IODP Expedition 397: Iberian Margin Paleoclimate

Site U1588 Summary

Site U1588 (proposed Site SHACK-10B) is the closest to the coast and the shallowest of the proposed depth transect (1339 m below sea level [mbsl]). The site is on a drift deposit formed under the influence of the lower Mediterranean Outflow Water (MOW). It lies on the broad, gently inclined middle-slope region of the Promontório dos Príncipes de Avis, on which the seismic data indicate an extensive plastered drift deposit located on the distal part of the contourite system (southwest Iberian Margin). The water depth of Site U1588 complements the sites drilled by IODP Expedition 339 in the Gulf of Cadiz (Sites U1386–U1390) and along the Portuguese margin (Site U1391) at intermediate water depths (560–1073 mbsl) to study past variations in the depth and intensity of the MOW.

Our objective at Site U1588 was to drill multiple holes to 500 m below seafloor (mbsf) to recover a continuous and complete Pliocene/Pleistocene sedimentary succession. Sedimentation rates are the highest (±20 cm/ky) of the four sites drilled during Expedition 397, which will provide a marine reference section for reconstructing climate variability at high temporal resolution (millennial to submillennial) and studying how the MOW has varied on orbital and millennial time scales.

Operations

The operational plan for Site U1588 was to core five holes with the advanced piston corer/extended core barrel (APC/XCB) systems. The first three were to be cored to 500 mbsf, and the final two holes cored to 250 mbsf. Downhole logging measurements were to be conducted in Hole U1588D. Owing to time constraints toward the end of the expedition and unexpectedly high methane gas content in the formation, the coring plan was shortened to three holes to approximately 350 mbsf, and a fourth hole cored as deep as possible with the remaining time, reaching a final depth of 412.5 mbsf. Downhole logging was cancelled.

Significant core expansion and curatorial difficulties encountered in Hole U1588A due to high methane gas content in the sediment led to a change in the XCB coring strategy starting on Core U1588A-25X and followed at all subsequent holes at the site. XCB cores were taken using half advances (~4.7 m), giving cores room to expand inside the core liners as gas was released.

Holes U1588A, U1588B, and U1588D were APC cored to 154.2 mbsf, 81.8 mbsf, and 90.5 mbsf, respectively, and then XCB cored to their final depths. Because of increasing seas, APC coring was omitted in Hole U1588C in favor of drilling ahead to 92.0 mbsf before starting to XCB core the lower section.

A total of 242 cores were taken at the site, 37 APC and 205 XCB. All APC cores used nonmagnetic core barrels and were oriented using the Icefield MI-5 orientation tool. In total, 1377.1 m were cored, recovering 1748.93 m (127%). Formation temperature measurements

were done with the advanced piston corer temperature (APCT-3) tool in Hole U1588A, on Cores 4H, 7H, 10H, and 13H. Site U1588 took 186.75 h (7.8 d) to complete.

Principal Results

1. Successful demonstration of an alternative coring method for gassy sediment involving half advances of the XCB, thereby allowing the core to expand into the empty part of the liner.
2. Recovery of an expanded 412.5 m sequence spanning the last 2.3 Ma with sedimentation rates averaging 18 cm/ky.
3. Site U1588 provides a marine reference section for studying Quaternary climate variability at very high temporal resolution (millennial to submillennial), including changes across the middle Pleistocene transition.
4. Proxy signal of surface temperature will constitute a marine sediment analog for the Greenland ice core.
5. Contourite sedimentation under the influence of the lower MOW, in conjunction with other Expedition 339 sites, will provide a detailed history of the response of the MOW to orbital and millennial climate change.

At Site U1588, because of the significant core expansion, all depths of the scientific results are reported in meters cored below seafloor, method B (m CSF-B) hereafter. The CSF-B depth scale method corrects for core expansion by uniformly compressing the recovery to the coring advancement.

The ~412.5 m thick sedimentary succession drilled at Site U1588 consists of one lithostratigraphic unit. Most sediments are from lithofacies 1 and consist primarily of nannofossil ooze, with varying amounts of inorganic/detrital/recrystallized calcium carbonate of indeterminate origin (hereafter “carbonate”) and clay. The abundance of nannofossil ooze with substantial amounts of clay and carbonate indicates the persistence of hemipelagic sedimentation and an indeterminate (recrystallized or detrital) source of carbonate at Site U1588 through the Pleistocene. Foraminifera, diagenetic features (dark patches, pyrite), and rare, subtle color-banding are disseminated throughout the cores. Bioturbation varies from absent to heavy and generally increases downhole. Deformational sedimentary structures are rare and, when present, are at a decimeter scale. Drilling disturbance is present within most cores in all holes, varies from slight to severe, and is influenced by the drilling type, operational conditions (ship heave), and methane gas contents of sediments.

Site U1588 ranges in age from the Holocene to the early Pleistocene (~2.2 Ma) based on calcareous nannofossil (21 bioevents) and planktonic foraminifera (six bioevents) biostratigraphy. The zonal schemes of calcareous nannofossils and planktonic foraminifera generally agree, and we estimate an average sedimentation rate of 18 cm/ky.

The site revealed excellent preservation conditions for all microfossils, including biogenic Si, mainly in the form of diatoms, sponge spicules, silicoflagellates, and radiolarians at specific depth intervals that are associated with some terminations during the latest glacial-interglacial

(Termination V and Termination IV). The occurrence of biogenic silica at these terminations are in good agreement with observations from Site 339-U1391 (Abrantes et al., 2016). All calcareous microfossils, including nannofossils, planktonic and benthic foraminifera, and ostracods are abundant to common and are generally well-distributed throughout the succession. Excellent preservation conditions are also indicated by the presence of pteropods. Ostracod diversity increases toward the top of the sequence, and variations in planktonic foraminifera species composition throughout the Pleistocene are likely associated with glacial-interglacial or even millennial-scale climate fluctuations. Benthic foraminifera assemblages suggest variability in organic flux and/or oxygen conditions relative to changes in surface productivity and bottom water oxygenation.

Magnetostratigraphy of Site U1588 was established based on the natural remanent magnetization (NRM) (after 20 mT demagnetization) inclination and (orientation-corrected) declination data from archive half core sections and stepwise NRM demagnetization data from discrete cube samples. The Brunhes/Matuyama boundary (0.773 Ma) is identified in APC cores from Hole U1588A and XCB cores from Holes U1588B, U1588C, and U1588D. The Jaramillo Subchron and the top of Olduvai Subchron (1.775 Ma) appear to be recorded in XCB cores from all four holes. However, the bottom of Olduvai Subchron (1.934 Ma) is only recorded in XCB cores recovered in the deepest Hole U1588D (>350 m CSF-B).

Geochemistry of intersitital water samples show that alkalinity, ammonium, and phosphate increase downhole in the upper 50 m CSF-B, whereas sulfate shows a two-step decrease in the upper 50 m CSF-B, indicating organic matter respiration. At this site, the sulfate reaches zero and stays low downhole. Methane levels increase downhole to about 45,000 ppmv at 50 m CSF-B but decline to ~5,000 ppmv by 100 m CSF-B until the bottom of the hole. Given the consistently high degassing of sediment below 50 m CSF-B, it is likely the decrease in methane concentrations measured in headspace samples does not accurately reflect the sediment gas content, which is supported by very high methane concentrations measured in void gas.

The $CaCO_3$ content varies between 16.0–53.6 wt%, averaging 30.2 wt%. This coulometer-determined $CaCO_3$ content shows consistent results with stoichiometric $CaCO_3$ calculated from the Ca concentrations measured by inductively coupled plasma–atomic emission spectroscopy, and it is positively correlated with L* reflectance and negatively correlated with natural gamma radiation (NGR). Total organic carbon (TOC), nitrogen (TN), and sulphur (TS) values in Site U1588 are generally low, ranging from 0.30–1.89 wt% (mean 0.74 wt%), 0.042–0.189 wt% (mean 0.085 wt%), and 0–3.18 wt% (mean 0.291 wt%), respectively. Organic C/N ratios (3.04–16.5 wt%; mean 8.97 wt%) suggest that organic matter is marine dominated.

Bulk sediment SiO_2, K_2O, and TiO_2, show strong positive correlations with Al_2O_3, indicating the dominance of terrigenous detritus. Relatively weak correlations are observed for Fe_2O_3, MgO, Na_2O, MnO, and Ba against Al_2O_3, due to the widespread presence of authigenic and biogenic phases; that is, pyrite, dolomite and/or Mg-bearing calcite, halite (NaCl) precipitated from seawater, Mn hydroxides, and barite, respectively. Bulk sediment Ca primarily represents biogenic carbonate ($CaCO_3$), and because of the incorporation of Sr into biogenic

carbonates, both elements show an inverse relationship with Al. Elemental ratios of Ca/Ti, Si/Al, Ti/Al, Zr/Al, K/Al, Sr/Ca, and estimated biogenic Ba are potentially useful proxies for provenance, weathering, and productivity.

Physical properties data acquired from whole-round core measurements for Site U1588 are in good agreement with measurements carried out on split-core and discrete samples. A decrease in magnetic susceptibility (MS) at shallower depths follows sulfate reduction in sediment pore waters. The cyclic variations in MS, NGR, and L* values are distinct throughout all holes, showing lower NGR and MS values in carbonate-rich sediments with higher L* values, whereas higher MS and NGR values occur in clay-rich sediments with lower L* values. The gradually increasing values of bulk density, thermal conductivity, and *P*-wave velocity, and a decreasing trend in porosity are attributed to the compaction of sediments with increasing depth. X-ray imaging of the core sections revealed the presence of authigenic minerals and burrows, further evidence on gas expansion, and drilling disturbance.

Downhole temperature measurements (APCT-3) were made in Hole U1588A at 30.7, 56.2, 87.7, and 116.2 m CSF-B. The calculated in situ sediment temperatures ranged from 12.12°C at 30.7 m CSF-B to 14.88°C at 116.2 m CSF-B, resulting in a geothermal gradient of 33.2°C/km. This value is slightly lower than that measured at Site 397-U1385 and the published value for the region.

Stratigraphic correlations between holes at Site U1588 were accomplished using Correlator software. Tie points were established using the MS from the Whole-Round Multisensor Logger, and NGR. A splice was constructed from 0 to 366 m core composite depth below seafloor, method B (CCSF-B) using four holes (Holes U1588A, U1588B, U1588C, and U1588D). The drilling and correlation strategies were unique at this site due to the severely expanded cores. A mixture of APC, full-advance XCB, and half-advance XCB coring was used for different levels of core expansion at each hole. Instead of CSF-A, the CSF-B depth method was used for the correlation. Considering the high-quality XCB cores and the high sedimentation rate at this site, the composite section was nearly complete with only one possible small gap.