen age datums were chosen to anchor the age-depth model. The succession appears relatively continuous down to ~22 m CSF-A. From ~22 to 28.83 m CSF-A, the succession is evidently condensed and/or includes hiatuses. From 28.83 to 135 m CSF-A there is a sequence of four magnetic reversals within the Matuyama, which together indicate a relatively rapid sedimentation rate over this interval. The age model for the lower part of the succession in Hole U1562A is based on a series of foraminifer, bolboform, and nannofossil biohorizons. These constraints are considered to have a low reliability, for various reasons related to taxonomic uncertainty, low or variable abundances, and/or age calibration issues. Linear extrapolation of the age model suggests an approximate age of 13.0 Ma for the oldest part of the sedimentary succession overlying basalt.