IODP Expedition 398: Hellenic Arc Volcanic Field

Site U1590 Summary

Background and Scientific Objectives

Site U1590 is located 5 km northwest of the submarine Kolumbo caldera on its flank in the Anhydros Basin at a water depth of 397 meters below sea level (mbsl) and with a target depth of 566 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 within the proposed drilling target depth. The anticipated lithologies were volcaniclastics, muds, and turbidites.

Site U1590 lies at the foot of the Kolumbo edifice, and the aim of drilling on the flanks of Kolumbo was to penetrate the different seismically recognized volcanic eruption units from that volcano, 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 and reconstruction of the entire history of Kolumbo Volcano, as well as construction of a coherent stratigraphy for Santorini and the submarine Kolumbo volcano chain together.

Intercalated seismic units are believed to contain the products of Santorini eruptions, including potentially those of smaller magnitude than recorded at the more distal basin sites. Gravity cores ~9 km to the west contain ash-to-lapilli pyroclastic layers from the Kolumbo 1650 CE and Late Bronze Age (LBA) eruptions intercalated within hemipelagic sediments (clayey silt to sandy silt). Sediments 15 and 9 km to the northwest and to the south, respectively, contain the typical tuffaceous hemipelagic muds of the region deposited at sedimentation rates of 5–8 cm/ky.

The drilling strategy at Site U1590 anticipated three holes (Holes U1590A, U1590B, and U1590C), all to the target depth using the advanced piston corer (APC), half-length advanced piston corer (HLAPC), and extended core barrel (XCB) tools.

Operations

The sea passage to Site U1590 (proposed Site CSK-03A) started at 1818 h on 31 December 2022. The vessel arrived on location and started lowering the thrusters at 1946 h. All thrusters were down and secured at 2012 h. The vessel was switched to dynamic positioning (DP) at 2020 h, officially starting Site U1590. The transit to Site U1590 took 1.9 h, covering 14.5 nmi at an average speed of 7.6 kt. The rig crew assembled the APC/XCB bottom-hole assembly (BHA) in preparation to start Hole U1590A. Hole U1590A was spudded with Core U1590A-1H from

403 meters below rig floor (mbrf) at 36°33.2938′N, 25°26.3888′E. The recovery was 4.3 m, giving a calculated seafloor depth of 397.1 mbsl. Coring continued to 89.8 mbsf. At 1200 h, the drill string took weight when trying to lower it, indicating ~8 m of fill that had fallen into the hole. Core 11H was retrieved. The driller worked the drill string with 50,000–70,000 lb overpull. Despite all efforts, the drill string was stuck—there was little to no vertical movement, no rotation, and 2000 psi standpipe pressure immediately upon pumping. The driller continued to work the drill string while preparations for the severing operation began.

The severing tool was assembled and run into the hole to 4.6 mbsf. The BHA was severed at the top of the tapered drill collar (TDC) at 1700 h on 1 January 2023. The severing tool was retrieved, and the drill string was pulled up and clear of the seafloor at 1735 h. The drill string cleared the rotary table at 2025 h and the vessel was secured for transit. All thrusters were raised at 2136 h, and the sea passage to Site U1591 (proposed alternate Site CSK-20A) began at 2148 h, ending Hole U1590A.

The site was revisited on 10 January, with the intention of coring a rotary core barrel (RCB) hole to the target depth of 566 mbsf. At 1852 h, the vessel came onto location at Site U1590. The transit of 20.3 nmi from Site U1591 was completed in 2.4 h, for an average speed of 8.5 kt. All thrusters were down and secured at 1912 h. The ship was switched to DP control at 1924 h. The vessel was offset 50 m northwest of Hole U1590A. An RCB BHA with bit was assembled and run to 373.9 mbrf. Hole U1590B was spudded at 0030 h on 11 January and further drilled down to 93.0 mbsf. High torque was observed at 26.4 mbsf and 83.8 mbsf.

At 0700 h, RCB coring started with Core U1590B-2R from 93.0 mbsf. As expected, the recovery was extremely low in the upper sections, but the decision to use RCB was made to reach the target depth. However, due to the low recovery and as a precaution, a bit deplugger (a tool to make sure no obstructions block the bit opening) was run before dropping the core barrel for Core 12R, with no noticeable effect. Coring continued through 12 January, with recovery being mostly very poor.

Despite significant hole trouble early on, through careful coring and the liberal use of mud sweeps, the target of 566 mbsf was surpassed. On 13 January, RCB coring was completed with Core 57R to 634.7 mbsf, the final depth for Hole U1590B. Coring was terminated in favor of other objectives at the following sites. On 14 January, the bit cleared the rotary table at 0155 h and the drill floor was secured at 0215 h.

The vessel was out of DP mode and under Bridge control at 0224 h. All thrusters were brought up and secured. The sea passage started at 0230 h, ending Site U1590.

Principal Results

Cores from Hole U1590A recovered a coherent stratigraphy from 0 to 91.45 mbsf in Cores U1590-1H through 11H, and partial stratigraphy in Hole U1590B from 93.0–627.76 mbsf in Cores U1590B-2R to 57R. The recovered sediment succession in the top ~90 m is dominated by volcanic ash, lapilli-ash, and lapilli, with minor tuffaceous muds and nannofossil oozes. The recovered material from the ~540 m cored at Hole U1590B consists of calcareous ooze, mud, sand, and tuffaceous sediments with intermittent ash or lapilli layers (pumice and scoria). Smear slides were prepared for microscopic analyses and supported the macroscopic descriptions by identifying small-scale changes in lithology and componentry, such as vitric particles in tuffaceous lithologies or crystals in ash layers. Two units were identified at Site U1590: Unit I, dominantly volcanic (Hole U1590A), and Unit II, nonvolcanic, tuffaceous, and minor volcanic intervals (Hole U1590B). Within Unit I, three subunits (Ia, Ib, and Ic) were identified based on the occurrence of tuffaceous muds and oozes within the predominantly volcanic succession. Recovery was poor (<20%) in Hole U1590B, which limited the ability to observe systematic changes in lithology downcore. Nonetheless, Unit II was divided into four subunits (IIa, IIb, IIc, and IId), which were interpreted based on the recovered lithology.

Structural geology analyses at Site U1590 included the description of cores retrieved from Holes U1590A and U1590B. Structures observed and measured in the cores are bedding planes, faults, deformation bands, and foliations inside slumps. A total of 53 structures were measured from relatively consolidated intervals between 0–627.8 mbsf. In general, bedding planes were horizontal throughout the boreholes, with dips less than 10°. Minor-scale slumps characterized by oblique foliation of sand-mud mixed layers were identified below 460 mbsf in Hole U1590B. Some minor faults and deformation bands were apparent on split core surfaces and were developed below 350 mbsf. All the deformation represented cohesive (“healed”) fault planes with closed fault planes.

Calcareous nannofossils and planktic and benthic foraminifers were examined from core catcher samples and additional split-core samples from Hole U1590A to develop a shipboard biostratigraphic framework for Site U1590. Additionally, benthic foraminifers provided data on paleowater depths, downslope reworking, and possible dissolution. Site U1590 cored the flank of the Kolumbo submarine volcano sedimentary sequence and recovered a thick Holocene to early Pleistocene sequence comprised primarily of volcanogenic sediments and calcareous oozes. Calcareous nannofossils and planktic foraminifers are typical of Holocene to early Pleistocene sediments. Hole U1590A recovered Holocene–late Pleistocene aged sediments, and Hole U1590B recovered late Pleistocene to early Pleistocene aged sediments. Low and only intermittent recovery in Hole U1590B made it difficult to construct a record of oceanicity and paleowater depth. All samples show a significant number of reworked microfossils, probably from outcrops on the surrounding islands.

Hole U1590A was drilled to a depth of 99.3 mbsf. Hole U1590B suffered from very low recovery in the first 17 cores, so the recovered interval began at 209 mbsf. Therefore, no stratigraphic correlation was possible.

Volcaniclastic materials (ash, lapilli-ash, and lapilli) in the upper 90 m at Site U1590 exhibit large variations in magnetic susceptibility. These subunits (as identified by the lithostratigraphy group) sometimes have low grain densities, less than 2.0 g/cm^3. At depths between 300 and 370 mbsf in Unit II muds and oozes, there are cyclic variations in natural gamma radiation. Poor recovery in both Holes U1590A and U1590B significantly limit the ability to document continuous variations in physical properties measurements over more than several tens of meters.

To determine the geochemistry of the volcaniclastic material at Site U1590, 11 and 4 samples were handpicked from volcaniclastic layers in Holes U1590A and U1590B, respectively. These volcaniclastic materials were cleaned, ground, fused, and dissolved. Shipboard analysis 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 was completed using inductively coupled plasma–atomic emission spectroscopy (ICP-AES). Of the volcaniclastic units sampled, one was classified as a basaltic andesite and ten as dacites. As expected, bulk chemistry values are less evolved than glass chemistry 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 most samples. Trace element ratios were used to broadly discriminate between the volcanic centers of Kolumbo and Santorini.

To determine the inorganic constituents of interstitial water (IW), five water samples were taken (one mudline sample and four from whole-round squeezing of sediment intervals) at Site U1590 in Hole U1590A and seven water samples (all from whole-round squeezing of sediment intervals) in Hole U1590B, mainly from sections dominated by calcareous ooze, but with volcanic input. Aliquots of IW were used for shipboard analyses, and the remaining water was taken for shore-based analysis. The retrieved IW was analyzed for salinity, alkalinity, and pH. Shipboard analysis of major anions (Cl^-, SO_4^{2-}, and Br^-), 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 was completed for all samples.

Headspace gas analyses were performed at a resolution of one sample per full-length core (9.5 m advance) throughout Holes U1590A and U1590B. The aim was to monitor the presence and abundance of C1–C3 hydrocarbons as part of the standard IODP safety protocol. A total of 11 and 26 headspace gas samples were analyzed by gas chromatography (GC) for Holes U1590A and U1590B, respectively. Methane is the dominant hydrocarbon present throughout both holes. The data show low methane concentrations in Hole U1590A (between 0.71 and 2.25 ppmv), with values below detection limit at 81.3 and 89.8 mbsf. Methane concentration was below detection limit throughout all depths of Hole U1590B. Ethane concentrations were below the detection limit for all samples measured in both Holes U1590A and U1590B.

Paleomagnetic analysis at Site U1590 focused on measurement and demagnetization of archive section halves and 31 discrete samples to determine magnetostratigraphic age controls. The low overall recovery in Hole U1590B resulted in a restricted distribution of magnetic data downhole and no reversal boundaries could be established. Nevertheless, by referring to biostratigraphic age constraints it was possible to make the useful correlations with the geomagnetic polarity timescale.

Due to the instability of the formations encountered, downhole logging was not conducted at Site U1590.