

IODP Expedition 398: Hellenic Arc Volcanic Field

Site U1595 Summary

Background and Scientific Objectives

Site U1595 (proposed Site CSK-08B) is located in the southern basin of the Santorini Caldera. It lies at a water depth of 292 meters below sea level (mbsl), and was drilled at three holes to 127.1 meters below seafloor (mbsf) with average hole core recoveries ranging from 46% to 73%.

The four caldera sites (U1594–U1597) were planned to sample intracaldera seismic Units S1–S3, to test the published correlations between the two caldera basins, to penetrate below Unit S3 (seismic Unit S4), and to address scientific objectives 1, 4, 5, and 7 of the Expedition 398 *Scientific Prospectus*. The seismic units were thought probably to consist of (S1) muds and sands from cliff mass wasting, (S2) compacted (possibly lithified) sandy volcanoclastics from Kameni Volcano, and (S3) consolidated coarse blocky tuffs, landslide debris and/or flood gravels. Seismic Unit S4 may be intracaldera tuffs. The goals were to ground truth the different seismic units, document the processes, products, and potential impacts of the Late Bronze Age (LBA) eruption, reconstruct the eruptive history of Kameni Volcano, penetrate below Unit S3, and discover the nature of Unit S4. The combined approach of drilling in the northern and southern caldera basins would enable us to test several hypotheses regarding the LBA caldera-forming eruption of Santorini. By drilling both caldera basins and exploiting our dense seismic reflection coverage, we would gain access to the 3D architecture of the entire caldera fill and better understand the relative roles of downfaulting and downsagging in the LBA caldera collapse. We would also target the question of why the northern basin is 100 m deeper than the southern one, with a thicker seismic Unit S1 but thinner seismic Unit S3. Finally, we would be able to test whether seismic Unit S3 consists of flood debris from the caldera-flooding event or whether it represents LBA intracaldera tuffs. The intracaldera sites would be used for the microbiological work of objective 7.

Operations

With the dynamic positioning (DP) move completed from Site U1594 at 0530 h on 23 January 2023, Hole U1595A (36°22.8955'N, 25°24.3630'E) was spudded at 0635 h. With a shot depth of 297.0 meters below rig floor (mbrf), Core U1595-1H recovered 3.6 m, and the calculated seafloor was 291.6 mbsl.

Advanced piston corer (APC) coring continued to Core U1595A-11H at 98.6 mbsf, the final depth for Hole U1595A. At 1315 h, while laying out Core U1595A-11H, the hole packed off suddenly. The fluid backpressure in the drill pipe exceeded 3400 psi within 1–2 s. The relief valve on both mud pump #1 and #2 ruptured. The pressure spike also sent the sinker bars up into

the rig, slamming into the oil saver, knocking it off and up into the top drive. With no core barrel in the pipe since the operation was planned to be switched to half-length advanced piston corer (HLAPC), the sinker bars were lost in the hole. The driller was still able to rotate the pipe, but there was no pressure. Lifting off the elevator showed the pipe to be stuck vertically as well. The mud pump relief valve discs were replaced, and the pumps were put back online. The driller started applying pressure, but the hole still appeared to be packing off, with intermittent pressure spikes lower than before, never exceeding 2800 psi.

An attempt to free the oil saver using the forward coring line sinker bars to drive it down was unsuccessful. However, the drill string was worked free. The drill string was pulled out of the hole with the top drive from 89.1 mbsf to 271.2 mbrf, with the bit clearing the seafloor at 1636 h. With the drill string out of the hole, the rig crew eventually was able to remove the oil saver after ~2 h. The bit cleared the rotary table at 2131 h. At 2300 h on 23 January, the vessel began a DP move to Site U1596 (proposed Site CSK-06B) in the northern portion of the Santorini Caldera, ending Site U1595.

The ship returned to Site U1595 at 0415 h on 2 February. The vessel was under DP control at 0440 h. The rig crew began assembling the bottom-hole assembly (BHA). From 0745 h to 0915 h, the vessel was on standby awaiting media and guests. The launch was alongside the vessel at 0900 h. Eight persons boarded via the pilot's ladder. The launch was away at 0915 h. Safety orientations for the oncoming visitors were completed and the film crews set up their equipment at the drill floor, catwalk, and in the laboratory.

Hole U1595B was spudded at 1010 h, 50 m from Hole U1595A. Core U1595B-1H was shot from 297.0 mbrf and recovered 3.7 m. The seafloor was calculated at 291.4 mbsl. Coring continued with the APC from Cores U1595B-2H to 13H. A 130,000 lb overpull was observed on Core 13H. The bit was advanced from 108.2 mbsf to 117.7 mbsf. The eight guests disembarked to the launch just after 1415 h. The launch was away at 1425 h.

At 1900 h, the HLAPC was deployed for Cores U1595B-14F to 15F to 127.1 mbsf, the final depth for Hole U1595B. The decision was made to terminate the hole due to maximum overpull and high amps on the bit advance. The drill string was tripped up with bit clearing the seafloor at 2320 h, ending Hole U1595B.

The vessel was again offset 50 m southwest along the seismic line toward proposed Site CSK-18A. Hole U1595C (36°22.8674'N, 25°24.3062'E) was spudded at 0005 h on 3 February, with Core U1595C-1H shot from 297.0 mbrf. The recovery of 3.8 m established the seafloor at 291.3 mbsl. A center bit was dropped for a 49.2 m drilled interval. With the drill down completed to 53.0 mbsf, coring was picked up again, with the HLAPC from Cores U1595C-3F to 11F to 95.3 mbsf.

A launch with fifteen guests and media arrived at 0910 h. After the visitors boarded via the ladder, the launch was away at 0920 h. Interviews and filming continued, primarily in the laboratory, the bridge, and on the forward fo'c's'le deck.

After Core U1595C-11F, the plan was to drill ahead to 104 mbsf and resume coring. However, high torque led to the drill string stalling. A 100,000 lb overpull was applied with no success. The drill pipe was worked, and after about ~30 min it regained rotation. The decision was made to abandon the hole.

The string was pulled out of the hole with the top drive, clearing the seafloor at 1115 h. The bit cleared the rotary table at 1347 h and the rig floor was secured for transit at 1415 h. Just after 1410 h, the fifteen guests disembarked to the launch. The launch was away at 1430 h. The DP move to Site U1596 (proposed Site CSK-06B) in the northern caldera began.

Principal Results

Cores from Site U1595 recovered coherent stratigraphy from 0 to 126.93 mbsf. The recovery of Hole U1595C is fragmentary.

The recovered material is unlithified sediment, dominated by volcanic material with very minor amounts of mud and tuffaceous mud in the upper 1 m of Holes U1595A and U1595B. Smear slides for microscopic analyses were prepared to confirm macroscopic descriptions of distinct lithology changes at the section level, such as the identification of vitric particles in tuffaceous lithologies or crystals in ash layers. X-ray diffraction (XRD) data were obtained from 12 interstitial water (IW) squeeze cake sediment residues from Holes U1595A, U1595B, and U1595C.

Structural geology analyses at Site U1595 included description of cores retrieved from all three holes. A total of 23 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°–2° per single measurement. Deformation related to drilling and core recovery was noted, but not recorded.

Foraminifers and calcareous nannofossils were examined from core catcher samples from Hole U1595A to assess the paleoenvironmental conditions of Site U1595. Additionally, benthic foraminifers provided data on paleowater depths and possible dissolution. No calcareous nannofossils or planktic foraminifers were found in core catcher samples; however, very rare benthic foraminifers and ostracods were found, though assemblage abundances were insufficient to permit paleoenvironmental analyses.

To establish a composite depth scale, Holes U1595A–U1595C were analyzed for their physical properties using the Whole-Round Multisensor Logger (WRMSL) for magnetic susceptibility (MS) and gamma ray attenuation (GRA) and the gamma ray track (for natural gamma ray [NGR] intensity), as well as core section photos. In general, correlation was very challenging at this site and only the MS data allowed several reliable correlations, while NGR and GRA density measurements were strongly overprinted by the irregular distribution of core material in cores with low recovery and a high content of water. All three holes recovered the mudline and Core U1595A-1H was used as the initial anchor for stratigraphic correlation. From thereon, the relative depth offset of each core was determined by establishing affine ties between the holes based on the maximum correlation of all measured physical properties. Once the composite depth scale was established, selected sequences from Holes U1595A to U1595C were spliced to create the most complete and representative section possible. From the mudline down to ~69 mbsf, the splice is continuous. The recovery became sparse below ~69 mbsf and the splice contains larger gaps below this depth.

There is a general trend of increasing bulk density and MS with increasing depth at Site U1595. Thermal conductivity is lower than typical values for sediments at similar depths. The physical properties at Site U1595 resemble those at Site U1594 in the upper 50 mbsf, where the two sites overlap in depth.

Sediment strength was measured with a pocket penetrometer on the catwalk immediately after cutting the sections. Automated vane shear (AVS) measurements were made on working half sections. Because volcanoclastic materials are not suitable for these measurements, few measurements could be made. A total of 204, 173, and 61 *P*-wave velocity measurements were conducted on working half sections for Holes U1595A, U1595B, and U1595C, respectively. A total of 38 discrete samples were collected for moisture and density (MAD) measurements.

To determine the geochemistry of the volcanic and tuffaceous materials, two tephra samples were handpicked from various layers within Hole U1595A. 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 volcanoclastic units sampled, both were classified 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 discriminate broadly between the volcanic centers of Kolumbo, Santorini, and Christiana.

To determine the inorganic constituents of IW, a total of five water samples were taken from the mudline and whole-round squeezing of sediment intervals at Site U1595. Aliquots of IW were used for shipboard analyses, and the remaining water was taken for shore-based analysis. 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) throughout Holes U1595A and U1595B with one sample taken per half-length core in Hole U1595B. The aim was to monitor the presence and abundance of C1–C3 hydrocarbons as part of the standard IODP safety protocol. A total of 14 headspace gas samples from this site were analyzed by gas chromatography (GC). Methane, ethane, and propane concentrations are below the detection limit through all holes. Concentrations of heavier hydrocarbons (*iso*-butane, *n*-butane, and *n*-pentane, etc.) were below the detection limit throughout.

Only five core sections from two cores (U1595A-7H and 8H) recovered at Site U1595 were suitable for paleomagnetic analysis using the superconducting rock magnetometer (SRM) system. Alternating field (AF) demagnetization of these sections yielded data at 242 intervals between 54.96–62.02 mbsf. Magnetizations generally decayed linearly to the origin following removal of a drilling-induced component of magnetization after demagnetization. The interval analyzed is therefore assigned to the Brunhes Chron, consistent with the age of the Santorini Caldera.

Microbiological analysis was conducted on 14 whole-round samples from Holes U1595B and U1595C. The whole round samples were split into 98 subsamples. Most of the microbiological analyses will be conducted on shore, but the first culturing experiments indicate the presence of the iron oxidizing bacterium, *Mariprofundus ferroxydans*.

Due to the instability of the formations encountered, downhole logging was not conducted at Site U1595.