IODP Expedition 398: Hellenic Arc Volcanic Field

Site U1593 Summary

Background and Scientific Objectives

Site U1593 (alternate Site CSK-04C) is located on the flank of the submarine Kolumbo volcano, 8 km northwest of its caldera in the Anhydros Basin at a water depth of 402 meters below sea level (mbsl) and with a target depth of 581 meters below seafloor (mbsf).

The seismic profiles across the Kolumbo edifice reveal five units interpreted as Kolumbo-derived volcaniclastics (K1 to K5 from the base up), with Unit K5 representing the 1650 CE eruption. The submarine cones northeast of Kolumbo postdate Unit K2 on seismic profiles, but their products are not expected to be prominent in our drill cores.

The aim of drilling on the flanks of Kolumbo was to penetrate the different seismically recognized volcanic eruption units from that volcano (K1, K2, K3, K5, or their thin, lateral equivalents), as well as many eruption units from Santorini and traces from the submarine cones northeast of Kolumbo. This would enable characterization of the products of the Kolumbo eruptions, as well as construction of a coherent stratigraphy for Santorini and the submarine Kolumbo volcano chain together. The anticipated lithologies were volcaniclastics, muds, and turbidites.

Site U1593 lies at the foot of the Kolumbo edifice, 3 km northwest of Site U1590. Owing to the poor recovery at the latter site, we decided to drill also at Site U1593, which lies on the other side (northwest) of the Kolumbo Fault. This has two advantages. First, we could measure the offset across the Kolumbo Fault by correlating key marker layers from one site to the other. Second, the sequence at Site U1593 is more condensed that at Site U1590, offering us older recovery and potentially improved hole stability.

Like Site U1590, Site U1593 allowed us to drill Seismic Units K1, K2, K3, and K5, and therefore nearly the entire history of the Kolumbo Volcano. Intercalated seismic units were believed to contain the products of Santorini eruptions, including potentially those of smaller magnitude than recorded at the more distal basin sites. The proposed drilling strategy at Site U1593 was to drill three holes to the target depth by utilizing the advanced piston corer (APC), half-length advanced piston corer (HLAPC), and extended core barrel (XCB) tools.

Operations

After arrival on 18 January 2023, the vessel was switched to dynamic position (DP) control at 2324 h. An APC/XCB bottom-hole assembly (BHA) with bit was assembled and Hole U1593A (36°34.5103′N, 25°24.8765′E) was spudded on 19 January at 0245 h from 409.0 meters below

rig floor (mbrf). Recovery for Core U1593A-1H was 4.7 m, giving a calculated seafloor of 402.5 mbsl.

APC coring continued from Cores U1593A-2H to 16H from 4.7 to 147.2 mbsf. Indications of impartial strokes on three consecutive cores, plus a high overpull on Core U1593A-16H, led to a switch to the HLAPC. HLAPC coring commenced with Core U1593A-17F and continued through Core U1593A-38F to 250.6 mbsf, the final depth for Hole U1593A. The drill string was tripped up with the top drive to 202.6 mbsf, the top drive was racked back, and the trip out continued to 404.9 mbrf. The bit cleared the seafloor at 0750 h on 20 January, ending Hole U1593A.

The rig crew serviced the rig while the vessel was offset 50 m southeast. At 0940 h on 21 January, Hole U1593B (36°34.4916′N, 25°24.9000′E) was spudded from 412.0 mbrf. The recovery of 6.20 m gave a calculated seafloor at 404.0 mbsl. APC coring continued with Cores U1593B-2H to 11H. HLAPC coring began with Core U1593B-12F at 101.2 mbsf and continued through Core U1593B-39F to 232.8 mbsf, the final depth for Hole U1593B. The bit cleared the rotary table at 1409 h on 21 January, ending Hole U1593B.

At 1445 h, the vessel was offset 25 m north. Meanwhile, the crew started assembling the rotary core barrel (RCB) BHA with a bit. Hole U1593C (36°34.5060′N, 25°24.8995′E) was spudded at 1752 h. The hole was advanced without core recovery to 192.6 mbsf. At the 192 mbsf mark, the drill pipe started experiencing increasing torque. The drill string was worked up from 189.3 to 173.1 mbsf. During the attempt to work the drill string back to bottom, excessive torque was still observed. The drill string was pulled up again, from 192.6 mbsf to 123 mbsf, when there was a loss of rotation. Attempts to free the string with mud sweeps and circulation proved fruitless. Overpulls on the drill string were increased to a final attempt at 150,000 lb, still with no success.

At 0830 h, the Schlumberger wireline was rigged up to sever the pipe. The drill string was severed at 37.0 mbsf at 1010 h on 22 January. The drill string immediately regained rotation and was tripped up with the top drive. The pipe cleared the rotary table at 1320 h. The drill floor was secured and thrusters were raised starting at 1646 h. The vessel was switched to bridge control at 1648 h. All thrusters were up and secured and the sea passage began at 1700 h, ending Site U1593.

Principal Results

Site U1593 recovered a coherent stratigraphy from 0 to 250.89 mbsf. The recovered material is unlithified sediment, dominated by volcanic and tuffaceous material interspersed with minor amounts of nonvolcanic sediments in both holes. Site U1593 has two lithostratigraphic units. Unit I is composed of four subunits (Ia, Ib, Ic, and Id), and Unit II, which is only present in Hole U1593A, has no subunits. Smear slides for microscopic analyses were prepared to confirm

macroscopic descriptions of distinct lithology changes at the section level, such as identification of vitric particles in tuffaceous lithologies or crystals in ash layers.

Structural geology analyses at Site U1593 included description of cores retrieved from Holes U1593A and U1593B. A total of 66 structures were measured, and most of those measurements derived from relatively consolidated intervals. The observed and measured structures on cores are all beddings. The precision of shipboard measurements equals that of terrestrial measurements in structural geology and accounts for numbers in the range of 1° to 2° per single measurement. The accumulation of single measurements within groups of identified structures are concentrated around means typically giving confidence intervals with errors much smaller than for single measurements. Deformation related to drilling and core recovery was noted, but not recorded.

Planktic and benthic foraminifers and calcareous nannofossils were examined from core catcher samples and additional split core samples from Holes U1593A and U1593B to develop a shipboard biostratigraphic framework for Site U1593. Additionally, benthic foraminifers provided data on paleowater depths, downslope reworking, and possible dissolution. Site U1593 cored a 250.89 m thick Holocene to early Pleistocene sequence comprised primarily of volcanogenic sediments and calcareous oozes. Calcareous nannofossils and planktic foraminifers are typical of late to early Pleistocene sediments.

Cores in Holes U1593A and U1593B had an overlap almost over the entire depth down to 232.8 mbsf. For correlations, the magnetic susceptibility (MS) derived with the Whole-Round Multisensor Logger (WRMSL) tool and half-core images were primarily used. In most cases both criteria delivered consistent results. Those correlations were used to determine affine ties between both holes and to apply some minor shifts to the cores that did not exceed 5.1 m.

Coarse volcaniclastic deposits at Site U1593 typically have low grain density and thermal conductivity compared to other sediments at this site. MS is highly variable in volcaniclastic layers and is sometimes very high. The typical increases of bulk density, *P*-wave velocity, and thermal conductivity with increasing depth are not clearly documented at this site. Whether the lack of a signature of compaction trend is real, a consequence of the limited depth of the holes, or an artefact of drilling and recovery disturbances, cannot be readily determined.

To determine the geochemistry of the volcanic and tuffaceous materials, 13 tephra samples were handpicked from various layers within Hole U1593A. Following cleaning, grinding, fusion, and dissolution, the materials were analyzed shipboard for major (Si, Al, Fe, Mg, and Ca), minor (Ti, Mn, Na, K, and P), and trace (Sc, V, Cr, Co, Ni, Cu, Zn, Rb, Sr, Y, Zr, Nb, Ba, Ce, and Nd) elements using inductively coupled plasma–atomic emission spectroscopy (ICP-AES). Of the volcaniclastic units sampled, one was classified as a basalt, one as basaltic andesite, three as andesites, and eight as dacites. Bulk chemistry values are less evolved than glass chemistry as expected due to bulk analyses including both minerals and glass. Concentrations are reported for all analyzed trace elements, but Ce, Cr, Cu, Nb, Ni, P, Rb, S, and V were below detection limits

in the majority of samples. Trace element ratios were used to broadly discriminate between the volcanic centers of Kolumbo, Santorini, and Christiana.

To determine the inorganic constituents of interstitial water (IW), a total of 17 water samples were taken from the mudline and the whole-round squeezing of sediment intervals at Site U1593 in Holes U1593A (11 samples) and U1593B (6 samples). Aliquots of IW were used for shipboard analyses, and the remaining water was taken for shore-based analysis. The retrieved interstitial waters were analyzed shipboard for salinity, alkalinity, pH, major anions (Cl^-, SO_4^{2-}, and Br^-), major cations (Ca^{2+}, Na^+, Mg^{2+}, and K^+), and major (S, Ca, Mg, K, and Na) and minor (B, Ba, Fe, Li, Mn, P, Si, and Sr) elements.

Headspace gas analyses were performed at a resolution of one sample per full-length core (9.5 m advance) or one sample every other core for half-length cores (4.7 m advance) throughout Hole U1593A. As the total depth of Hole U1593B did not exceed Hole U1593A, headspace gas analyses were not necessary in this hole. The aim was to monitor the presence and abundance of C1–C3 hydrocarbons as part of the standard IODP safety protocol. A total of 27 headspace gas samples from Hole U1593A were analyzed by gas chromatography (GC). Methane, ethane, and propane concentrations were below the detection limit in all measured samples.

Paleomagnetic analysis at Site U1593 focused on measurement and demagnetization of archive section halves to determine magnetostratigraphic age controls, together with demagnetization of 19 discrete samples. The upper 117 m of the sequence sampled in Hole U1593A carries normal polarity remanences acquired during Chron C1n (Brunhes). No cores suitable for paleomagnetic analysis were recovered in the 88 m below this, but a 2 m interval with normal polarity at ~206 mbsf is also assigned to the Brunhes Chron.

The interval between 217–240 mbsf is marked by wide variations in magnetic inclinations. This can only be explained by variable, partial to complete diagenetic overprinting of a reversed polarity depositional remanent magnetization acquired during the Matuyama Chron (C1r.1r) by a chemical remanence acquired during the subsequent normal polarity Brunhes Chron (C1n). We note that a discrete sample in Section U1593A-35F-1 displayed apparent normal polarity but appears to be affected by gyroremanent magnetization acquisition at higher demagnetizing fields and is considered unreliable.

Due to the instability of the formations encountered, downhole logging was not conducted at Site U1593.