IODP Expedition 398: Hellenic Arc Volcanic Field

Site U1592 Summary

Background and Scientific Objectives

Site U1592 is located ~10 km southeast of Anhydros Island within the Anafi Basin in a water depth of 693 meters below sea level (mbsl). The aim at the site was to penetrate the entire volcano-sedimentary fill as far as the Alpine basement in order to reconstruct the evolution of the Anafi basin: history of subsidence, the presence of volcanic event layers in the basin sediments, and links between volcanism and crustal tectonics. Drilling strategy involved two holes using the advanced piston corer (APC) and extended core barrel (XCB) and possibly spot coring within Hole U1592B.

The basin potentially records the full volcanic history of Santorini (and any older centers) since rift inception, but was also envisaged probably to contain few eruptive products from Kolumbo. Drilling would enable reconstruction of the volcanic, sedimentary, and tectonic histories of the Anafi basin, allowing us to compare its evolution with that of the Anhydros Basin. Previously published analyses of the seismic data suggested the following possible interpretations:

- Units U1 and U2: Sediment packages predating Santorini and Kolumbo volcanism.
- Unit U3: Sediments and the products of early Kolumbo volcanism and some of the Kolumbo cones.
- Unit U4: Sediments associated with a major rift pulse.
- Units U5 and U6: Sediments and the products of Santorini activity, some of the Kolumbo cones, and the later eruptions of Kolumbo including the 1650 CE eruption.

Units U3 to U6 were believed to be of Pleistocene age~~,~~ and units U1 and U2 of possibly Pliocene age.

The site would enable us to test this hypothesis by using the cores to reconstruct a near-complete volcanic stratigraphy consistent with both onshore and offshore constraints and pinned by chronological markers from biostratigraphy, magnetostratigraphy, and astronomically tuned sapropel records. Benthic foraminifers from fine-grained sediments could provide estimates of ancient water depths and, via integration with seismic profiles and chronologic data, of time-integrated basin subsidence rates.

Coring at Site U1592 in the Anafi Basin addressed scientific objectives 1–4 and 6 in the Expedition 398 *Scientific Prospectus*. It is complemented by Site U1589 in the Anhydros Basin, because each basin taps a different sediment distributary branch of the Christiana-Santorini-Kolumbo volcanic system.

Operations

The operations involved two holes, but with a switch to the rotary core barrel (RCB) for Hole U1592B, following slow progress with the XCB. Hole U1592A was advanced using the APC and the half-length advanced piston corer (HLAPC) to 339.2 meters below seafloor (mbsf). Hole U1592B used the RCB to 527.8 mbsf, with an initial 293.0 m drilled interval. Downhole logging was not attempted, as there were several sections of the same loose, unconsolidated layers that had been causing problems at earlier sites.

On 14 January 2023, the rig crew proceeded to make-up the APC/XCB bottom-hole assembly (BHA) with a used bit. Hole U1592A was spudded at 0830 h from 700 meters below rig floor (mbrf) at 36°33.9358′N, 25°45.6784′E. Core U1592A-1H recovered 5.1 m, giving a calculated seafloor of 693.1 mbsl. APC was continued to Core 16H from 135.3 mbsf, but the last three cores suffered partial strokes. Coring was switched to the HLAPC with Core U1592A-17F. HLAPC continued into 15 January with Core 45F to 273.8 mbsf, where the barrel became stuck. Overpulls up to 50,000 lb were ineffective. In attempting to drill over the barrel, the drill pipe became stuck, with indications the hole was filling in. The drill pipe was worked free and eventually the barrel was freed with 120,000 lb overpull.

At 1330 h, an XCB barrel was dropped and coring reconvened with Core U1592A-46X from 273.8 mbsf. Coring continued into 16 January to Core U1592A-55X at 339.2 mbsf, the final depth for Hole U1592A. The rate of penetration (ROP) for the XCB was slowing to ~4 m/h, and the decision was made to switch to RCB. At 0730 h on 16 January, XCB coring was terminated. The drill string was tripped out with the top drive from 339.2 mbsf to 285.5 mbsf. The top drive was racked back and the pipe trip continued. The bit cleared the rotary table at 1120 h, ending Hole U1592A.

On 16 January at 1120 h, the crew began assembling the RCB BHA with bit. Meanwhile, the vessel was offset 50 m southeast of Hole U1592A.

Hole U1592B was spudded at 1600 h at 36°33.9164′N, 25°45.7027′E. The seafloor depth was again 693.1 mbsl measured by offset. A drill ahead without core recovery commenced to 293.0 mbsf with several mud sweeps.

The driller started RCB coring with Core U1592B-2R from 293.0 mbsf. Cores U1592B-8R through 13R had almost no recovery and were assumed to be a pumice layer judging from the seismic profiles. Core U1592B-11R was a “punch” core, a 2 m advance with little to no rotation or pump, to try to recover some of the difficult pumice section. The recovery was still very poor but measurable, as it recovered a handful of the pumice lapilli. Following Core U1592-12R, the drill string became stuck, requiring several minutes, 100,000 lb overpull, and two mud sweeps to come free.

Coring continued into 18 January until 1545 h with Core U1592B-26R recovered from 527.8 mbsf, the final depth for Hole U1592B. The bit cleared the rotary table at 2001 h and the

rig crew secured the floor for transit. The thrusters were raised, beginning at 2048 h. The vessel was out of dynamic positioning (DP) control at 2052 h. All thrusters were up and secure and the sea passage started at 2100 h, ending Site U1592.

Principal Results

Cores from Site U1592 recovered a fairly coherent stratigraphy from 0 to 518.92 mbsf. Hole U1592A consists of Cores U1592-1H through 55X (0–338.35 mbsf). Hole U1592B consists of Cores U1592-2R through 26R (293.0–518.92 mbsf). Recovery at Hole U1592B began at 293.0 mbsf, with the goal of overlapping with the bottom of Hole U1592A to get better sediment recovery using the RCB, and then continuing to core deeper in the section.

The recovered material is unlithified sediment, dominated by volcanic and tuffaceous material in the upper 266 m with fewer nonvolcanic lithologies (Lithostratigraphic Unit I), which transitions to dominantly ooze and other nonvolcanic lithologies interspersed with minor volcanic and tuffaceous sediments between 138–403.93 mbsf (Lithostratigraphic Unit II). The following ~90 m are composed of dolomitic mud and sand with shell fragments (Lithostratigraphic Unit III), which transitions into a thin (~15 m) unit of bioclastic limestone (Lithostratigraphic Unit IV). Approximately 10 m of limestone and marble were recovered within Lithostratigraphic Unit IV. The limestone and marble unit was defined as basement, and designated Lithostratigraphic Unit V. 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. Within Unit I, the succession of volcanic layers and tuffaceous or nonvolcanic layers defines four subunits (Ia, Ib, Ic and Id). These subunit distinctions were corroborated by physical property data, i.e., magnetic susceptibility (MS) and natural gamma ray (NGR).

Structural geology analyses included description of cores retrieved from Holes U1592A and U1592B. A total of 323 structures was measured, and most of those measurements derived from relatively consolidated intervals. Observed and measured structures on cores are bedding, faults, deformation bands, and sediment veins. The precision of shipboard measurements equaled 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 were 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 foraminifers, benthic foraminifers, and calcareous nannofossils were examined from 72 core catcher samples and additional split-core samples from Holes U1592A and U1592B to develop a shipboard biostratigraphic framework for Site U1592. Additionally, benthic foraminifers provided data on paleowater depths, downslope reworking, and possible dissolution.

Site U1592 drilled the Anafi Basin sedimentary sequence and upper portion of the limestone and marble basement, recovering a 518.92 m thick Holocene to early Pleistocene sequence of variable lithology. Calcareous nannofossils and planktic foraminifers provided good resolution in the Holocene through the early Pleistocene sediments. Ages provided by benthic foraminifers were inconsistent with those of planktic foraminifers and calcareous nannofossils and consequently were not used. Additionally, due to the high sedimentation rates through much of the cored section, semiquantitative planktic foraminiferal assemblage data were used in conjunction with calcareous nannofossil and planktic foraminiferal biostratigraphic datums to tentatively assign Marine Isotope Stage boundaries. These were based primarily on fluctuations of the warm water species *Globigerinoides ruber*, *Globigerinoides elongatus*, and *Globigerinoides pyramidalis*.

The stratigraphic correlators identified several correlations in the overlapping core sections between 293 and 339.2 mbsf, mainly based on the MS and NGR measurements derived with the Whole-Round Multisensor Logger (WRMSL) as well as on half core images. Those correlations were used to determine affine ties between both holes and to apply some minor shifts to the cores that did not exceed 6 m.

Physical properties at Site U1592 were correlated with lithology and respective units. The topmost volcaniclastic Subunit Ia had low NGR counts and high MS relative to other volcaniclastic units. Grain densities are as low as 1.9 g/cm^3, in coarse, pumice-rich deposits. Volcaniclastic layers in Subunit Ic had lower MS and a factor of two higher values for NGR than Subunits Ia and Ib. Subunit Id exhibited large variations in MS and often had high MS compared to other sediments at this site. In Unit II, which is dominated by nannofossil-rich oozes, *P*-wave velocity increased with depth, NGR was low, and MS was low except where thin volcaniclastic layers have high MS. The dolomitic and siliciclastic layers of Unit III often displayed cyclic variations in NGR that were correlated with organic-rich layers. Limestones and marbles in Units IV and V had higher *P*-wave velocity, thermal conductivity, and bulk density, and lower NGR, than Units I–III.

To determine the geochemistry of the volcanic and tuffaceous materials, nine tephra and ash samples were hand-picked from various layers within Hole U1592A. 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). Several samples were run multiple times to determine analytical reproducibility.

Of the volcaniclastic units sampled, two were classified as basaltic andesites, two as andesites, and five as dacites. 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 32 water samples were taken from the mudline and whole-round squeezing of sediment intervals at Site U1592 in Holes U1592A (19 samples) and U1592B (13 samples). Aliquots of IW were used for shipboard analyses, and the remaining water was taken for shore-based analysis, following protocols specified by individual scientists. The retrieved pore 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 U1592A. The aim was to monitor the presence and abundance of C1–C3 hydrocarbons as part of the standard IODP safety protocol. A total of 40 headspace gas samples from this hole were analyzed by gas chromatography (GC). Methane, ethane, and propane concentrations are below the detection limit throughout Hole U1592A. Headspace gas analyses were resumed on Hole U1592B when a depth was reached that was deeper than that of Hole U1592A, which occurred at 345.27 mbsf. Below this depth, headspace gas analyses were performed at a resolution of one sample per core or one sample every other core for half-length cores to the base of the hole. A total of 11 headspace gas samples were analyzed by GC. Methane, ethane, and propane concentrations are below the detection limit throughout Hole U1592B.

Paleomagnetic analysis at Site U1592 focused on measurement and demagnetization of archive section halves to determine magnetostratigraphic ages controls. The upper 82 m of the sequence sampled at Hole U1592A carries normal polarity remanences acquired during the Brunhes chron. Beneath this, the cores recovered from Hole U1592A were unsuitable for paleomagnetic measurement. The interval from ~270–348 mbsf in Hole U1592B is also normally magnetized and assigned to the Brunhes Chron. The Brunhes/Matuyama transition (0.773 Ma) was not recovered, but the sequence below 400 mbsf exhibits changes in magnetic polarity, allowing three reversal boundaries to be tied precisely to the geomagnetic polarity timescale (corresponding to the start/end of the Jaramillo subchron at 1.008/1.076 Ma and the start of the Cobb Mountain normal polarity subchron at 1.189 Ma in the Matuyama Chron).

Due to the instability of the formations encountered, downhole logging was not conducted at Site U1592.