IODP Expedition 402: Tyrrhenian Continent–Ocean Transition

Site U1613 Summary

Background and Objectives

Site U1613 (proposed Site TYR-07A, expected water depth 2700 m) is located on the Cornaglia Terrace at the western end of the planned west–east transect across the Tyrrhenian Sea. The basement target at this site is expected to be either continental or basalt, formed by magmatic accretion before mantle exhumation in the Vavilov Basin. As in the Vavilov Basin sites, the plan was to core the sedimentary section, capture the sediment/basement interface, and then continue coring up to 70 m into basement using the rotary core barrel (RCB) drilling system. Only a single hole was planned for this site, reaching a total depth of 265 meters below seafloor (mbsf), followed by followed by downhole logging. Seismic reflection data suggest that Messinian evaporites may be present at the base of the sedimentary column.

Operations

The ship completed the 76.4 nmi transit to Site U1613 at an average speed of 11.75 kt, arriving at 1930 h on 19 February 2024 and transitioning to dynamic positioning mode at Hole U1613A at 2007 h. A new bottom-hole assembly with a C7 RCB bit was made up to better recover hard formations such as the basalt basement lithology anticipated at Site U1613. Pipe was tripped to the seafloor and Hole U1613A was spudded at 0830 h on 20 February, with a seafloor depth of 2706.8 meters below sea level (mbsl). Coring reached a total depth of 223.6 mbsf in Core U1613A-24R, recovering 99.63 m of material (45%).

Core U1613A-2R had 0 m of recovery, later attributed to a malfunctioning core catcher (CC), which was removed and repaired. A hard layer identified as sandstone was encountered in the CC of Core 16R. The rate of penetration decreased substantially below that depth, varying between 14.7 m/h in Core 17R to 1.2 m/h in Core 22R, relative to the average 80.2 m/h for Cores 1R–16R. The sandstone in Section U1613A-16R-CC was preliminarily determined to be continental basement, suggesting that the targeted basalt layer is not present at this site, and the decision was made to stop coring after Core 24R.

Temperature measurements using the Sediment Temperature 2 (SET2) tool were made at depths of 67.1, 95.6, and 125.9 mbsf, following Cores U1613A-7R, 10R, and 13R. The third-generation advanced piston corer temperature (APCT-3) tool was also run to seafloor depth to verify the calibration of the SET2. Nonmagnetic core barrels were used on all cores in Hole U1613A.

Logging was planned in Hole U1613A to better characterize intervals of low recovery and borehole physical properties. To prepare for logging, we swept the hole with 90 bbl of high-viscosity sepiolite. We then ran the rotary shifting tool to drop the RCB bit at the bottom of the hole. The knobbies were laid out and the top drive was set back, and pipe was tripped up to 74 mbsf. A first logging run was made with the triple combo tool string starting at 1430 h on 22 February. The tool string encountered a ledge at 127 mbsf but was able to work through it. A second ledge at 197 mbsf could not be worked through. Given the poor hole conditions, only a single pass was made with the triple combo. As a consequence of the poor hole conditions, the Formation MicroScanner (FMS) was removed from the standard FMS-sonic tool string and a single pass was made with just the Dipole Sonic Imager (DSI) tool. This modified tool string was deployed at 2100 h and reached a depth of 182 mbsf. The tool string was recovered by 0100 h on 23 February and the pipe tripped back to the surface. Hole U1613A and Site U1613 ended at 0935 h on 23 February, as the vessel transitioned into cruise mode and began the transit to proposed Site TYR-11A (Site U1614). Operations at Site U1613 took 3.6 d in total.

Principal Results

Lithostratigraphy

Four lithological units were preliminarily defined for sediments from Hole U1613A. The first two units transition from soupy, nannofossil-rich very fine sand to ooze with mud, with a layer of foraminifera-rich material in Unit II. Several organic-rich layers with coarser texture as well as glauconite-rich layers are encountered in Unit I. Reddish brown layers in Unit II are attributed to an increased content of iron-rich minerals. Contacts are either sharp erosive or defined by a color change. Bioturbation is absent to sparse. Unit III encompasses the Messinian gypsum-rich silt facies underlain by oxide-rich sand, matrix-supported polymict sand, and sandy mudstone. Unit IV contains sandy mudstone and silty rich black shale.

Basement at Site U1613 is defined as a potential Triassic to Paleozoic succession. Based on analogies with similar formations in Sardinia, three main basement units were identified and described: conglomerates (Unit IV), green/red shales (Unit V), and black shales (Unit VI). The probable difference in depositional ages of the different units indicates the occurrence of unconformities in the basement. The Unit IV conglomerates consist of rounded to subrounded clasts of quartz and volcanic material in a reddish, fine-grained matrix. Unit V contains sandy mudstone and a layer of polymictic conglomerate. The black shale of Unit VI is crosscut by thin carbonate veins, and it additionally contains clay minerals, pyrite, and Ti-bearing phases observable in thin section. Pollen spores identified in the thin section provide a preliminary late Permian age for the interval.

Biostratigraphy

Fourteen out of the 22 CC samples (U1613A-1R-CC to 15R-CC) in Hole U1613A were used for biostratigraphic analyses. According to planktic foraminifera data, nine biosubzones from Holocene to Lower Pliocene (Zanclean) were identified. According to nannofossil data, the upper part of the recovered succession (top down to Section 11R-CC) is Middle Pleistocene–Gelasian in age and is characterized by a sedimentation rate of ~48 m/My. Both foraminifera and nannofossil data indicate a temporal hiatus ~1.5 My long and is latest Zanclean/earliest Gelasian in age. Samples from Sections 12R-CC to 14R-CC are of Zanclean age (Early Pliocene). In Section U1613A-15R-2, an 8 cm horizon comparable to one of the late Messinian salinity crisis onset events was identified and is 5.97 to 5.85 Ma in age. Sediments and sedimentary rocks below Core U1613A-16R were correlated to units outcropping on Sardinia and correspond to continental basement.

Paleomagnetism

Core recovery in Hole U1613A was higher (45%) than at Site U1612, resulting in a more continuous paleomagnetic profile. Cores U1613A-1H through 5H were measured on the superconducting rock magnetometer; however, the material is reworked and the observed irregular polarity changes are not reliable for magnetostratigraphy. Alternatively, some reversal records correspond to lithological variations in these cores, suggesting an influence of diagenesis on the natural remanent magnetization (NRM). A deeper normal-reversal sequence is reliable and suggests an age of ~5 Ma at 125 mbsf. The NRM of the continental basement rocks is lower than other stratigraphic units at this site, reflecting a low concentration of magnetic minerals or drilling disturbance.

Structural Geology

The main structural observations of Site U1613 are from the documented Messinian unit in the sediment and a thick incohesive, cataclastic zone in the assigned basement below, between volcanoclastic deposits and black shales. Interestingly, the dip of the structures increases with depth, shifting from 1° to 20° in the sediments to 21° to 70° in the basement. The number of fractures and reverse faulting also increases with depth. The change in bedding dip at the base of Lithostratigraphic Unit II indicates an angular unconformity or the transition from a high-energy depositional environment to a relatively low-energy depositional environment. We interpret the cataclastic zone (Unit V) above the black shales in Unit VI as a fault gouge, either related to normal faulting or reactivation of a normal fault in reverse shearing. Reverse shearing can be explained by compressive strength on the ridge flanks due to the spreading ridge.

Sediment and Pore Water Geochemistry

In Hole U1613A, sediment interstitial water (IW) salinity shows an increasing trend with depth and is higher than 45.0 below 100 mbsf. A maximum salinity value of 50.5 is reached at 166.22 mbsf (Section U1613A-18R-1). The Ca^{2+} concentration exhibits a similar trend, which may suggest the formation of evaporites. Dissolved Li and Sr have higher concentrations in the lower part of the cored interval, consistent with precipitation of authigenic minerals in dry environments. The percentage of sediment calcium carbonate varies from 0.6 wt% (Section U1613A-19R-1, 176.4 mbsf) to 69.3 wt% (Section U1613A-12R-3, 170.6 mbsf). Low total organic carbon (TOC, 0.07–0.39 wt%), total nitrogen (TN, 0.00–0.05 wt%) and total sulfur (TS, 0.0–0.2 wt%) contents were measured in sediments collected from this site. Higher atomic TOC/TN ratios (15.0–37.0) occurred at 61.6, 77.9, 119.1 and 130.3 mbsf, indicating higher inputs of terrestrial organic matter and/or diagenetic processing of organic matter.

Chemical analysis of sediments also included 37 samples analyzed via portable X-ray fluorescence spectrometry and nine samples analyzed via loss on ignition and inductively coupled plasma–atomic emission spectroscopy. Chemical compositions of sediments show drastic change between Cores U1613A-14R and 15R, where oxide abundances increase and lithological classification changes from muddy ooze to silt or sand downhole. The SiO_2, Al_2O_3, Fe, and Rb contents increase downhole starting at Cores 14R to 15R, whereas the CaO, MnO, and Sr contents decrease. The black shale of Core 24R is higher in Ca and Mn (~21 wt% CaO and ~0.12 wt% MnO) than the above sections composed of silt and sand (~10 wt% CaO and 0 wt% MnO).

Physical Properties

Cores recovered from Hole U1613A on the Cornaglia Terrace were measured for gamma ray attenuation (GRA) density, magnetic susceptibility (MS), and *P*-wave velocity (V_P) on the Whole-Round Multisensor Logger, as well as X-ray imaging and natural gamma radiation (NGR). Discrete samples were taken for moisture and density analysis, in addition to discrete measurements of thermal conductivity and V_P made on the Gantry system. Our measurements highlight the changes in physical properties between the sedimentary cover and the pre-Messinian basement and allow us to identify various heterogeneities within the sediments, such as coarse-grained layers or changes in the organic content. For example, a thin gypsum layer just above basement is evident from changes in all measured parameters. Measured physical properties within the basement show trends consistent with the presence of alternating layers of sandy mudstone and conglomerate.

Across lithostratigraphic Unit I, GRA density increases and porosity decreases downhole from ~70% to ~56%. A layer of medium-grained sand with higher bulk density, V_P, NGR, and MS is observed in Sections U1613A-3R-6 through 3R-7. Physical properties remain relatively constant throughout Unit II, then change sharply in Unit III, with increased density, thermal conductivity, V_P, and NGR, and decreased porosity. V_P, thermal conductivity, and density increase substantially in the basement units, while MS is low and constant.

Downhole Measurements

Downhole measurements conducted in Hole U1613A included three runs of the SET2 tool and downhole logging runs with two tool strings.

In situ formation temperature measurements were taken with the SET2 following Cores U1613A-7R, 10R, and 13R. Two of the three SET2 runs were successful, recording temperatures of 24.06° and 29.65°C, respectively, at depths of 67.1 and 125.9 mbsf. These temperatures are coherent with an equilibrium seafloor temperature of 13.58°C recorded before and after the second SET2 run, yielding a thermal gradient of 12.7°C/100 m and a heat flow in the range of 127 mW/m^2 using an average value of 1.0 W/(m·K) for the thermal conductivity measured from the cores. The APCT-3 tool was also run to seafloor depth to verify the calibration of the SET2.

The first logging tool string deployed in Hole U1613A was the triple combo, including the logging equipment head for borehole fluid temperature, the Hostile Environment Natural Gamma Ray Sonde tool, the Hostile Environment Litho-Density Sonde for bulk density, photoelectric factor, and a one-arm caliper, the High-Resolution Laterolog Array electrical resistivity tool, and the Magnetic Susceptibility Sonde. Because of poor hole conditions, we made a single pass with this string. The second tool string included just the DSI tool.

Logging data from Hole U1613A may be more qualitative than quantitative due to the single passes made with each tool string in addition to the large hole size. Spectral gamma ray values are relatively low throughout Lithologic Unit II but increase in the nannofossil ooze/chalk intervals. The density and MS profiles are in good agreement with core data when not affected by the hole size.

Microbiology

Whole-round samples and syringe plugs of core were collected on the catwalk for metagenomics, 16S rRNA, microbial experiments, and viral counts in sediment from

Site U1613. Metagenomic and 16S rRNA samples were frozen at –86°C immediately after collection. Samples for viral counts were fixed in formaldehyde. Microbial experiments were initiated in anaerobic conditions, including enrichment cultures in a sample from Section U1613A-5R-5 and viral incubations and prophage induction experiments in Sections 1R-2 and 11R-2.

Oxygen measurements were made on whole-round cores from Hole U1613A immediately after core recovery and 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. Core U1613A-1R exhibited significant disturbance, particularly in Sections 1R-1 and 1R-3, which hindered the generation of reliable data. From Core 3R downward, the oxygen profile exhibited a consistent decline, maintaining low or zero concentration levels. In Cores 11R and 13R, oxygen levels increase marginally. To confirm these results, measurements in Cores 11R and 13R were repeated in at least one additional section of each core, yielding similar values, which were associated with the presence of a void space in the core liner.