

IODP Expedition 401: Mediterranean–Atlantic Gateway Exchange

Site U1385 Summary

Background and Objectives

Site U1385 (37°34.2849'N, 10°7.5616'W) was first drilled during Integrated Ocean Drilling Program Expedition 339 to provide a marine reference section of Pleistocene millennial climate variability. Five holes were cored (Holes 339-U1385A–U1385E) to a maximum penetration of 151.5 meters below seafloor (mbsf) using the advanced piston corer (APC) system (Stow et al., 2013). The record extends to 1.45 Ma (Marine Isotope Stage [MIS] 47) with an average sedimentation rate of 11 cm/ky (Hodell et al., 2015).

Site U1385 was reoccupied during International Ocean Discovery Program (IODP) Expedition 397 (2022) to deepen the sequence to 400 mbsf, just above the Miocene/Pliocene boundary (~5.3 Ma; Hodell et al., 2023). Five more holes were cored (Holes 397-U1385F–U1385J) ~500 m from the Expedition 339 location, using the APC to about 110 mbsf and the extended core barrel (XCB) system beneath that depth. During Expedition 397, Site U1385 was part of a four-site depth transect designed to capture and reconstruct water mass changes during the Pliocene and Pleistocene (Hodell et al., 2023). The two deeper water sites, U1587 and U1586, also recovered late Miocene successions. Results from Site U1385 demonstrate that the Iberian margin yields long, continuous records of millennial Pliocene–Pleistocene climate variability permitting detailed land-sea comparisons (Hodell et al., 2023).

Expedition 401 used the same site designation for this site, coring Holes 401-U1385K and U1385L, and we distinguish between the intervals recovered by the different expeditions by prefixing the expedition number to the site: Site 339-U1385, Site 397-U1385, and Site 401-U1385. Site 401-U1385 is located ~20 m from Site 397-U1385, at a water depth of 2590 meters below sea level (mbsl), placing it in the core of Lower Northeast Atlantic Deep Water today. Seismic data indicate the stratigraphy is continuous between the locations.

Objectives

Extending this remarkable sediment archive back into the late Miocene was one of the primary goals of reoccupying Site U1385 during Expedition 401. Equivalent aged sediments recovered at the deeper Site U1587 (Hodell et al., 2023) can be traced upslope on the seismic profile to Site U1385. These late Miocene sediments at Site U1587 display well-developed precessional cyclicity. However, the poor carbonate preservation at this greater water depth (3480 m water depth) means that high-

resolution carbonate-based proxy records cannot be generated (Hodell et al., 2023). The shallower water depth of Site U1385 (2590 m water depth) means it was likely to have better carbonate preservation, making these essential proxy records viable.

Site U1385 is Expedition 401's deepest site. It is located along an elevated ridge, minimizing the chances of disturbance by downslope transport. In combination with Site U1609 and the two deeper water Expedition 397 Sites, U1587 and U1586, the late Miocene records from Site U1385 complete a depth transect equivalent to the Pliocene–Pleistocene transect generated by Expedition 397. The initial objective in the expedition's *Scientific Prospectus* was to recover the deeper part of the section at Site 397-U1385 up to a maximum depth of 873 mbsf. However, the late-Tortonian to Messinian age interval of interest was likely not to require that full depth.

The specific objectives of coring Site 401-U1385 are as follows:

1. Document the nature, amplitude, and pacing of climate cycles in the Atlantic, before, during, and after the Messinian Salinity Crisis, and
2. Examine water mass variability during this time period characterized by extreme regional changes in oceanographic context.

Operations

Holes 401-U1385K and U1385L were cored after drilling down to start coring a little shallower than 400 mbsf, the depth reached at this site during Expedition 397.

Hole 401-U1385K

The 154 nmi voyage from Site U1610 to Site U1385 took 12.8 h at a speed of 12.0 kt. We lowered the thrusters at 1622 h on 12 January 2024 and switched to dynamic positioning mode at 1652 h. The APC/XCB bottom-hole assembly (BHA) was assembled with a polycrystalline diamond compact (PDC) bit and was lowered toward the seafloor, and a pipe-cleaning “pig” was pumped down to clean the inside of the drill pipe. The ship was positioned 20 m east of Hole 397-U1385J.

Hole 401-U1385K was started at 0035 h on 13 January and was drilled ahead, reaching 385.0 mbsf at 1615 h. The center bit was retrieved and we started coring. Cores U1385K-2X to 6X returned nearly empty, so we ran the bit deplugger to ensure that the bottom of the BHA was free from loose sediment, which may have entered during the preceding drill down. Recovery improved in subsequent cores and we continued coring until Core 21X at 1035 h on 15 January, having reached the age target of 8 Ma. Cores U1385K-2X to 21X penetrated from 385.0 to 552.5 mbsf and recovered 127.9 m (76%).

We pulled up the pipe, clearing the seafloor at 1328 h on 15 January and ending Hole 401-U1385K.

Hole 401-U1385L

The ship was offset 20 m to the north, and we started Hole 401-U1385L at 1455 h on 15 January, drilling ahead without coring to 376 mbsf. Coring began at 0330 h on 16 January and Cores U1385L-2X to 8X penetrated from 376.0 to 443.9 mbsf, recovering 58.4 m (86%). We stopped coring at 1645 h because of the high wind and wave conditions forecast for the evening and next day. The bit cleared the seafloor at 1835 h and pulled up to a depth of 332 mbsl while the ship began waiting on weather (WOW). After coring Hole 401-U1385K, we had a choice between going directly to the next site or staying to core Hole 401-U1385L; we prioritized collecting core from Hole 401-U1385L, knowing that it would mean WOW the following day.

The ship began WOW at 2315 h on 16 January. At midmorning on 17 January, the average wind speed reached 35 kt, gusting to 65 kt, then it eased throughout the day. After WOW for 28.25 h, at 0330 h on 18 January we were able to resume operations. The BHA was raised, disassembled, and stowed. The thrusters were raised at 0720 h, and at 0736 h we started the transit to Site U1611 (proposed Site WAB-03A), ending operations at Site U1385.

Principal Results

Lithostratigraphy

The following lithostratigraphic units were defined based on core description of Cores U1385K-2X and 7X to 21X (385.0–552.65 mbsf) and Cores U1385L-2X to 8X (376.0–442.6 mbsf).

Units I to IV are characterized by alternating light-colored (light greenish gray, GLEY1 6/1, GLEY1 7/1), dark-colored (greenish gray, GLEY1 5/1, GLEY1 6/1; and gray (5Y 6/1, 5Y 5/1, 10YR 6/1) beds composed of clayey calcareous ooze and calcareous clay with lighter and darker shades and gradational and sharp boundaries. Minor lithologies include clay-rich and pyrite-rich intervals and horizons exhibiting multiple hues, including shades of orange-brown and blue-green. Trace fossils include *Chondrites*, *Planolites*, *Thalassinoides*, and *Zoophycos*, and rare *Asterosoma*, *Palaeophycos*, and *Schaubcylindrichnus*. Pyrite nodules and shell fragments are disseminated throughout. Sediments are initially interpreted as deepwater hemipelagic deposits.

Unit I extends from 385 to 430 mbsf in Cores U1385K-2X to 9X and from 376 to 430.5 mbsf in Sections U1385L-2X-1 to 7X-4. Unit I comprises clayey calcareous ooze (light greenish gray) and calcareous clay (greenish gray). Unit II extends from 436 to 458.5 mbsf in Sections U1385K-10X-1 to 12X-2 and from 430.5 to 442.6 mbsf in Sections U1385L-7X-5 to 8X-CC. Unit III extends from 458.5 to 519.6 mbsf in Sections U1385K-12X-3 to 18X-4. Units II and III contain clayey calcareous ooze (light greenish gray) and calcareous clay (variable greenish gray and gray). Unit IV extends from 519.6 to 552.65 mbsf in Sections U1385K-18X-5 to 21X-CC and is dominated by calcareous clay (variable greenish gray and gray) with minor clayey calcareous ooze (light greenish gray).

Biostratigraphy

Calcareous microfossils are typically abundant with moderate and good preservation, and planktonic foraminifers are well preserved with evidence of fragmentation in only a few samples. The age of the succession is constrained by eight nannofossil events and four foraminifer events. The highest occurrence (HO) of *Orthorhabdus rugosus* (5.23 Ma) and the lowest occurrence (LO) of *Ceratolithus acutus* (5.36 Ma) are recorded between Sections U1385L-4X-CC and 5X-CC at ~409 mbsf, constraining the Messinian/Pliocene boundary within Core U1385L-5X. The oldest bioevent we found was the base of the paracme of *Reticulofenestra pseudoumbilicus* (8.8 Ma) between Sections U1385K-19X-CC and 20X-CC at ~517 mbsf. The core catcher samples were also analyzed for benthic foraminifer content.

Paleomagnetism

Pass-through paleomagnetic measurements were performed using the superconducting rock magnetometer (SRM) to investigate the natural remanent magnetization (NRM) on a total of 132 archive section halves (91 from Hole 401-U1385K and 41 from Hole 401-U1385L). Alternating field (AF) demagnetization was performed on the SRM by applying stepwise peak fields of 5, 10, 15, and 20 mT, with measurement of the remaining magnetization taken at 2 cm resolution. In addition, we collected and measured 117 discrete samples of the working half split core sections, between three to seven discrete samples from each core. First, the anisotropy of magnetic susceptibility (AMS) and bulk magnetic susceptibility (MS) were measured on all samples using the MFK2 KappaBridge instrument. Next, the NRM of 61 cube samples, 47 from Hole 401-U1385K and 14 from Hole 401-U1385L, was measured on the AGICO JR-6A spinner magnetometer. Stepwise AF demagnetization was performed at successive peak fields of 0, 5, 10, 15, 20, 30, 40, 50, 60, and 70 mT, up to a maximum of 80 mT for the samples of Hole 401-U1385K, and up to a maximum of 40 mT for Hole 401-U1385L.

where the magnetic signal was weaker. When magnetization became erratic, demagnetization was stopped.

Constrained by stratigraphic correlation to Hole 397-U1385J, the topmost core of Hole 401-U1385L is <5 Ma. We then correlated the reversal pattern in inclination values of SRM measurements after 20 mT and JR-6A measurements after 20 mT to the most recent geomagnetic polarity timescale (GPTS). Based on this magnetostratigraphy, the base of Hole 401-U1385K is slightly older than 8.2 Ma, and the average sediment accumulation rate is ~5 cm/ky for the Messinian part of the record.

The AMS results of Holes 401-U1385K and U1385L show an overall vertical direction of the K_{\min} axis, in agreement with a sedimentary fabric and a vertically drilled hole, unlike the previous site, Site U1610.

Geochemistry

Carbonate geochemistry shows lithology-dependent variations and signs of carbonate diagenesis. At Hole 401-U1385K, the geochemistry team collected headspace gas samples and interstitial waters (IW) at a rate of one per recovered core. Gas content at Hole 401-U1385K was within the safety range; only methane and ethane were detected, but no higher hydrocarbons. The inorganic geochemistry team sampled IW from Hole 401-U1385K and measured salinity, pH, and alkalinity. Salinity remained invariant at 32 throughout the cored interval. IW major and trace elements were measured by ion chromatography (IC) and inductively coupled plasma–atomic emission spectroscopy (ICP-AES). Sediment samples were obtained from the IW squeeze cake residues in Hole 401-U1385K and one sample per core from Hole 401-U1385L to understand geochemical variations. Sediment samples were dried, ground, and weighed to measure C, N, and CaCO₃. Calcium carbonate abundance varies from 39 to 69 wt% and correlates well with natural gamma radiation (NGR), showing that mixing of carbonate and siliciclastic fractions is controlling the observable cyclicity at this location.

Physical Properties and Downhole Measurements

The full suite of physical properties measurements was made on cores and samples from Holes 401-U1385K and 401-U1385L. Moisture and density measurements show a compaction trend with depth: bulk density increases from ~1.9 g/cm³ at 378 mbsf to 2.0 g/cm³ at 548 mbsf, and porosity decreases from 50% to 43% over the same depth interval. NGR and MS records contain cyclic alternations on a meter to submeter scale throughout the cored interval, with relatively higher amplitude cycles from ~420 to 505 mbsf. No downhole measurements were made at Site U1385.

References

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