IODP Expedition 397: Iberian Margin Paleoclimate

Site U1587 Summary

Background and Scientific Objectives

The location of Site U1587 (proposed Site SHACK-14A) was motivated by Shackleton's classic study of nearby piston core MD95-2042 (Shackleton et al., 2000, 2004) that demonstrated the potential of correlating Iberian margin sediments with the polar ice cores and European terrestrial sequences. Site U1587 is positioned at 3480 m below sea level (mbsl) and is bathed today by a mixture of 75% North Atlantic Deep Water and 25% Lower Deep Water sourced from the Southern Ocean. The mixing ratio of these water masses has changed in the past as well as their vertical position in the water column, which has implications for ventilation and carbon storage in the deep Atlantic.

The upper Miocene to Quaternary sequence is expanded at Site U1587 and is more than 500 m thick. Sedimentation rates are estimated to average ~10 cm/ky. We received permission from the IODP Environmental Protection and Safety Panel (EPSP) to drill to 500 m below seafloor (mbsf) at this site. We then requested and were granted permission to drill an additional 50 m to extend the record well into the late Miocene.

Site U1587 was designed to recover an expanded sequence of late Miocene to Quaternary sediments with which to address several expedition objectives related to the history of millennial climate variability (MCV), orbital forcing of glacial-interglacial cycles, cyclostratigraphy, warm Pliocene climate, and the Messinian salinity crisis. The high sedimentation rates and long continuous record at Site U1587 will permit climate reconstruction at millennial resolution as the system evolved from the warm Pliocene, through the intensification of northern hemisphere glaciation in the late Pliocene, the obliquity-dominated "41 ky world," the middle Pleistocene transition, and the Great Ice Ages of the "100 ky world."

Operations

We arrived at Site U1587 at 1121 h on 1 November 2022 after completing the 16.9 nmi transit from Site U1586 with the thrusters down and the vessel heading controlled by dynamic positioning (DP). The drill crew made up an advanced piston corer/extended core barrel (APC/XCB) bottom-hole assembly using the same APC/XCB polycrystalline diamond compact bit used at Site U1586.

The plan for Site U1587 was to core four holes with the APC and half-length APC (HLAPC) systems to refusal (estimated to be approximately 250 mbsf), then core to a maximum depth of 500 mbsf using the XCB coring system. Formation temperature measurements were planned for the first hole using the advanced piston corer temperature (APCT-3) tool, and core orientation was planned for all APC cores. Downhole logging with the triple combo tool string was also planned for Hole U1587D.

Once on site, weather conditions and high seas caused some delays, and the coring strategy was adjusted, removing the fourth hole from the plan after all site objectives had been met. Permission to deepen the site was asked for and approved by the EPSP while coring Hole U1587B. The site consisted of three holes. Hole U1587A was cored to 500 mbsf, Hole U1587B was cored to 547.8 mbsf, and Hole U1587C was cored to 567.9 mbsf. As at Site U1586, the drilling strategy consisted of using the APC system until the first partial stroke and then extending the hole to total depth using the XCB coring system. Hole U1587C was successfully logged using the triple combo tool string to a depth of 558 mbsf, roughly 10 m above the total depth of the hole. The drill string was raised, clearing the seafloor at 0850 h on 15 November, ending Hole U1587C and the site. The bit was raised to 2484 m below rig floor (mbrf), and at 1115 h we started the transit to Site U1385 (proposed Site SHACK-04C) under DP navigation mode.

All APC cores used nonmagnetic core barrels and were oriented using the Icefield MI-5 orientation tool. In total, 1615.7 m were cored at Site U1587 using the APC and XCB systems, with a recovery rate of 97%. The site took 335.5 h (14.0 d) to complete.

Principal Results

1. Recovery of a 567 m sequence at Site U1587, ranging in age from the late Miocene (Tortonian, ~7.8 Ma) to Quaternary, with sedimentation rates from 6.5 to 11 cm/ky.
2. Continuous deposition and high sedimentation rates for the last 1.5 Ma are ideal for studying MCV and correlating Site U1587 to the polar ice core records (Beyond EPICA Oldest Ice project).
3. Pliocene sediments contain very strong precession scale cycles in color and other physical properties (magnetic susceptibility [MS], density, and natural gamma radiation [NGR]). Amplitude modulation of these precession cycles by eccentricity provides a powerful tool for developing an orbitally-tuned time scale for Site U1587.
4. Recovery of an apparently complete Messinian Stage (7.246–5.333 Ma) of the late Miocene with strong Milankovitch cyclicity consisting of alternating dark clay-rich sediments and lighter nannofossil ooze. This sequence will permit study of the Messinian salinity crisis in an open-ocean setting adjacent to the Mediterranean.
5. Complete logging run from 81 to 558 mbsf showing cyclic variations in NGR that will be used for core-log integration.
6. Expanded late Pliocene section documenting the intensification of Northern Hemisphere glaciation between 3.3 (MIS M2) and 2.6 Ma (MIS 100), including the mid-Pliocene warm period (3.3 to 3 Ma).

Coring in Holes U1587A, U1587B, and U1587C recovered a total of 1566 m of sediment. The dominant lithologies are nannofossil ooze and clay in varying proportions, which manifest as light and dark sediment layers reflected by changes in sediment physical properties. Pyrite nodules and infilled pyrite borrows are common throughout the sedimentary sequence. Bioturbation varies from slight to heavy. Drilling disturbance in a few APC cores include soupy/slurry sediments, mostly in Section 1, and slight uparching toward

the bottom of the APC interval. XCB cores are generally undisturbed but biscuiting occurs mainly below 204 mbsf.

Nannofossils are extraordinarily abundant, and all calcareous microfossils, including ostracods, are present and well-preserved. Planktonic foraminiferal preservation decreases with depth, and Miocene specimens are very small in size, recrystallized, and challenging to identify. Fifty-one biostratigraphic markers (37 nannofossils and 14 planktonic foraminifera) were recognized and suggest a continuous sequence from late Miocene (Tortonian, 7.8 Ma) to Holocene. Nannofossil and planktonic foraminifera stratigraphic events are in good agreement with magnetostratigraphy. Sedimentation rate varies between 11 and 6.5 cm/ky.

A large abundance of ichthyoliths, accompanied by a high diversity of benthic foraminifera and a monospecific ostracod assemblage consisting of the genus *Xylocythere,* were found in Sample U1587A-22X-CC. *Xylocythere* is an ostracod genus known from chemosynthetic environments, such as hydrothermal vents, cold seeps, and fish carcasses. They are also known to inhabit oligotrophic, deep-sea sediments.

Paleomagnetic investigations of Site U1587 sediments focused on the measurement of natural remanent magnetization of archive half core sections and on a total of 142 cube samples taken from split cores and subject to stepwise alternating field demagnetization with peak fields up to 50 or 80 mT. Magnetostratigraphy of Site U1587 included the identification of the following polarity reversals and subchrons: the Brunhes/Matuyama boundary (0.773 Ma), the Matuyama/Gauss boundary (2.595 Ma), and the C3An.1n (6.023–6.272 Ma) and the C3An.2n (6.386–6.727 Ma) Subchrons. The Jaramillo (0.99–1.07 Ma) and possibly Cobb Mountain (1.18–1.215 Ma) Subchrons were identified in APC cores from Hole U1587A. The C3Bn Chron (7.104–7.214 Ma) could be recorded in Holes U1587B and U1587C, and the bottom ~20 m of sediments in Hole U1587C possibly records part of the C4n Chron (7.537–8.125 Ma).

Interstitial water (IW) samples show an increase in alkalinity, ammonium, and phosphate in the upper 50 mbsf, whereas sulfate correspondingly decreases rapidly in the upper 30 mbsf, indicating sulfate reduction and organic matter respiration. As sulfate reaches zero, the concentration of methane begins to increase, reaching about 40,000 ppmv at 125 mbsf.

Calcium carbonate ($CaCO_3$) content in the sediments varies between 2.9–78.1 wt%, with an average of 37.4 wt%. Total organic carbon, total nitrogen, and total sulphur values are generally low, ranging within 0–2.02 wt% (mean 0.48 wt%), 0–0.13 wt% (mean 0.05 wt%), and 0–0.37 wt% (mean 0.03 wt%), respectively. Organic carbon/nitrogen ratios (0–86.7 wt%; mean 20.0 wt%) suggest that organic matter has marine and terrestrial sources.

Inductively coupled plasma–atomic emission spectroscopy (ICP-AES) data from the bulk sediment indicates elemental oxides of SiO_2, K_2O, and TiO_2 are strongly and positively correlated to Al_2O_3, reflecting the dominance of terrigenous detritus. The manganese and carbonate association in bulk sediment reinforces the IW indication of microbial mediated respiration reactions. Furthermore, elemental ratios of Ca/Ti, K/Al, Si/Al, Sr/Ca, and estimated biogenic Ba are potential proxies for provenance, weathering, and productivity.

Physical properties data show strong cyclic variations in MS, NGR, and color throughout the sedimentary succession retrieved at Site U1587, reflecting variations in relative proportion of carbonate and clay. MS and NGR show lower values in lighter carbonate-rich sediments, whereas MS and NGR values are higher in darker clay-rich sediments. MS decreases in the upper 40 mbsf as sulfate reduction produces H_2S that reacts with magnetite to form iron sulfide minerals (e.g., pyrite). The X-ray images reveal the presence of pyrite nodules and burrow fill, diagenesis, and drilling disturbances. The gradual increasing trend of bulk densities, thermal conductivity, and *P*-wave velocities, and the decreasing trend in porosity are attributed to the compaction of sediments with depth.

Following completion of drilling at Hole U1587C, the bit was pulled to a depth of 80.1 mbsf for downhole logging. The triple combo tool string was deployed into the hole to a depth of 558 mbsf. Next, we conducted an upward pass with the caliper open at a pace of 274 m/h over the entire hole to achieve the maximum possible data resolution from the natural gamma ray sonde of the triple combo. Initial evaluation of the log from Hole U1587C looks promising for correlating many of the cyclic features seen in core physical property measurements.

A composite splice was constructed from 0 to 593 m core composite depth below seafloor (CCSF-A) using all three holes (U1587A, U1587B, and U1587C). A disturbed interval occurs from ~198–210 m CCSF-A, interrupting the sequence that is otherwise easy to correlate to late Pliocene and Pleistocene oxygen isotope stages. The disturbed interval appears to be in a similar stratigraphic position as the one identified at Site U1586, but removes much less section: the gap is equivalent to MIS 64–76. The late Miocene/Pliocene sequence is without apparent stratigraphic gaps and the Pliocene sequence correlates cycle-for-cycle to Site U1586. An interval of expanded sedimentation with cycles of ~1.5 m thick occupies the late Messinian. The cyclicity in sediment physical properties is remarkably strong at Site U1587 with a strong precession signal expressed throughout the late Miocene and Pliocene, which will be valuable for developing an astronomically tuned timescale.