IODP Expedition 398: Hellenic Arc Volcanic Field

Site U1600 Summary

Background and Scientific Objectives

Site U1600 is located 10 km south of Anhydros Island within a small graben atop the Anhydros Horst. The Anhydros Horst separates the Anhydros Basin to the west from the Anafi Basin to the east. The water depth is 326 meters below sea level (mbsl). Site U1600 was drilled at three holes (Holes U1600A, U1600B, and U1600C) for a total penetration of 188.5 meters below seafloor (mbsf) with average hole recoveries of 61%, 75%, and 30%, respectively.

The site was chosen because of its position on the Anhydros Horst immediately east of the Kolumbo chain of volcanoes, and for the well stratified nature of the graben fill on seismic profiles. It was targeted to drill a condensed sequence of muds and tephra for chronology, which appeared sheltered from the large-scale mass wasting of the main basins.

Drilling at Site U1600 would enable us 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 paleowater depths and, via integration with seismic profiles and chronologic data, of time-integrated basin subsidence rates. Drilling on the Anhydros Horst addressed science Objectives 1–4 and 6 of the Expedition 398 *Scientific Prospectus*.

Operations

Hole U1600A (proposed Site CSK-24A; 36°32.6277′N, 25°39.0553′E) was spudded with Core U1600A-1H on 29 January 2023 at 0710 h. The recovery of 4.0 m gave a calculated seafloor of 326.2 mbsl. Coring continued with the advanced piston corer (APC) from Cores 2H to 4H. Prior to Core 4H, two misfires (pins did not shear) were experienced with the APC. An extended core barrel (XCB) was run as a bit deplugger. Core 4H fired on the third attempt with good recovery, but with 45,000 lb overpull and a completely fractured liner.

The switch was made to the half-length advanced piston corer (HLAPC) with Cores U1600A-5F to 10F to a depth of 60.7 mbsf. Core 10F saw an overpull of 50,000 lb. Coring was then switched to the XCB from Core 11X to 13X to 84.4 mbsf, the final depth for Hole U1600A. The recovery with the XCB system was extremely poor and the decision was made to move to Hole U1600B. The drill string was pulled up with the top drive, clearing the seafloor at 1905 h, and ending Hole U1600A.

The ship was positioned 50 m southwest of Hole U1600A. Hole U1600B (36°32.6092′N, 25°39.0311′E) was spudded with Core U1600B-1H on 29 January at 2005 h. Recovery of 6.8 m established the water depth at 326.3 mbsl. Coring switched to the HLAPC and Cores U1600B-2F to 19F were retrieved to a final depth of 91.4 mbsf. The drill string was tripped out of the hole with the top drive, clearing the seafloor at 0735 h on 30 January. The bit cleared the rotary table at 0900 h and the drill floor was secured for transit. The crew started raising the thrusters at 0954 h. The vessel was under bridge control at 0956 h, and all the thrusters were up and secure and the sea passage started at 1000 h, ending Hole U1600B.

The vessel returned to Site U1600 on 4 February. Once on site, the rig crew assembled the rotary core barrel (RCB) bottom-hole assembly (BHA). Hole U1600C (36°32.5890′N, 25°39.0067′E) was spudded at 0655 h. The hole was advanced to 75.0 mbsf. The RCB recovered Cores U1600C-2R to 14R from 75 to 188.5 mbsf, the final depth for Hole U1600C. After confirming that the basement was reached, the string was tripped up with the top drive, and the bit cleared the seafloor at 0410 h on 5 February. The bit cleared the rig floor at 0525 h. The drill floor was secured at 0548 h, the vessel was switched to bridge control and the thrusters raised starting at 0550 h. All thrusters were up and secure, starting the sea passage at 0600 h, ending Site U1600.

Principal Results

Cores from Site U1600 recovered relatively coherent stratigraphy from 0 to 184.24 mbsf. The recovered material is sedimentary and unlithified in Holes U1600A and U1600B, with a gradual transition to stiffer and more consolidated material towards the bottom of Hole U1600B. Hole U1600C consists of more consolidated sediments, as supported by higher *P*-wave velocity; however, the change from sediment to sedimentary rock was clearly identified, hence the lithology name changes from sediment (e.g., mud) to sedimentary rock (e.g., sandstone).

The upper sedimentary succession is dominated by volcanic and tuffaceous lithologies with minor intermittent intervals of nonvolcanic muds and sands (lithostratigraphic Unit I). All cores in Unit I are rich in bioclasts (shells and shell fragments), even the volcanic intervals. In cases where ash or lapilli intervals have >25% bioclasts, they are denoted by the name “bioclastic ash,” and where bioclasts were present in abundances <25%, that name became “with shells.” There are few ooze intervals in Unit I; most tuffaceous and nonvolcanic sediments are muds and sands, and the criteria for the “bioclastic” prefix and the “with shells” suffix is the same as described above. 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. X-ray diffraction (XRD) data were obtained from three interstitial water (IW) squeeze cake sediment residues from Hole U1600A, and five squeeze cake sediment residues each from Hole U1600B and Hole U1600C, respectively.

Lithostratigraphic Unit II, observed in the bottom of Hole U1600B and Hole U1600C, is a continuation of the calcareous muds and sands present in Unit I, but with two important distinctions: 1) these sediments are devoid of any volcanic and tuffaceous intervals, whereas Unit I in Holes U1600A and U1600B has abundant volcanic and tuffaceous intervals, and 2) the sediments in Unit II are almost entirely organic-rich. Given these differences, all of Hole U1600C is designated as Unit II until a sharp discontinuity with ultramafic basement rock. These basement rocks are designated as lithostratigraphic Unit III.

A total of 70 structures were measured and most of those measurements derived from relatively consolidated intervals. Observed and measured structures on cores are beddings including lamination, fault, deformation bands, breccia, and mineral veins. 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. Here we describe and provide examples of the features that were recorded.

Site U1600 recovered a 184.24 m thick Holocene to upper Pliocene sequence. Calcareous nannofossils and planktic foraminifers provide a well constrained biostratigraphy in the Holocene through upper Pliocene sediments. Ages provided by benthic foraminifers are consistent with those of planktic foraminifers and calcareous nannofossils.

To establish the composite depth scale, Holes U1600A and U1600B 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 photos. The MS data showed to be the most reliable physical parameter for correlations. Since Hole U1600C had no overlap with Holes U1600A and U1600B, no correlation was possible. Both Holes U1600A and U1600B preserved the mudline and Core U1600A-1H was used as the anchor for stratigraphic correlation. Using this anchor core, 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. In general, reliable correlations between most cores of Hole U1600A and U1600B were identified. Interruptions in the correlation occurred in ashy and tuffaceous segments, where no reliable correlations were possible. For each of these interruptions, the relative offset between untied (noncorrelated) cores derived from the core depth below seafloor, Method A (CSF-A) depth scale was used in order to keep the composite depth scale as close to the original CSF-A scale as possible.

The MS is high and highly variable in the volcaniclastic deposits and is exceptionally high in the basement, >10,000 SI. Two high *P*-wave velocity layers, correspond to lapilli-ash layers. A total of 149, 221, and 223 discrete *P*-wave velocity measurements were conducted on Holes U1600A, U1600B, and U1600C working half sections, respectively. Discrete measurements of *P*-wave velocity on working half core sections show similar downhole variations as those measured by WRMSL measurements on whole-round cores. There is no clear trend of increasing velocity with increasing depth. Rather, the highest velocities, and largest variability, are found in the volcaniclastic materials at various depths throughout the record.

A total of 25, 8, and 13 discrete samples were collected from Holes U1600A, U1600B, and U1600C, respectively, to conduct moisture and density (MAD) measurements. Bulk density derived by MAD measurements on discrete samples should be more reliable than density data from WRMSL measurements on whole-round cores though, in both cases, coring and recovery disturbances may have impacted measured values.

To determine the geochemistry of the volcanic and tuffaceous materials, seven tephra samples were handpicked from various layers within Hole U1600A. 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, two as andesites, and three 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 IW, a total of 14 water samples were taken from the mudline and whole-round squeezing of sediment intervals at Site U1600 in Holes U1600A (4 samples), U1600B (5 samples), and U1600C (5 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. Salinity ranges from 38‰–40‰. The highest salinity value of 40‰ was recorded at the mudline.

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 U1600A. Analyses were resumed on Hole U1600B when depth of penetration exceeded recovery in Hole U1600A, and in Hole U1600C when depth of penetration exceeded recovery in Hole U1600B. The aim was to monitor the presence and abundance of C1–C3 hydrocarbons as part of the standard IODP safety protocol. A total of 19 headspace gas samples from this hole were analyzed by gas chromatography (GC). Methane, ethane, and propane concentrations are below the detection limit in all measured samples.

Paleomagnetic analysis at Site U1600 focused on measurement and demagnetization of archive section halves to determine magnetostratigraphic age controls, together with demagnetization of 17 discrete samples. The upper sequence sampled at this site carries normal polarity remanences acquired during the Brunhes Chron. The interval below is marked by wide variations in inclinations estimated using automated principal component analysis, calculation of Fisher mean directions of magnetization using the data from the 15, 20, and 25 mT demagnetization steps, and inclinations of the 25 mT step. This can only be explained by variable, partial to complete diagenetic overprinting of a reversed polarity depositional remanent magnetization acquired during the Matuyama Chron by a chemical remanence acquired during a subsequent normal polarity chron.

Microbiological analysis was conducted on three whole-round samples from Site U1600. The whole-round samples were split into 21 subsamples. Most of the microbiological analyses will be conducted on shore, but 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 U1600.