IODP Expedition 402: Tyrrhenian Continent–Ocean Transition

Site U1612 Summary

Background and Objectives

Site U1612 (proposed Site TYR-09A) is one of four drill sites in the Vavilov Basin of the Tyrrhenian Sea that target exhumed mantle peridotites at a water depth of 3574 m. At each of these sites, the plan is to core the sedimentary section, capture the sediment/basement interface, and then continue coring either 70 m or 140 m into the basement. This plan ensures that at least two sites cross the exhumation fault zone at the top of the basement, assumed to be ~100 m thick or less.

Site U1612 was considered the highest priority site because of its location near the intersection of the planned west–east and north–south transects across the Vavilov Basin and, as such, it is the first site visited during IODP Expedition 402. In Hole U1612A at this site, the planned operations were to rotary core barrel (RCB) core to a total depth of 418 meters below seafloor (mbsf), including an estimated 278 m of sediment and 140 m of basement, followed by downhole logging. If recovery of the sediment/basement interface in Hole U1612A was poor, and if time allowed, the plan was to drill an additional hole to 228 mbsf using the advanced piston corer/extended core barrel (APC/XCB) coring system, followed by XCB coring of the lowermost 50 m of sediment to reach the sediment/basement interface.

Operations

The *JOIDES Resolution* departed Napoli, Italy, on 14 February 2024, with the pilot boarding at 0651 h and the last line released at 0724 h. The pilot disembarked at 0755 h and the ship completed the 86.6 nmi transit to Site U1612. The ship arrived on site at 1530 h and transitioned from cruise mode to dynamic positioning (DP) mode. The precision depth recorder (PDR) reading determined the seafloor to be at 3572.6 meters below sea level (mbsl). Hole U1612A was spudded at 0800 h on 15 February and the water depth was determined to be 3573.8 m.

RCB drilling in Hole U1612A advanced through the sediment column with a formation change to basement at 333 mbsf in Core U1612A-35R. Core recovery throughout the sediment column was poor (72.5 m or 22%). Seventeen cores had no recovery or recovery of <0.5 m core material, including Cores 1R and 2R at the seawater/sediment interface. Recovery improved near basement; Cores 32R through 34R had an average of 98% recovery. During sediment coring, the Sediment Temperature 2 (SET2) tool was run three times, following Cores 11R, 17R, and 21R. The measurement attempted after Core 17R did not provide a good reading, likely due to poor contact between the probe and the formation. Cores 35R through 39R advanced into basement. Including the ~0.5 m of basement recovered in Core 34R, we penetrated 15.7 m into basement, recovering 3.45 m of material (22%).

The drill pipe became stuck while coring Core 40R, losing rotation and vertical movement. The decision was made to sever the pipe at the bottom-hole assembly (BHA). A severing charge was lowered into the hole to 207 mbsf and detonated. A decrease in string weight was not observed, indicating that the pipe was stuck further up in the sediment column. A second severing charge was lowered to the sediment/water interface and detonated at 0235 h on 19 February. An immediate drop in string weight indicated the pipe was successfully severed and was free. Pipe was tripped back to surface. The decision was made to discontinue operations at Site U1612.

Principal Results

Lithostratigraphy

Cores U1612A-1R to 34R (0–323.7 mbsf) were described both macroscopically and microscopically (via smear slides). Two lithological units were tentatively defined.

Unit I extends from 0 to 238.8 mbsf (Cores U1609A-1R to 26R). This unit is composed of gray nannofossil ooze with variable content of volcaniclastic material. Contacts between lithologies are mostly gradational and marked by subtle color changes. Bioturbation is sparse to moderate.

Unit II extends from 238.8 to 323.7 mbsf (Core U1609A-26R to 34R). It is composed of nannofossil chalk with siltier horizons rich in Radiolaria and diatoms. Bioturbation is moderate and occasionally abundant. There are a few shell fragments and pyrite precipitates, as well as black organic matter patches. Several sapropel and tephra layers were noted, including a faulted sapropel.

Much of the cored material was slightly to severely disturbed, including biscuiting and cracking.

Biostratigraphy

The biostratigraphy of planktic foraminifera as well as calcareous nannofossils was analyzed from core catcher (CC) samples in Hole U1612A. Both microfossil groups are abundant at this site in the nannofossil ooze lithologies and preservation across is good in general. Some CC samples with significant amounts of volcanogenic clastic materials as well as lithic fragments and volcanic glass did not contain foraminifera. Twenty-six CC samples were collected as a part of the sediment drilling, with additional toothpick samples for nannofossil analysis taken from Cores 33R and 34R to refine the age of the oldest sediments recovered.

From planktic foraminifera assemblages, four biosubzones from the Holocene through Pleistocene were identified, coinciding with the most common occurrences of marker species. The top three cores recovered from the site are estimated to be <0.53 Ma followed by a thick volcanogenic sediment sequence from ~27–165 mbsf without the presence of any prominent biozone marker species. Calcareous oozes are more prevalent beneath that sequence, with occasional volcanogenic layers, permitting biozones assignments.

Nannofossil biostratigraphy is in general agreement with the foraminfera. Samples from Cores U1612A-1R to 16R were assigned to the late Calabrian–Holocene time interval, while Core 27R is likely early Calabrian. Sample U1612A-33R-6, 127 cm, contains well-preserved nannofossils that are Piacenzian in age. In the next core, Section U1612A-34R-CC, nannofossils are absent and dolomite granules present.

These data indicate a high sedimentation rate, especially in the upper part of the Hole U1612A sediment succession, where about 170 m of sediments were deposited over 1.20 My (sedimentation rate ~14 cm/ky). Two hiatuses are preliminarily identified, corresponding to ~0.5 and 0.6 Ma. A lower sedimentation rate of ~4 cm/ky is observed downhole.

Paleomagnetism

The superconducting rock magnetometer (SRM) and AGICO JR-6A spinner magnetometer were tested with a variety of parameters to determine proper measurement sequences for archive half sections and discrete samples, respectively. Alternating field (AF) demagnetization of natural remanent magnetization (NRM) of a 1.5 m archive half section was set up to 20 mT in four steps to remove secondary magnetization such as drilling overprint. AF demagnetization of NRM of discrete samples was up to 100 mT in eight steps to reveal characteristic remanent magnetization (ChRM). Measurements on archive half sections of Cores U1612A-1R to 31R (~294 mbsf) were completed. While several geomagnetic reversals are expected over this interval, all inclinations show normal polarity. ChRM of discrete samples suggests that a secondary component, likely drilling overprint, can be removed around 20 mT, confirming the results of archive half sections. However, recovery in Hole U1612A was very low, which may account for the fact that no reversals were measured.

Following a more in-depth discrete sample demagnetization analysis, a possible reversal in Section U1612A-31R-1 is identified. While limited data points for this reversal are found, it correlates strongly with shipboard biostratigraphy. The unit directly overlying this interval is a volcaniclastic tuff, which could be responsible for the loss of preservation of a larger portion of this reversal.

Igneous and Metamorphic Petrology

Hole U1612A recovered a variety of igneous rocks, ranging from volcaniclastics within the sediments to basalts to intrusive rocks interpreted to represent the local geologic basement. Volcaniclastic layers encountered within the sediment were poorly recovered. Recovery was sufficient to define unit boundaries but not the contacts or transitions. In Core U1612A-31R (~284 mbsf), a basalt clast marks the transition between a volcaniclastic layer and sediments. The sediment/basement interface was encountered at ~324 mbsf, beginning with an unconsolidated breccia containing clasts of diverse lithologies including basalt, peridotite, and granite. The nature of this basal breccia (e.g., a sedimentary deposit or the result of displacement along a fault) remains uncertain due to the poor recovery. However, the primary contact with the sediments is exceptionally well-preserved in a 10 cm thick interval of pillow basalt that still contains slightly altered rims. Below the breccia, a crystalline interval was penetrated from ~333 to ~345 mbsf. These rocks consist mainly of a single unit of a variably deformed granitoid with a predominantly quartz-diorite composition. Two peridotite pebbles were in the basal breccia of Core U1612A-35R and an 8 cm long mantle serpentinized peridotite cobble was recovered at the bottom of Core U1612A-37R without contacts with granitoids. These observations suggest that mantle peridotites were exposed on the seafloor prior to sedimentary deposition.

Structural Geology

Sediments cored at Site U1612 mostly show subhorizontal, parallel lamination; below 220 mbsf, tilted beds are more common. Observed deformation structures include faulted and folded lamination, normal and reverse faulting, and boudinage. Clasts just below the sediment/basement interface suggest a polymictic breccia underlain by variably deformed gneiss. The mylonitic and ultramylonitic fabric progressively decreases to a weak foliation downhole.

Sediment and Pore Water Geochemistry

The sediment and pore water geochemistry team collected samples in Hole U1612A for both shipboard and postexpedition research. For shipboard analyses, these samples include (1) sediment plugs and small pieces of concretions and/or rocks for measuring hydrocarbon gas concentrations and distribution to ensure safety from all cores recovered (Cores U1612A-1R to 35R), (2) 5 cm long whole-round samples taken from 13 cores to extract the interstitial water (IW) by squeezing, and (3) sediments from different layers identified by sedimentologists during shipboard discrete sampling.

Only very small concentrations of methane were measured between 0 and 323.7 mbsf, varying from 0.20 to 3.06 ppmv. While pH values of IW are relatively stable with depth, a slight increase in salinity and chloride concentrations occurs between 143.9 and 208.9 mbsf. This same trend is observed for other anions and cations, possibly reflecting mineral dissolution. Sulfate concentrations are stable in the first few cores, then increase down section to 319.8 mbsf. A slight decrease in alkalinity and magnesium between 20.8 and ~150 mbsf could indicate precipitation of authigenic dolomite.

All sediments, including squeeze cakes and additional discrete samples chosen according to changes in lithology were freeze-dried, ground to a fine powder and homogenized using an agate pestle and mortar, and then analyzed for (1) total inorganic carbon content, (2) percentage of total carbonate content, (3) total carbon, nitrogen, and sulfur content, and (4) total organic carbon (TOC) and matter content. Atomic TOC/total nitrogen ratios range widely from 1.5 to 28.6, indicating changes in organic matter origin (marine versus terrestrial).

Igneous Geochemistry

At Site U1612, igneous geochemistry analyses were made on recovered core via portable X-ray fluorescence (pXRF) and inductively coupled plasma–atomic emission spectroscopy (ICP-AES). Three samples representing the range of igneous rocks were analyzed via ICP-AES, while additional intervals were selected for pXRF measurements. For pXRF rock standards, it was observed that lighter elements are measured as being lower in concentration than their known values. For instance, when analyzing pure SiO_2, the pXRF indicated that the material was only 80% SiO_2. To compensate, all available shipboard standards were measured with the pXRF and a correction curve was generated for each reported element.

Loss on ignition is higher in the basalt than in the felsic rocks. MgO content in the basalts appears spatially variable across the unit, but the relatively high MgO content overall may indicate a primary origin. The two samples of felsic rock analyzed are granite to granodiorite in composition based on a total alkali-silica diagram. The igneous geochemists also conducted pXRF analyses on IW squeeze cake residues and sediment section halves adjacent to IW samples to better interpret sediment geochemical records.

Physical Properties

A complete set of physical properties measurements were made on core recovered from Hole U1612A during the first week of the expedition, including density, magnetic susceptibility (MS), and *P*-wave velocity (V_P) using the Whole-Round Multisensor Logger (WRMSL; 71 core sections), X-ray imaging, and natural gamma radiation (NGR; 62 core sections). X-ray and NGR analyses were made immediately after core recovery, while cores were not run on the WRMSL until they had equilibrated to room temperature for at least 4 h. In addition, the group performed 51 discrete V_P measurements, collected and processed 30 moisture and density (MAD) samples, and performed 23 measurements of thermal conductivity, four of which were unsuccessful due to poor contact between the probe and sample.

For the X-ray imaging, the group compared results from 71 whole-round sections scanned at multiple angles (0°, 45°, 90°, and 135°) as well as 62 section halves. The multiple-angle scans provided quality images of low-density fractures and their orientations. However, indentations on the core exterior left by the CC during the coring process obscured some of these images. In contrast, section-half X-ray scans of sedimentary cores at a single overhead angle yielded better images of sedimentary structures. Since the recovery of sediment cores is faster than hard rocks and the multiple angles are time consuming, we decided only to X-ray section halves for sediment cores and scan whole rounds at multiple angles for hard rock cores.

Despite the poor core recovery, the physical properties data show notable variations that can be associated with lithological changes. Seismic velocities measured by WRMSL are consistent with discrete V_P measurements with the Gantry system. The overall increasing trend downhole from ~1500 to ~1700 m/s in the sedimentary section coincides with the bulk density change from ~1.6 to ~2.0 g/cm^3 and a porosity decrease from ~75% to ~45%, which we interpret as general compaction of sediments. V_P increases dramatically at a depth of ~333 mbsf to values greater than 4000 m/s, supporting the preliminary designation of this depth as basement. MS is generally low, with values near 50 IU and local peaks up to 2143 IU associated with volcaniclastic material in sediments or with serpentinized peridotites in the polymictic breccia above the basement. NGR varies from 10 to 223 counts/s with higher values generally in volcanic-rich sedimentary intervals and in the basement. Thermal conductivity increases with depth and varies from 0.9 W/(m·K) on the top of the sedimentary section to 2.9 W/(m·K) measured for the metamorphic basement. The basement rocks are characterized by high density (~2.63 g/cm^3) and low porosity (~1%) based on three MAD measurements.

Downhole Measurements

The SET2 downhole instrument was deployed three times in Hole U1612A to measure in situ sediment temperatures. Two measurements appeared successful at 103.9 mbsf (Core 12R) and 198.9 mbsf (Core 22R), with equilibrium temperatures of 33.39°C and 48.45°C, respectively. These temperatures are coherent with an equilibrium seafloor temperature of 14.95°C, yielding a thermal gradient of 15.25°C/100 m and a heat flow in the range of 152 mW/m^2 using an average 1.0 W/(m·K) for thermal conductivity. A third temperature measurement made at 160.9 mbsf (Core 18R) gave a reading of 15.92°C. However, given the granular lithology recovered in the following core (18R), this data point is interpreted as an erroneous measurement caused by poor contact between the probe tip and the formation. Hole conditions did not permit any additional downhole measurements.

Microbiology

For Hole U1612A, whole round samples and syringe plugs of core were collected on the catwalk for metagenomic analyses (5 cm whole round), 16S rRNA (10cc plug), viral counts (1cc plug), and microbial enrichments (5 cm whole round). Metagenomic and 16S rRNA samples were bagged and frozen at –86°C immediately after collection. Samples for viral counts were fixed in 37% formaldehyde. Viral activity incubations were initiated and subsamples were taken at 0, 4, 8, 12, and 24 h in triplicate. Incubation subsamples were fixed with 37% formaldehyde and frozen at –86°C, and microbial enrichments were initiated (two samples) and kept in the dark.

Oxygen profiles for Hole U1612A were taken from Cores U1612A-3R, 4R, 9R, 10R, 16R, and 22R in either or both Sections 2 and 3, which were typically the least disturbed. The remainder of the cores between Cores 1R and 22R had little or no recovery, preventing oxygen profiling. Oxygen measurements were made on whole-round core sections immediately after core recovery, prior to temperature equilibration, by drilling two small holes in the core liner and inserting the oxygen and temperature probes into the undisturbed core center. Oxygen concentrations in Core 3R were undetectable, but continued measurements were made once per core through Core 22R to verify the absence of oxygen. 2.7 μM oxygen was measured in Core 16R. Occasionally, observed higher oxygen concentration values may indicate intrusion of oxygenated drill fluid or air into the sample through core disturbance or cracking during probe insertion.