IODP Expedition 398: Hellenic Arc Volcanic Field

Site U1589 Summary

Background and Scientific Objectives

Site U1589 (proposed Site CSK-01A) lies 10 km southwest of the Greek Amorgos Island within the NE–SW-trending Anhydros Basin. The basin is a half-graben with a volcano-sedimentary fill that proved during drilling to be 600 m thick to acoustic basement at this site.

The site was chosen as it is situated on a sediment distribution pathway that leads downstream from both Santorini and Kolumbo volcanoes. It was therefore expected that the site would receive volcaniclastic material from both volcanic systems as turbidity currents directed by the basin bathymetry and as tephra fallout controlled by high-altitude wind patterns.

The aim of drilling at this site was to accomplish the following objectives:

- Fingerprint the volcaniclastic layers at the site.
- Correlate them using chemical and mineralogical criteria with their source volcanoes.
- Establish a complete stratigraphy for Santorini and Kolumbo and how they interrelate.
- Seek links between volcanic activity and the tectonic history of the Anhydros Basin as recorded on seismic profiles.

Core recovery in both advanced piston corer/extended core barrel (APC/XCB) Holes U1589A and U1589B was 83%, and for the rotary core barrel (RCB) Hole U1589C it was 24%. The good recovery in Holes U1589A and U1589B led to the construction of a preliminary splice with only a few gaps. A large set of biostratigraphic constraints enabled us also to construct a detailed age-depth model for the site, with many paleobathymetric estimates from benthic fauna. The site also enabled us to reconstruct a near-complete volcanic stratigraphy consistent with both onshore and offshore constraints and pinned by chronological markers from biostratigraphy, magnetostratigraphy, and some astronomically tuned sapropel records. The lithologies encountered included hemipelagic muds, volcaniclastics, turbidites, and basement limestones.

Operations

We started our 1241 nmi voyage across the Mediterranean Sea to Aegean Sea Site U1589 at 1254 h local time on 16 December 2022 in Tarragona, Spain, and completed the transit on 21 December at 0715 h.

The bottom-hole assembly (BHA) and drill string were assembled and lowered to the seafloor at 484.3 meters below sea level (mbsl). Using the APC, half-length APC (HLAPC), and XCB, Hole

U1589A had a cored interval of 446.7 m, recovering 350.55 m of volcaniclastic and hemipelagic to pelagic sediments.

Hole U1589B was spudded in a water depth of 482.6 mbsl and recovered 331.46 m of volcaniclastic sediments, reaching a maximum depth of 381 meters below seafloor (mbsf).

To measure the formation temperatures, the advanced piston corer temperature (APCT-3) tool was deployed during Cores U1589A-4H, 7H, 10H, and 13H, and Cores U1589B-5H, 6H, 11H, and 14F. At the base of Core U1589B-70F, the Sediment Temperature 2 (SET2) probe was deployed to analyze the formation temperature at the bottom of Hole U1589B.

The BHA for RCB coring was assembled and tripped back down to the mudline, spudding Hole U1589C in a water depth of 482.6 mbsl at 2304 h on 26 December. The first 360 m of Hole U1589C were drilled without recovery and continued at a depth 20 m above the base of Hole U1589B. Cores U1589C-2R to 28R were recovered. Beginning in Core 25R, we began to recover pebbles of limestone. Coring continued to Core 28R with all cores containing limestone pebbles. The basement depth was determined at a depth of 589 mbsf. Following Core U1589C-28R, coring in Hole U1589C ended. In total, coring in Hole U1589C recovered 62.08 m of sediments, volcaniclastic rocks, and limestone basement, reaching a total depth of 621.9 mbsf.

The hole was prepared for downhole logging, and the triple combo was assembled. During logging run #1, the tools encountered an obstruction at 544.9 mbsf that could not be passed. After a quick logging run up and down again, the tool got stuck at 227.7 mbsf. The remainder of onsite operations was spent retrieving the logging tools.

After tool recovery, the drill string was found to be stuck. After several attempts to free the pipe, the decision was made to sever the string during the late evening on 30 December, and the line was successfully severed. At 1800 h on 31 December, the rig floor was secured for transit. All thrusters were up and secured, and sea passage to Site U1590 (proposed Site CSK-03A) started at 1818 h.

Principal Results

Cores from three consecutively cored holes at Site U1589 (U1589A, U1589B, and U1589C) recovered a coherent stratigraphy from 0 to 612.4 mbsf. There is very good overlap between Holes U1589A and U1589B. Hole U1589C begins near the bottom of Holes U1589A and U1589B and overlap is minimal, with penetration to the alpine basement. The majority of the recovered core is sedimentary, dominated by ash, lapilli, lapilli-ash, and tuffaceous mud in the uppermost Unit I; calcareous/nannofossil oozes and muds below in Unit II; shell-bearing siliciclastic sediments in Unit III; altered sands and conglomerates in Unit IV; and in Unit V, limestone basement below 589 mbsf.

The first four units (I–IV) are distinguished from each other based on the presence or absence of volcanic material, calcareous nannofossils, shell fragments, and the level of red-hued oxidation and matrix carbonation. Smear slides for microscopic analysis were prepared often to confirm macroscopic observation of distinct lithology changes at the section level, such as observation and abundances of vitric particles in tuffaceous lithologies. The upper and lower boundaries of each lithostratigraphic unit are defined by lithologic changes that are usually accompanied by a change in physical properties, e.g., magnetic susceptibility.

Unit I consists primarily of tuffaceous mud intercalated with intervals of ash, lapilli-ash, and lapilli, punctuated by less abundant non-tuffaceous mud and ooze intervals. Unit II primarily consists of muds and oozes, interspersed with intermittent volcanic layers and possible sapropels. Unit III is distinguished from Unit II by a gradual increase in both grain size and shell content. It consists primarily of sand with ash and shells interspersed with calcareous mud and possible sapropels. Unit IV consists of intercalated sand and matrix-supported breccia showing brown to reddish colors. The fifth lithostratigraphic unit, Unit V, is a lithified limestone unit that is the basement rock on which the above-lying sediments were deposited.

Structural geology analyses included descriptions of cores retrieved from all holes. Features observed and measured in the cores include bedding planes, faults, carbonate veins, and breccia. A total of 230 structures were measured, and most of those measurements come from relatively consolidated intervals. Where possible, we corrected the measurements of planar and linear structures to true geographic coordinates using paleomagnetic data.

Calcareous nannofossils and planktic and benthic foraminifers recovered from core catcher samples and additional split-core samples from Holes U1589A, U1589B, and U1589C were used to develop a shipboard biostratigraphic framework for Site U1589. Calcareous nannofossils and planktic foraminifers provided good age resolution throughout the Pleistocene sediments. Ages provided by benthic foraminifers were also consistent with those of calcareous nannofossils and planktic foraminifers. The data indicate highly variable sedimentation rates in different parts of the basin fill. In addition, benthic foraminifers provided data on paleowater depths.

To establish the depth scale using core composite depth below seafloor, Method A (CCSF-A), we analyzed Holes U1589A and U1589B for their physical properties using the Whole-Round Multisensor Logger (WRMSL; for magnetic susceptibility [MS], gamma ray attenuation [GRA] bulk density, and *P*-wave velocity), the Natural Gamma Radiation Logger (NGRL), and the Section Half Multisensor Logger (SHMSL; for MS and color reflectance), as well as photos once the cores were split into working and archive halves. In general, we found that MS was the most reliable physical parameter for correlations, while NGR and GRA density measurements were often significantly overprinted by the irregular distribution of core material in cores with low recovery and a high content of water. MS also proved to be an excellent proxy for the presence of volcanic material in the cores. We spliced selected sequences from Holes U1589A and U1589B to create the composite depth scale and added the additional, but scattered, parts of Hole U1589C to create the most complete and representative section possible.

Downhole variations in physical properties arise from changes in lithology, compaction, and other diagenetic processes. Differences between volcanic and other lithologies are most prominent in MS owing to the abundance of ferromagnetic minerals (e.g., magnetite) in volcanic (high) and hemi-/pelagic (low) sediments. While density is expected to increase progressively with increasing depth owing to compaction, low density pumice deposits and unconsolidated ash layers between compacted biogenic ooze create a more complex porosity structure throughout the drilled formation. Similarly, shear strength and thermal conductivity both increase with depth, but are often reduced in volcaniclastic units relative to adjacent materials. In general, at this site volcaniclastic units have higher MS, lower *P*-wave velocity, and lower density than other sediments at the same depth. Physical property measurements thus can be used to interpret downhole wireline logging data and to help identify thin ash and pumice layers in mostly biogenic, compacted sediment.

To determine the geochemistry of the volcaniclastic layers, 17 tephra and ash samples were handpicked from various layers at Hole U1589A. Following cleaning, grinding, fusion, and dissolution, the volcaniclastic material was analyzed shipboard for major, minor, and trace elements using inductively coupled plasma–atomic emission spectroscopy (ICP-AES). Trace element ratios were used to broadly discriminate between the volcanic centers of Kolumbo and Santorini. These correlations were tentative, because the analytical precision of certain trace elements such as Nb are not very good on the shipboard ICP instrument, limiting our ability to discriminate between compositionally similar volcanic sources.

To determine the inorganic constituents of interstitial water (IW), 47 water samples were squeezed from whole-rounds of sediment intervals at Site U1589 in Holes U1589A, U1589B, and U1589C. Salinity of the IW varies throughout the succession. IW concentrations of Ca, Mg, K, and SO_4^{2-} show downhole variations that are strongly correlated with lithology. Salinity, Cl^-, Br^-, SO_4^{2-}, Na^+, and K^+ all peak at the same level in Unit II. Methane is the dominant hydrocarbon present with generally low concentrations. Ethane, propane, butane, and other heavier hydrocarbons are either low or below detection.

Paleomagnetic analyses at Site U1589 focused on measurement of the remanent magnetization of archive-half sections on the superconducting rock magnetometer (SRM) before and after alternating field (AF) demagnetization. Natural remnant magnetization (NRM) of archive-half core sections from all holes was measured to provide the magnetostratigraphy of Site U1589 and followed stepwise demagnetization of the archive halves using the SRM. Analyses of the archive halves were complemented by analyses on discrete cubic specimens taken from working-half core sections. Detailed analysis revealed several instances of so-called gyroremnant magnetization that point to the presence of greigite (Fe_3S_4), a characteristic diagenetic mineral. Identifying and understanding these intervals significantly helped to gain a better overview of intervals with true magnetic excursions and reversals vs. intervals with a diagenetic overprint.

Downhole wireline logging characterizes subseafloor lithologies and their structures. It is especially important to fill gaps at depth intervals where XCB and RCB coring may retrieve cores with lower recovery in stiff sediments, boulder deposits, and basement rocks. A suite of downhole logging tools provides continuous physical properties data in situ at sampling intervals ranging from 2.5 mm to 0.15 m. These data help with the interpretation of lithostratigraphy, formation fluid properties, and measured temperatures. Downhole logs are ultimately used to conduct multiscale correlations of data acquired throughout and beyond Expedition 398 by bridging measurements on discrete sample/whole and/or half core and various regional-scale data, including seismic reflection records. After drilling operations in Hole U1589C, we deployed the triple combo logging string, equipped with the Hostile Environment Natural Gamma Ray Sonde (natural gamma radiation; HNGS), Hostile Environment Litho-Density Sonde (HLDS), High-Resolution Laterolog Array ~~tool~~ (electrical resistivity; HRLA) tool, and the Magnetic Susceptibility Sonde (MSS). For all sensors, we got one complete downhole log to 544.9 mbsf, as well as two partial uphole log runs. The tool got stuck at 227.7 mbsf, but it was recovered successfully several hours later. Analysis of all data, measured in a 5 cm interval, shows a very high degree of correlation to shipboard logging track data and provides a nearly complete record for Hole U1589C.