IODP Expedition 402: Tyrrhenian Continent–Ocean Transition

Site U1615 Summary

Background and Objectives

Site U1615 (proposed Site TYR-16A) is one of four drill sites in the Vavilov Basin targeting exhumed mantle peridotites. Site U1615 is near the eastern end of the planned east–west transect across the Vavilov Basin and is located on an irregular basement high, interpreted to be the uplifted footwall of a long-offset low-angle detachment fault that exhumed the mantle. As for the other sites in the Vavilov Basin, the scientific objectives of Site U1615 are (1) to date with biostratigraphy and magnetostratigraphy the oldest sediment above the basement contact to constrain the timing of mantle exhumation, (2) to sample sediments and pore fluids above the basement contact to investigate fluid-rock interactions, and (3) to recover basement samples to determine the heterogeneous composition of the exhumed mantle, its degree of serpentinization and alteration, and its pattern of structural deformation.

After the loss of two rotary core barrel (RCB) system bottom-hole assemblies when they were irremediably stuck in Holes U1612A and U1614C in the Vavilov Basin, we were forced to reevaluate the drilling plan. We decided to not drill any sites at the northern end of the north–south Vavilov Basin transect (proposed Sites TYR-17A, TYR-18A, and TYR-19A) because their thick sediment cover (~500–1000 m) was likely to contain unstable volcaniclastic gravels and tuffs. We concentrated instead on Sites U1615 and U1616, located on basement highs in the east–west transect where the estimated sediment cover was substantially thinner (~200 m). The original order of planned drilling operations in these sites was reversed to core a hole first with the advanced piston corer/extended core barrel (APC/XCB) system. The expected high recovery of the sediment interval in this hole would provide a high-quality record above the sediment/basement interface and would allow for determining the extent and depth distribution of unconsolidated volcaniclastics. We would then compare the results with those obtained in a similar APC/XCB hole to be drilled at Site U1616, also located in the east–west transect, about 10 km west of Site U1615. Based on the observations from the two APC/XCB holes, we would then select one of Sites U1615 or U1616 to drill a second hole and install a casing string that would reach below the base of the problematic volcaniclastics that may pose a risk to hole stability. This second hole would then be cored with the RCB system starting above the sediment/basement interface, with the ultimate goal of recovering the target 140 m thick basement interval. After coring, downhole geophysical logging was planned in the RCB hole with a focus on obtaining electrical and ultrasonic borehole wall images to complement core recovery and to provide key input to the interpretation of the drilled basement interval.

Operations

The 5.1 nmi transit from Site U1614 to Site U1615 was completed in dynamic positioning (DP) mode at 1608 h on 7 March 2024. Tripping toward the seafloor began while the ship was still in transit. Hole U1615A was spudded at 2230 h with the bit positioned 5 m above the precision depth recorder water depth of 3571.4 m. Core U1615A-1H recovered the mudline and 7.49 m of material from a 7.3 m advance (103%), confirming the water depth as 3568.6 m. Coring in Hole U1615A continued through Core 34X, achieving a total depth of 300.0 meters below seafloor (mbsf) and recovering 115.09 m of sediment (38%). Recovery was high in the first five cores (97%) but low throughout much of the rest of the hole, including six cores with no recovery. Formation temperature measurements using the third-generation advanced piston corer temperature (APCT-3) tool were taken during Cores 4H, 7H, and 10H. Cores 8H and 10H experienced partial strokes, likely caused by the sandy formation; as such, Cores 11F to 13F were taken as half-length APC (HLAPC) cores before transitioning to XCB for the remainder of the hole. Overall, the full-length APC was used for 10 cores over an 86.4 m interval with 79% recovery, the HLAPC was used for three cores over a 14.1 m interval with 24% recovery, and the XCB was used for 21 cores over a 199.5 m interval with 22% recovery. Nonmagnetic core barrels were used for all APC and HLAPC cores, and all full-length APC cores were oriented. The microbial contamination tracer perfluorodecalin (PFD) was pumped along with the drill fluid during coring operations.

Because of the poor core recovery in sediment and because the basement contact appears to be deeper than predicted at this site, we determined it would not be a suitable location for the next casing installation and we ended operations at Site U1615 at 1500 h on 9 March after Core 34X. At midnight, the vessel began the 4.8 nmi transit in DP mode to Site U1616 (proposed Site TYR-15A) at a speed of 0.5 kt. Operations at Site U1615 took 2.3 d.

Principal Results

Lithostratigraphy

Site U1615 sediment was split into two units based on lithology, with the first unit divided into three subunits. The determination was primarily made by the relative abundance of volcaniclastics and coarse-grained material, although volcaniclastics are present throughout the sediment column in varying amounts. The top of Unit I consists of alternating layers of dark gray volcaniclastic-rich silts and light brown nannofossil oozes with mud. In Unit IB, volcaniclastic gravel becomes dominant, as has been observed at other sites. Wood fragments are present throughout the unit. Unit IC consists of nannofossil chalk with some layers of volcaniclastic-rich material. Intervals of volcaniclastic gravel are interpreted as fall-in due to their consistent occurrence in the top of cores, but volcaniclastic-rich sands and muds are present throughout. Some intervals are also rich in foraminifera. We observe a few layers of organic-rich material that may be classified as sapropel. Unit II contains limited volcaniclastic material, and mainly consists of nannofossil ooze and silts/sands. The top of Unit II shows signs of soft sediment deformation in the form of clast-supported polymictic conglomerates and slump deposits.

Biostratigraphy

Hole U1615A was drilled into 300 m of the sediment, recovering ~115 m (38%). The marker species assemblages of planktic foraminifera as well as calcareous nannofossils were analyzed from the core catcher (CC) samples and a few additional samples from split core sections to decipher the biostratigraphic zonation scheme at the site.

The sedimentary interval at the site contains many volcanoclastic-rich mud to gravel layers along with a few interbedded nannofossil ooze layers. The volcanoclastic sediments in Samples U1615A-5H-CC to 13F-CC, 18X-CC to 22X-CC, and 25X-CC to 34X-CC were barren or contained few (≤10) marker species of planktic foraminifera, making biostratigraphic assignments across these sedimentary layers challenging. However, the few CC and core section samples that were comprised of nannofossils contain relatively well-preserved planktic foraminifera species that constrain the age of the sediments. Holocene–Lower Pleistocene (upper Gelasian stage) sediments ≤2 Ma in age were recovered from this site.

Calcareous nannofossils were analyzed in 25 CC samples of Hole U1615A. The uppermost part of the succession (Sample U1615A-1H-CC) falls within the middle Pleistocene MNQ20 biozone (0.46–0.26 Ma). All the studied samples from Sample U1615A-2H-CC down to sample U1615A-25X-CC fall within the MNQ19d biozone (0.46–0.96 Ma; early-middle Pleistocene). The lowermost part of the succession contains reworked nannofossil assemblages, with older taxa found together with younger ones. The oldest sample studied at this site is U1615A-30X-CC, assigned to the early Pleistocene MNQ19b biozone (1.24–1.61 Ma).

Paleomagnetism

For Hole U1615A, 34 cores of sediments were recovered down to 300 mbsf with a recovery of 95%. Like previous sites, demagnetization of archive half sections and discrete samples shows only normal polarity, despite the fact that reversed polarity is expected given the age of microfossil biozones present. Low recovery and the presence of substantial volcanic material further limited the utility of this site for paleomagnetic analyses.

Structural Geology

Structural geology measurements included the orientation of bedding, fractures, faults, and folds throughout the recovered cored interval. The poor recovery of this site is partly responsible for the scatter of the acquired data. Throughout the hole, the bedding dip rarely exceeds 20°. The variation of bedding dip slightly increases in the vicinity of the identified slumps. The observed bedding dips are concentrated at 59.37–87.68 mbsf and 186.22–208.76 mbsf, which correspond to intervals within the volcaniclastic-rich layer of Unit I and the slump deposits of Unit II, respectively. Two observed faults have higher dip angles, but this may be related to drilling disturbance.

Sediment and Pore Water Geochemistry

For the 17 interstitial water (IW) samples collected from Hole U1615A, the pH value is within a narrow range of 7.4–8.0, suggesting that bicarbonate ion (HCO_3^-) is the dominant carbonate species. Alkalinity is higher (2.3–5.6 mg/L) above 65.28 mbsf and decreases to less than 2.0 mg/L toward the bottom of the cored interval. The concentration of the major elements Na^+ and Cl^- vary from 505.26 to 561.68 mM and 608.47 to 646.73 mM, respectively. Both elements reach a maximum value at 169.89 mbsf. Depth profiles of salinity and Ca^{2+} follow the same trend as those of Na^+ and Cl^-, reaching their respective maximum values of 40.0 g/kg and 39.37 mM at intermediate depths. Mg^{2+} concentrations exhibit the opposite pattern, decreasing from the highest concentration of 57.22 mM near the seafloor, to a minimum concentration of 17.31 mM at 190.44 mbsf, and then increasing to 29.31 mM at the base of the cored interval. The minor elements B and Sr increase in concentration with depth. Sulfate accounts for the majority of total sulfur content and ranges between 23.84 and 30.72 mM, with no obvious pattern with depth. The nutrients ammonium and phosphate decrease in concentration downhole, with ammonium (range: 64.45–737.32 µM) significantly higher than phosphate (range: 1.77–4.69 µM).

Methane, the only hydrocarbon gas detected in the cores at this location, shows a relatively stable concentration profile (mean value of 0.86 ± 0.42 ppmv) throughout the sediments. A small peak (maximum concentration of 5.16 ppmv) occurs near the top of Unit II.

The percentage of calcium carbonates varies from 1.9 to 47.2 wt%. Sedimentary total organic carbon (TOC) and total nitrogen (TN) contents range from 0.01 to 1.15 wt% and from 0.004 to 0.21 wt%, respectively. Most sediment samples show a TOC/TN ratio of less than 12, indicating that sedimentary organic matter originates from marine sources, except in the interval 12.8–22.5 mbsf. However, the occurrence of inorganic nitrogen could result in an overestimation of the relative contribution of the marine source. Total sulfur (TS) generally varies between below detection and 0.90 wt%.

Eighteen of the sediment IW squeeze cakes and intervals in the corresponding archive section halves were analyzed via portable X-ray fluorescence. The data show a high degree of scatter, possibly due to frequent changes between nannofossil and/or foraminifer-rich materials and volcaniclastic-rich materials. Different water content between the squeeze cakes and core sections may also contribute to scatter in the data. However, general trends, such as increases in K_2O and Rb contents and decreases in CaO, Sr, and Ni contents downhole, can be recognized in the squeeze cakes extracted from the topmost sediment layer down to ~50 mbsf. Two intervals of sediment from Site U1615 were chosen for analysis via inductively coupled plasma–atomic emission spectroscopy.

Physical Properties

Physical properties measurements were acquired on the 34 recovered cores from Site U1615, including *P*-wave velocity (V_P), gamma ray attenuation bulk density, and magnetic susceptibility (MS) via the Whole-Round Multisensor Logger, and natural gamma radiation (NGR). Twenty-seven discrete samples were collected for moisture and density (MAD) analysis and calculation of density and porosity, and 17 thermal conductivity measurements were performed.

Our measurements showed that the MAD bulk density of recovered sediments in Hole U1615A varies from 1.345 to 1.957 g/cm^3 (average of 1.61 g/cm^3), while porosity changes from 81% at the top of the hole to 45% to the bottom (average of 63%), revealing a typical sedimentary compaction trend. This trend is consistent with the increase in V_P (1481 m/s to 1846 m/s, average value of 1596 m/s) based on the Gantry measurements. NGR increases with depth in a range from 23 to 331 counts/s with an average value of 78 counts/s. Thermal conductivity shows a general decrease with depth ranging from 1.675 to 0.879 W/(m·K) and with an average value of 1.15 W/(m·K). MS is highly variable in the top 211 m with individual peaks over 2000 IU, while it is more stable for the rest of the core with an average of 37 IU.

Downhole Measurements

The APCT-3 downhole instrument was deployed three times in the upper part of Hole U1615A to measure in situ sediment temperatures. All measurements were successful and reveal a thermal gradient of 11.8°C/100 m. A heat flow of 134 mW/m^2 was calculated using the thermal gradient and a value of 1.132 W/(m·K) for thermal conductivity, the average of physical properties measurements across the interval where APCT-3 measurements occurred.

Microbiology

In Hole U1615A, whole-round samples and syringe plugs of the core were collected on the catwalk for viral metagenomics, 16S rRNA, microbial experiments, and viral counts. Viral metagenomics and 16S rRNA samples were double-bagged and frozen at –86°C immediately after collection. Samples for viral counts were fixed in a phosphate-buffered saline and formaldehyde solution. Microbial experiments were initiated under anaerobic conditions, including enrichment cultures, viral incubations, and a prophage induction incubation in the sample from Section U1615A-2H-5.

Oxygen measurements were conducted on whole-round cores from Hole U1615A immediately after core recovery and prior to temperature equilibration. In Core U1615A-1H, oxygen was detected across the first 20 cm of Section 1H-1, with a maximum value of 76.31 μM at 5 cm depth, and the lowest detectable value of 0.73 μM at 20 cm. Measured oxygen concentrations increased throughout Cores 3H and 4H to a subsurface maximum of 17.93 μM; however, this trend may be the result of drilling disturbance and the lithology. An attempt was made to continue with the measurements beyond Core 7H, but the cores were either disturbed, too sandy, or had too much intruded water and drill fluid for reliable measurements.

Additional samples were taken for PFD microbial contamination tracer analysis in each core from which a microbiology sample was collected. PFD was detected in all core exterior samples, demonstrating successful delivery of the tracer. Five out of 13 core interior samples (from Cores 21X-2, 24X-6, 25X-4, 29X-3, and 30X-2) contained detectable PFD, suggesting some amount of drilling fluid intrusion and microbial contamination.