INTERNATIONAL OCEAN DISCOVERY PROGRAM

International Ocean Discovery Program Expedition 397 Scientific Prospectus

Iberian Margin Paleoclimate

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Abstract

The Iberian margin is a well-known source of rapidly accumulating sediment that contains a high-fidelity record of millennial climate variability (MCV) for the late Pleistocene. The late Sir Nicholas (Nick) Shackleton demonstrated that piston cores from the region can be correlated precisely to polar ice cores in both hemispheres. Moreover, the narrow continental shelf off Portugal results in the rapid delivery of terrestrial material to the deep-sea environment, thereby permitting correlation of marine and ice core records to European terrestrial sequences. Few places exist in the world where such detailed marine-ice-terrestrial linkages are possible. The continuity, high sedimentation rates, and fidelity of climate signals preserved in Iberian margin sediments make this region a prime target for ocean drilling.

During Integrated Ocean Drilling Program Expedition 339 (Mediterranean Outflow), one of the sites proposed here was drilled to a total depth of 155.9 meters below seafloor in multiple holes. At Site U1385 (the "Shackleton site") a complete record of hemipelagic sedimentation was recovered for the last 1.45 My corresponding to Marine Isotope Stage 47 with sedimentation rates of 10–20 cm/ky. Preliminary results from Site U1385 demonstrate the great promise of the Iberian margin to yield long records of millennial-scale climate change and land–sea comparisons.

International Ocean Discovery Program (IODP) Expedition 397 will extend this remarkable sediment archive through the Pliocene and expand the depth range of available sites by drilling additional sequences in water depths from 1304 to 4686 meters below sea level (mbsl). This depth transect is designed to complement those sites drilled during Expedition 339 (560–1073 mbsl) where sediment was recovered at intermediate water depth under the influence of Mediterranean Outflow Water (MOW). Together, the sites recovered during Expeditions 339 and 397 will constitute a complete depth transect with which to study past variability of all the major subsurface water masses of the eastern North Atlantic. Because most of the mass, thermal inertia, and carbon in the ocean-atmosphere system is contained in the deep ocean, well-placed depth transects in each of the major ocean basins are needed to understand the underlying mechanisms of glacial–interglacial cycles and MCV. We have identified four primary sites (SHACK-4C, SHACK-10B, SHACK-11B, and SHACK-14A) at which multiple holes will be drilled to ensure complete recovery of the stratigraphic sections at each site, ranging in age from the latest Miocene to Holocene. Building on the success of Site U1385 and given the seminal importance of the Iberian margin for paleoclimatology and marine-ice-terrestrial correlations, the cores recovered during Expedition 397 will provide present and future generations of paleoceanographers with the raw material needed to reconstruct the North Atlantic climate at high temporal resolution for the entire Quaternary and Pliocene.

Plain language summary

International Ocean Discovery Program (IODP) Expedition 397 will take place off the Iberia Peninsula where rapidly accumulating sediments contain a high-fidelity record of past climate change. Most sediment in the deep sea accumulates at rates of 1–2 cm every thousand years, whereas sediments in the targeted area accumulate ten times faster (10–20 cm every thousand years), making it possible for climate events to be resolved on timescales of hundreds (centennial) to thousands (millennial) of years.

Previous studies of marine sediment sequences from this area have demonstrated that the sedimentary profiles can be correlated precisely to the polar ice cores in Greenland and Antarctica. Moreover, the narrow continental shelf (ocean bottom at a water depth of 0–200 m) permits a rapid delivery of material from the nearby continent to the deep-sea environment, thereby providing a record of European terrestrial climate at the same location. During Integrated Ocean Drilling Program Expedition 339, Site U1385 was drilled in the same location to 155.9 m below the seafloor. The study of Site U1385 has confirmed the continuity of high sedimentation rates (10–20 cm per thousand years) for the last 1.45 million years and the uniqueness of the detailed marine-ice-terrestrial linkages possible at this location.

Expedition 397 will extend this remarkable sediment archive back to 3–5 million years ago through the geologic periods known as the Quaternary and Pliocene. Furthermore, we will drill additional sequences in water depths of 1304–4686 m below sea level. This depth transect is designed to study the past variability of all the water masses that fill the eastern North Atlantic Basin. Of particular interest are the behavior of the deeper water masses and their role in carbon storage and its effect on atmospheric carbon dioxide. The sediment cores recovered during Expedition 397 will be important for studying the role that millennial climate variability has played in the waxing and waning of the great Northern Hemisphere ice sheets during the last 3 million years.

The fidelity of the climate signals preserved in the sediments to be drilled during Expedition 397 will provide the greatest possible potential to reconstruct the natural variability of the North Atlantic climate (before human impact) at unprecedented temporal resolution back through the Pliocene (last 5 million years).

1. Schedule for Expedition 397

International Ocean Discovery Program (IODP) Expedition 397 is based on IODP drilling Proposal 771 (including versions 771-Full2, 771-Add, and 771-Add2 available at **http://iodp.tamu.edu/scienceops/expeditions/iberian_margin_paleoclimate.html**). Following evaluation by the IODP Scientific Advisory Structure and Environmental Protection and Safety Panel (EPSP), the expedition was scheduled for the research vessel (R/V) *JOIDES Resolution*, operating under contract with the *JOIDES Resolution* Science Operator (JRSO). At the time of publication of this *Scientific Prospectus*, the expedition is scheduled to start in Lisbon, Portugal, on 6 October 2022 and to end in Tarragona, Spain, on 6 December. A total of 55 days will be available for the transit, drilling, coring, and downhole measurements described in this report (for the current detailed schedule, see **http://iodp.tamu.edu/scienceops**). Further details about the facilities aboard *JOIDES Resolution* can be found at **http://iodp.tamu.edu/labs/index.html**.

2. Introduction

The polar ice cores have provided unrivaled records of climate and atmospheric compositional changes that have become benchmarks for late Pleistocene climate variability; however, the oldest continuous ice cores recovered to date in Greenland and Antarctica are ~122 and 800 ka, respectively (Figure **F1**). The international ice core community is now planning to obtain continuous ice cores that may stretch as back as far as 1.5 My (Fischer et al., 2013). An important challenge for the IODP paleoceanographic community is to identify complementary marine sections with sufficiently high sedimentation rates and climate signals suitable for comparison with the polar ice core records (Alley, 2003; Thurow et al., 2009). The Iberian margin has long been recognized as an important region for providing high-fidelity records of millennial-scale climate variability for the last glacial cycle (Figure **F1**) (Shackleton et al., 2000, 2004). In fact, few marine sediment cores have played such a pivotal role in high-resolution paleoclimate research as those from the Portuguese margin. Millennial-scale variability in these cores can be correlated confidently to polar ice cores in both hemispheres (Figure **F1**). Shackleton et al. (2000) demonstrated that surface oxygen isotope and sea-surface temperature (SST) records mirror those of Greenland ice core records, whereas the deepwater signal follows the Antarctic ice core climate record, thereby preserving a history of both polar ice cores in a single sedimentary archive. The relative timing of surface (Greenland) and deepwater (Antarctic) signals in the same core provides a means to assess interhemispheric phasing of climate change (e.g., "bipolar seesaw"), which has been independently verified by methane synchronization of ice cores for the last glacial period (Blunier and Brook, 2001; WAIS Divide Project Members, 2015). Moreover, the narrow continental shelf off Portugal results in the rapid delivery of terrestrial material to the deep-sea environment, permitting correlation of marine and ice core records to European terrestrial sequences (Margari et al., 2010, 2014; Sánchez Goñi et al., 1999; Shackleton et al., 2003; Tzedakis et al., 2009, 2004). Few, if any, places exist in the world ocean where such detailed marine-ice-terrestrial linkages are possible. For this reason, the

Iberian margin has become a focal point for studies of millennial climate variability (MCV) over the last several glacial cycles.

Extending this remarkable sediment archive further back in time is an obvious and worthwhile goal. A proof-of-concept Site U1385 was drilled during Integrated Ocean Drilling Program Expedition 339 (Mediterranean Outflow) in late 2011 in a water depth of 2582 meters below sea level (mbsl) (Hodell et al., 2013b; Expedition 339 Scientists, 2013a). Five holes were cored using the advanced piston corer (APC) system to a maximum depth of ~155.9 meters below seafloor (mbsf). Immediately after the expedition, cores from all holes were analyzed by core scanning X-ray fluorescence (XRF) at 1 cm spatial resolution (Hodell et al., 2015). Ca/Ti data was used to accurately correlate hole-to-hole and construct a composite spliced section, containing no gaps or disturbed intervals to 166.5 meters composite depth (mcd). The oxygen isotope record confirms that Site U1385 contains a continuous record of hemipelagic sedimentation from the Holocene to 1.45 Ma (Marine Isotope Stage [MIS] 47) (Figure **F2**) with sedimentation rates of ~10–20 cm/ky. The record can be correlated unambiguously to the LR04 benthic $\delta^{18}O$ stack (Lisiecki and Raymo, 2005) to provide an oxygen isotope age model. Strong precession cycles in color and elemental XRF signals from Site U1385 can also be used to develop an orbitally tuned reference timescale that is independent of LR04 (Hodell et al., 2015).

A highly coordinated sampling effort was undertaken with Site U1385 cores to produce the widest range of proxy measurements possible on the same set of samples, including foraminifer isotopes and trace elements, foraminifer and nannofossil assemblages, pollen, organic biomarkers and geochemistry, diatoms, trace fossils, dinocysts, sedimentology (clay mineralogy), paleomagnetics, cosmogenic nuclides, XRF, and radiogenic isotopes (for complete reference list, search the Scien-

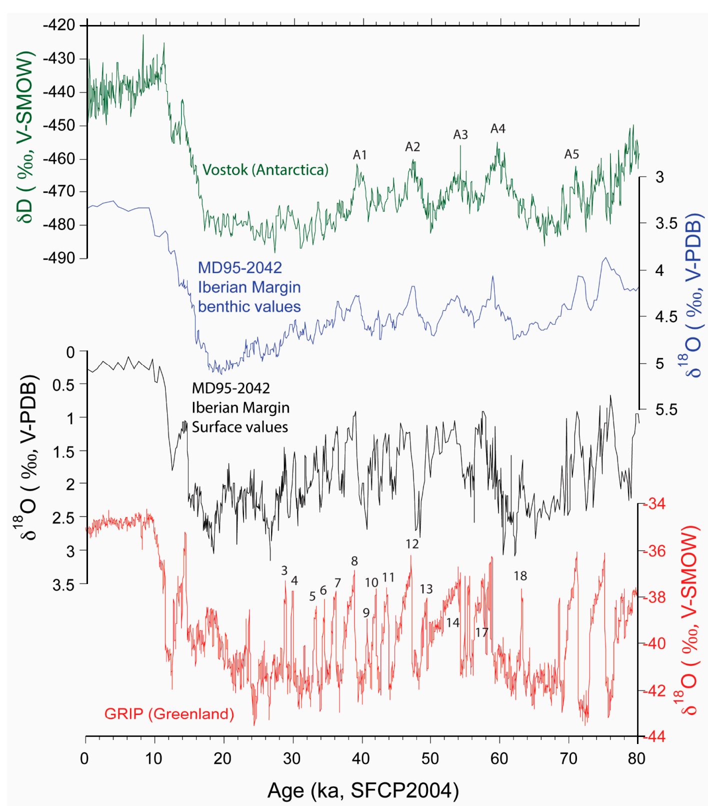

Figure F1. Correlation of $\delta^{18}O$ record of Greenland ice core (GRIP; red) to $\delta^{18}O$ of *Globigerina bulloides* (black) in Core MD95-2042 (Shackleton et al., 2000). Resulting correlation of Vostok δD (green; Jouzel et al., 2007) and benthic $\delta^{18}O$ of Core MD95-2042 (blue) is based on methane synchronization. Phasing of proxies that monitor surface and deepwater properties in the same marine sediment core is a powerful tool for examining the relative timing of interhemispheric climate change. Selected Dansgaard-Oeschger events are labeled in GRIP record and Antarctic isotope maxima (A1–A5) are labeled in Vostok. Timescale is SFCP2004 published by Shackleton et al. (2004). V-SMOW = Vienna standard mean ocean water, V-PDB = Vienna Peedee belemnite. From Hodell et al. (2013b).

tific Ocean Drilling Bibliographic Database [**https://iodp.tamu.edu/publications/bibliographic_information/database.html**] using key term Site U1385). Although results are still emerging, Site U1385 demonstrates the great potential of the western Iberian margin to yield long, undisturbed records of millennial-scale climate change and land–sea comparisons (Figure **F2**).

Additional drilling during Expedition 397 is needed to (1) extend the record beyond the base of Site U1385 (1.45 Ma) to the entire Pliocene–Pleistocene and possibly latest Miocene and (2) recover a full depth transect of sites spanning the range of the major subsurface water masses of the North Atlantic.

3. Background

3.1. Geological setting

The region proposed for drilling is a spur along the continental slope of the southwestern Iberian margin, the Promontório dos Principes de Avis (PPA) (Figure **F3**). The PPA is a relatively small topographic feature measuring approximately 100 km long by 50 km wide with a bathymetric

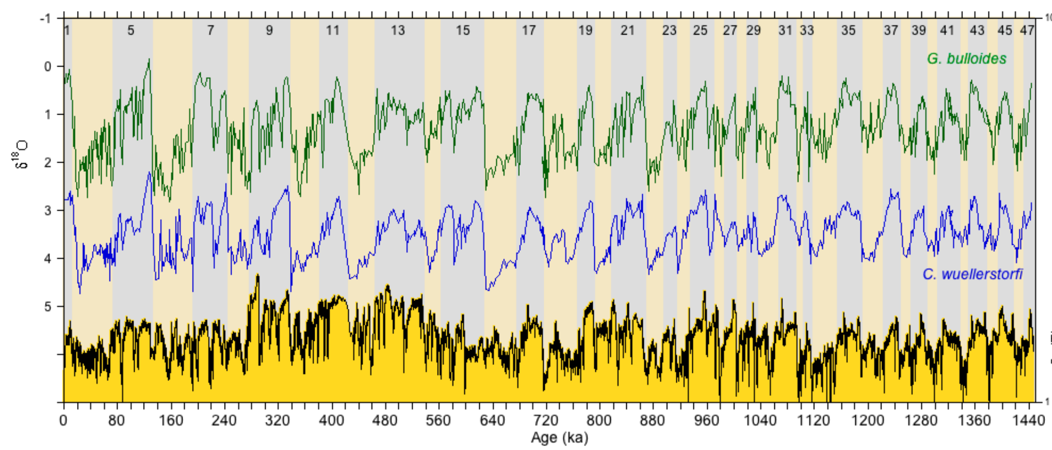

Figure F2. Oxygen isotope record of *Globigerina bulloides* (green), *Cibicidoides wuellerstorfi* (blue), and Ca/Ti (black) for spliced composite section of Site U1385 spanning the last 1.45 My to MIS 47. Interglacial stages (gray) are numbered. Stable isotope data were collected every 20 cm, whereas Ca/Ti was measured at 1 cm resolution. Data from Hodell et al. (2015).

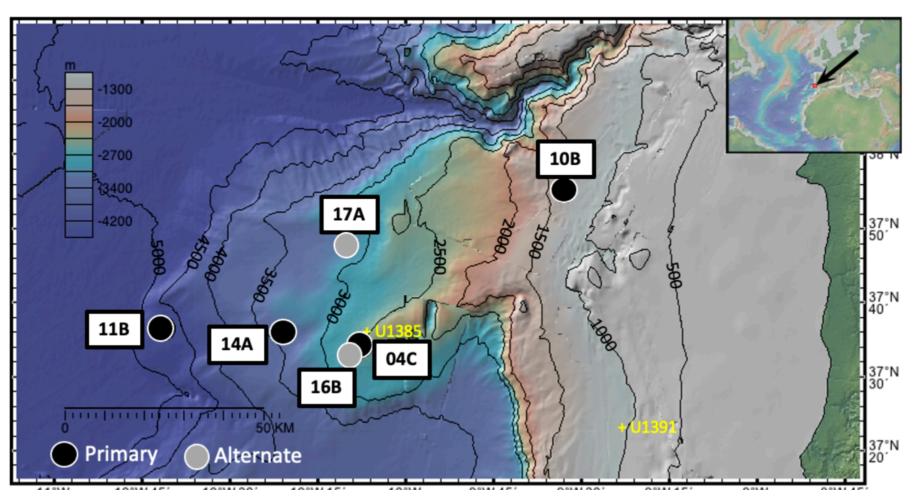

Figure F3. Detailed bathymetry of Promontório dos Principes de Avis (Zitellini et al., 2009) showing locations of Expedition 397 proposed primary (black circles) and secondary (gray circles) sites. Yellow crosses = Expedition 339 Sites U1385 and U1391.

relief of 4 km. The PPA is elevated above the abyssal plain and is topographically isolated from turbidites that are funneled to the Tagus Abyssal Plain via the bordering submarine canyons to the north and south.

Site selection for Expedition 339 was accomplished by examining available seismic data. Geophysical coverage of the PPA is excellent with a dense network of multichannel seismic lines, including those obtained during our site survey cruise (JC089) and existing industry seismic data (TGS-NOPEC Geophysical Company, ASA) (Figure **F4**). A dedicated site survey cruise aboard the RSS *James Cook* (**https://www.bodc.ac.uk/data/information_and_inventories/cruise_inventory/report/13392/**) was conducted in 2013 when a total of 755 line kilometers of seismic reflection profiles were acquired using a 3 km streamer and air gun source consisting of a generator-injector (GI) gun. Data quality is high with penetration of 3–4 s two-way traveltime (TWT). The seismic lines cross at 34 points providing a large selection of potential primary and alternate sites. Swath bathymetry was also acquired during the cruise using a Kongsberg EM 120 Deep Water Multi-beam echo sounder.

The hemipelagic sediments on the PPA are uniform, consisting of nannofossil muds and clays, with varying proportions of biogenic carbonate and terrigenous sediments (Baas et al., 1997; Expedition 339 Scientists, 2013a). High sedimentation rates, ranging 10–20 cm/ky, occur during both glacial and interglacial periods and are attributed to the copious sediment supply and lateral transport of sediment by bottom and contour currents. Enhanced lateral transport and deposition of finer sediments (i.e., silts) on the Iberian margin are affected by an enhanced nepheloid layer that develops between the Mediterranean Outflow Water (MOW) and Atlantic water masses (Magill et al., 2018). Detrital input from rivers (Tagus) channeled by turbidity currents is limited to submarine canyon systems (Lebreiro et al., 2009) and abyssal plains (Lebreiro et al., 1997) and do not affect open slope deposition.

3.1.1. Subsurface hydrography

The flanks of the PPA intersect each of the major subsurface water masses of the North Atlantic and are ideal for the placement of a depth transect of sites (Figure **F5**). During Cruise JC089, 13 conductivity-temperature-depth (CTD) casts were made and subsurface water masses were recognized by their temperature-salinity characteristics (Figure **F6**). Eastern North Atlantic Central Water (ENACW) occupies the depth interval below the thermocline between ~50 and 500 m (van Aken, 2000). Between 500 and 1500 m, the warm, salty MOW dominates. MOW forms as warm, salty water from the Mediterranean flows over the Strait of Gibraltar into the Gulf of Cadiz and

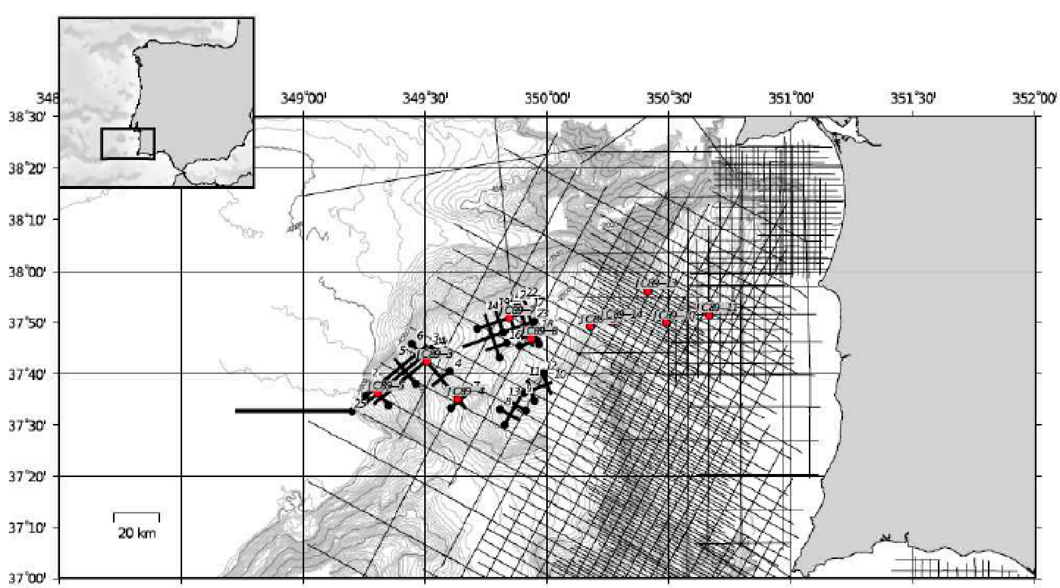

Figure F4. Multichannel seismic line coverage on southwest Iberian margin. Bold lines = collected during site survey Cruise JC089, thin lines = industry (TGS-NOPEC), red dots = locations of cores recovered during Cruise JC089.

splits into two cores centered at ~800 and 1200 m (Ambar and Howe, 1979), flowing north along the western Iberian margin. Below 2000 m, recirculated Northeast Atlantic Deep Water (NEADW) prevails, representing a mixture of Labrador Sea Water (LSW), Iceland Scotland Overflow Water (ISOW), Denmark Strait Overflow Water (DSOW), and to a lesser extent of MOW and Lower Deep Water (LDW) (van Aken, 2000). The deepest water mass is southern-sourced LDW, which is modified Antarctic Bottom Water that enters the eastern Atlantic Basin through the Vema Fracture Zone at 11°N (Saunders, 1987).

Jenkins et al. (2015) performed an optimum multiparameter analysis (OMPA) water mass analysis for the stations along the GEOTRACES North Atlantic transect. OMPA assesses the relative contributions of end-member water masses by a least-square optimization using input values for con-

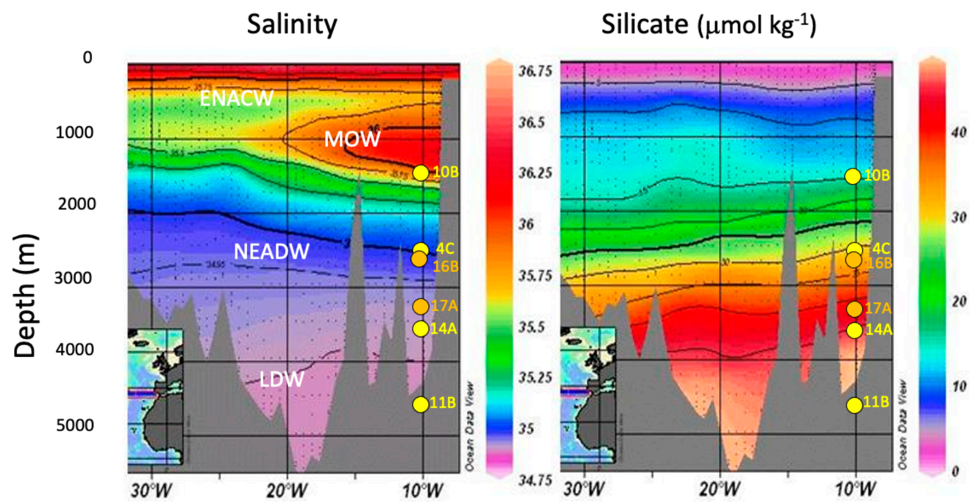

Figure F5. Salinity and silicate profiles on WOCE Line A03 (36°N) showing proposed site locations on Iberian margin. Tongue of high salinity water between 600 and 1200 m is MOW. High Si (>35 mmol/kg) below 3000 m represents a contribution from LDW sourced from the Southern Ocean. Water masses do not have clearly defined boundaries but rather consist of a series of core layers bordered by transition (mixing) zones between adjacent layers. Numbers indicate depths of proposed drill site locations, which intersect each of the important subsurface water masses. Together with Expedition 339 that drilled five sites between 566 and 980 mbsl in MOW, the sites constitute a complete depth transect with which to study past water mass properties.

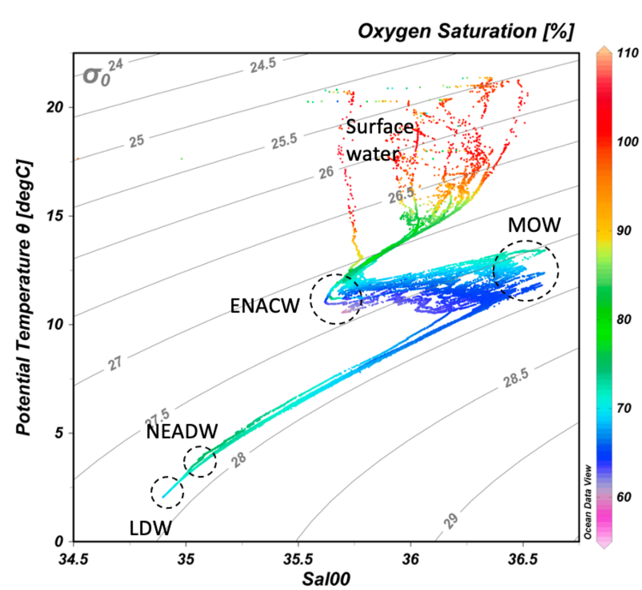

Figure F6. Temperature vs. salinity of CTD casts made during Cruise JC089 to the Iberian margin showing major subsurface water masses. Contours = potential density.

servative properties. We used this analysis to identify the optimal site locations based on the relative contribution of end-member water masses at each of the proposed drill sites.

3.1.2. Dip stick strategy

We propose a “dip stick” approach whereby the seabed is sampled beneath each of the major subsurface water masses. The PPA provides the bathymetric relief that in a limited area intersects all the principal water masses involved in the Atlantic thermohaline circulation (Figures **F5**, **F6**).

We have identified four primary locations (Proposed Sites SHACK-4C, SHACK-10B, SHACK-11B, and SHACK-14A) along a bathymetric transect (Figure **F7**). Water depths at the sites range 1304–4686 mbsl permitting the sampling of paleowater mass properties of intermediate-water (Mediterranean Overflow) and deepwater masses (NEADW and LDW).

The water depth range also complements those sites drilled during Expedition 339, which focused on the variability of MOW at five sites (Integrated Ocean Drilling Program Sites U1386–U1390) in the Gulf of Cadiz in water depths ranging 566–980 mbsl and one site (Integrated Ocean Drilling Program Site U1391) on the southwest Iberian margin at 1074 mbsl. Together with Expedition 339, the proposed sites will constitute a complete depth transect from 566 to 4686 mbsl on the eastern margin of the North Atlantic Basin. This bathymetric array will complement similar depth transects obtained during Ocean Drilling Program Legs 162 (North Atlantic Gateways) and 172 (Western North Atlantic Sediment Drifts) in the northern and western North Atlantic, respectively.

Because the depth ranges of water masses differed in the past, it is vital to sample the sediment column under a wide range of bathymetric and hydrographic conditions. The sedimentary dip sticks will permit a comprehensive reconstruction of past water mass variability in the North Atlantic through the Pliocene–Pleistocene, much of which appears to be related to spatial redistributions on both glacial–interglacial and millennial timescales. Understanding the role of the deep ocean in climate change is necessary to identify the underlying mechanisms of glacial–interglacial cycles and millennial-scale variation (Adkins, 2013). XRF scanning results of cores collected during the site survey cruise demonstrate stratigraphic sequences can be confidently correlated with each other on the basis of variations in elemental ratios (Figure **F8**). Surface signals are similar among the sites because the geographic area is small, whereas benthic signals will differ reflecting the range of subsurface water mass properties. Ongoing studies of the Cruise JC089 piston cores have demonstrated this strategy is effective at reconstructing temporal changes in the physical and chemical properties of water masses across the last deglaciation (Skinner et al., 2021).

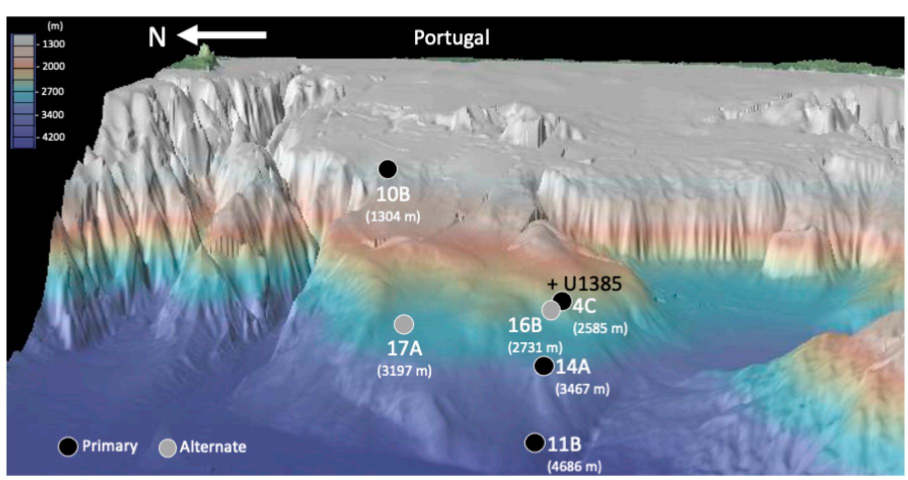

Figure F7. Depth distribution of proposed Expedition 397 drill sites on Promontório dos Principes de Avis looking onshore to the east. We will employ a dip stick drilling strategy such that the sites intersect each of the major subsurface water masses of the North Atlantic. Depth transect ranges from 1304 (Site SHACK-10B) to 4686 mbsl (Site SHACK-11B).

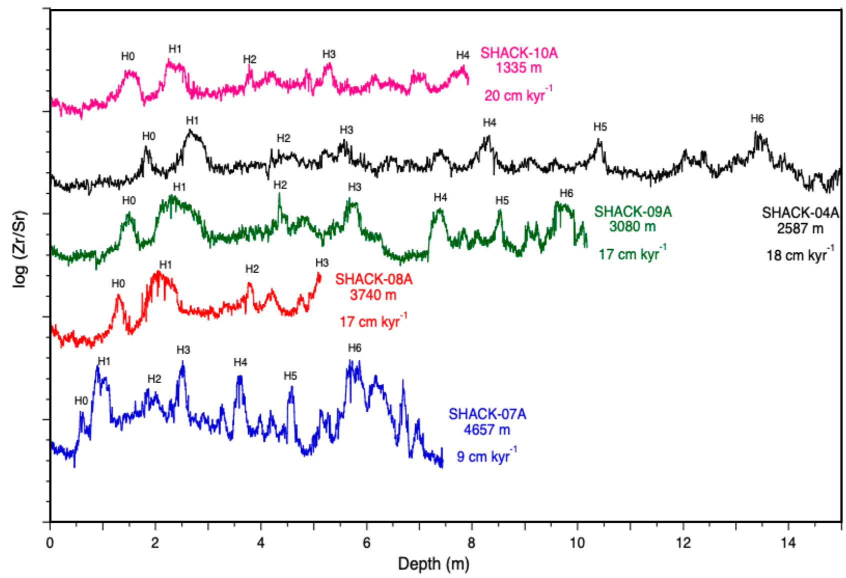

Figure F8. Log (Zr/Sr) for selected cores recovered during site survey Cruise JC089. Not all cores correspond to the proposed drill sites, but figure illustrates that XRF records can be correlated from site-to-site in water depths ranging 1335–4657 mbsl. Peaks in Zr/Sr mark increases in proportion of detrital sediment relative to biogenic carbonate. Peaks in Zr/Sr coincide with stadial events, especially those associated with Heinrich events, when SSTs were cold on the Iberian margin. Heinrich stadials (H0–H6) can be recognized at each proposed drill site along the depth transect.

3.2. Seismic studies/site survey data

The supporting site survey data for Expedition 397 are archived at the IODP Site Survey Data Bank (**https://ssdb.iodp.org/SSDBquery/SSDBquery.php**; select P771 for proposal number).

4. Scientific objectives

The overall objective of the Expedition 397 drilling proposal is to recover the late Miocene–Pleistocene sediment archive located offshore Portugal in a range of water depths to document past changes in vertical water mass structure and its relation to global climate change. By producing multiproxy time series at each site and placing them on an integrated stratigraphy, these sediments will provide the information needed to study MCV over the Pliocene–Pleistocene and understand its underlying causes and evolving contextuality.

Some of the specific scientific objectives include the following:

1. Document the nature of MCV for older glacial cycles of the Quaternary beyond the limit of Site U1385 (1.45 Ma), including the earliest Pleistocene and the Pliocene prior to the intensification of Northern Hemisphere glaciation (NHG).
2. Derive a marine sediment proxy record for Greenland and Antarctic ice cores to examine the amplitude and pacing of MCV during the Quaternary.
3. Determine interhemispheric phase relationships (leads/lags) by comparing the timing of proxy variables that monitor surface (Greenland) and deepwater (Antarctic) components of the climate system.
4. Study how changes in orbital forcing and glacial boundary conditions affect the character of MCV and, in turn, how MCV interacts with orbital geometry to produce the observed glacial-to-interglacial patterns of climate change.
5. Determine how MCV evolved during the Pliocene–Pleistocene as glacial boundary conditions changed with the progressive intensification of NHG.
6. Reconstruct the history of changing local dominance of northern-sourced versus southern-sourced deep water using the depth transect of IODP sites on orbital and suborbital timescales during the Quaternary.

7. Investigate climate during past interglacial periods, including the warm Pliocene period prior to the intensification of NHG.
8. Link terrestrial, marine, and ice core records by analyzing pollen and terrestrial biomarkers that are delivered to the deep-sea environment of the Iberian margin.
9. Contribute to the development of a global stratigraphy having sufficient resolution to capture the true waveforms (shapes) of the glacial–interglacial cycles and resolve MCV.

4.1. Toward an integrated global stratigraphy

Without a robust stratigraphic framework, paleoenvironmental observations and interpretations remain ambiguous and of limited use. Precise stratigraphy is the main factor limiting our ability to determine phase relationships (leads/lags) among various variables in the ocean-atmosphere system, which is essential for testing causal mechanisms of global climate change. Marine sediments off Portugal have the potential to significantly improve the precision with which marine climate records can be correlated to other records including polar ice cores and terrestrial sequences. A great strength of the Iberian margin sediment record is the fact that it contains proxies of marine, atmospheric (ice core), and terrestrial signals that are coregistered in a single archive. It is thus possible to determine the relative phasing of changes in proxy variables that monitor different components of the ocean climate system in the same core (Shackleton et al., 2000, 2004). For example, temporal comparisons between marine stable isotope and pollen records in the same core have permitted the evaluation of phase relationships during the last 420 ky (Margari et al., 2010, 2014; Roucoux et al., 2001; Shackleton et al., 2000, 2003, 2002; Tzedakis et al., 2004). A similar strategy can be applied to the entire Quaternary sequence recovered by Expedition 397, thereby circumventing many of the problems associated with core-to-core correlation and developing age models on millennial timescales (Blaauw, 2012).

At Site U1385, we found that variations in sediment color contain a strongly modulated precession signal over the past 1.4 Ma (Hodell et al., 2013a, 2013b). The modulation of precession by eccentricity provides a powerful tool for developing an orbitally tuned age model (Shackleton et al., 1995). An astronomically tuned timescale has been produced for Site U1385 by correlating variations in sediment color to precession of the Earth's orbit (Hodell et al., 2015). The tuned timescale offers the potential of a more accurate timescale than can be achieved solely by correlating benthic $\delta^{18}O$ to a reference curve. We expect that the strong precession signal in Iberian margin sediments should continue beyond 1.45 Ma (base of U1385) and permit astronomical tuning of the entire Pliocene–Pleistocene sequence. Such a precession-tuned timescale will also offer the opportunity to correlate Iberian margin cores into the sapropel layers and cyclostratigraphy of the Mediterranean (Hilgen, 1991; Konijnendijk et al., 2015).

4.2. Marine sediment analog to the polar ice cores

Ice cores offer the most detailed records available for reconstructing changes in climate and greenhouse gases in the latest Pleistocene. However, many of the mechanisms that control atmospheric composition and climate are rooted in the oceans. The answers to Pleistocene climate questions require a coupled ocean-atmosphere approach where ice core data are integrated with marine sediment cores. In this regard, Iberian margin sediments are important for comparison to existing and future ice core records from Greenland and Antarctica (Nehrbass-Ahles et al., 2020; E. Wolff et al., unpubl. data). Given that the Greenland ice core is limited to the last glacial cycle and the oldest ice core in Antarctica (EPICA Dome C) is limited to the last 800 ka, we must rely on marine sediment records to provide the longer-term history of changes in polar climate.

If we assume the correlation between rapid temperature changes on the Iberian margin and over Greenland has held for older glacial periods, then sediment recovered during Expedition 397 can serve as a marine sediment proxy record for the Greenland ice core beyond the age of the oldest undisturbed ice (~122 ka). Comparing surface water signals from the Iberian margin with the synthetic Greenland reconstruction (Barker et al., 2011) has demonstrated a strong similarity for the last 400 ka (Hodell et al., 2013a). Similarly, millennial-scale variability in benthic $\delta^{18}O$ from the Iberian margin is similar to EPICA δD for the last 800 ky. Beyond the last three glacial cycles, the temporal resolution of the EPICA Dome C record diminishes because of compression and diffusion, which hinders clear detection of millennial to submillennial events for older glacial periods depending on sampling resolution (Jouzel et al., 2007; Pol et al., 2010). Problems of diffusion and compression will undoubtedly be more severe in older ice to be recovered by the Beyond EPICA-Oldest Ice (BE-OI) project (Fischer et al., 2013; Bereiter et al., 2014; E. Wolff et al., unpubl. data). Comparison of MCV in CH_4 and δD from BE-OI and sediment recovered during Expedition 397 will allow an assessment of whether there has been significant loss of climate information at higher frequencies due to diffusion and migration in the ice core record.

4.3. Millennial-scale variability during the Pliocene–Pleistocene

Although much progress has been made toward understanding the orbital effects on climate, a complete theory of the ice ages still remains elusive (Raymo and Huybers, 2008). A missing piece of the puzzle may be understanding how climate change on shorter timescales (i.e., suborbital) interact with the effects of orbital forcing to produce the observed patterns of glacial–interglacial cycles through the Pleistocene. For example, MCV may play an important role in longer-term climate transitions, such as glacial terminations (Cheng et al., 2009; Denton et al., 2010; Wolff et al., 2009; Barker and Knorr, 2021). Studying the coevolution of orbital and suborbital variability requires a new caliber of sediment archive with a high level of chronological precision. With few exceptions, deep-sea sedimentary records generally lack the resolution needed to delineate such variability; however, exceptions do exist such as those from the Portuguese margin (Figure **F1**). MCV has been well documented for the last glacial cycle in the North Atlantic, but relatively little is known about similar variability during older glacial periods of the Pleistocene (de Abreu et al., 2003; Margari et al., 2010; Martrat et al., 2007; Rodrigues et al., 2011). Some marine records of MCV exist beyond the last glacial cycle (Alonso-Garcia et al., 2011; Barker et al., 2015, 2011; Hodell et al., 2008; Jouzel et al., 2007; Kawamura et al., 2007; Dome Fuji Ice Core Project Members, 2017; Margari et al., 2010; Martrat et al., 2007; McManus et al., 1999; Oppo et al., 1998; Rodrigues et al., 2017), but only a few extend beyond 800 ka into the early Pleistocene (Barker et al., 2021; Billups and Scheinwald, 2014; Birner et al., 2016; Hodell and Channell, 2016; Hodell et al., 2008; Mc Intyre et al., 2001; Raymo et al., 1998).

The proposed Expedition 397 drill sites will provide long, continuous time series with which to evaluate the evolving character of MCV for older glacial periods of the Pleistocene and Pliocene. MCV is thought to be a pervasive feature of Quaternary climate change (Jouzel et al., 2007; Weirauch et al., 2008; Hodell et al., 2015; Sun et al., 2021), but its pacing and amplitude are likely to be influenced by changing orbital and ice sheet boundary conditions. Expedition 397 is aimed at assessing the influence of the climate background state on the nature of MCV and its cause(s) during the Quaternary. Correlation of Iberian margin proxy records with European speleothems provide a novel opportunity to tie marine records into a radiometrically dated chronology using U-Th and U-Pb isotopes (Tzedakis et al., 2018; Bajo et al., 2020).

Study of Site U1385 has demonstrated that MCV was a persistent feature of glacial climates over the past 1.45 My (Hodell et al., 2015), including glacial periods of the early Pleistocene ("41 ky world") when boundary conditions differed significantly from those of the late Pleistocene (Birner et al., 2016). But does similar MCV persist beyond 1.5 Ma during glacial periods throughout the entire Quaternary? How does the nature (intensity, duration, pacing) of MCV change with orbital configuration and climate background state (ice volume, sea level, ice sheet height) throughout the Quaternary? How did MCV change with the intensification of NHG during the late Pliocene? Was MCV suppressed during the warm Pliocene prior to the intensification of NHG as it was during most interglacial stages of the Pleistocene? The cores recovered during Expedition 397 will provide an opportunity to address these questions and lead to a fuller understanding of how climate variability on orbital and suborbital interact, including how they evolved during the Pliocene–Pleistocene.

4.4. Testing the bipolar seesaw in glacial periods

The leading cause to explain MCV recorded in Greenland and Antarctic ice cores during the last glacial period is changes in the strength of Atlantic Meridional Overturning Circulation (AMOC), which alters interhemispheric heat transport and results in opposite temperature responses in the two hemispheres. However, we know little about whether this bipolar seesaw was a persistent feature of older glacial climate states.

Determining phase relationships of MCV in glacial periods beyond the last climate cycle is challenging because absolute dating of marine cores is too imprecise to correlate and resolve small differences in the timing of paleoclimate signals (Blaauw, 2012; Andrews et al., 1999; Wunsch, 2006). An alternative approach is to determine the relative phasing of changes in proxy variables in the same core that monitor different components of the ocean climate system. A great strength of the Iberian margin sediment record is the fact that it contains signals of both Greenland and Antarctic ice cores in a single archive. Shackleton et al. (2000, 2004) demonstrated it is possible to determine the relative phasing of changes in Greenland and Antarctic climate by comparing planktonic and benthic $\delta^{18}O$ signals in Core MD95-2042 (Figure **F1**). This phasing of surface and deepwater signals on the Iberian margin is consistent with the bipolar seesaw; that is, the rate of change of Antarctic temperature (time derivative) is close to being in phase with Greenland temperature variations apart from a short 200 y offset (WAIS Divide Project Members, 2015). Iberian margin sediments can be used to test if similar phasing patterns existed in older glacial periods, consistent with the operation of a bipolar seesaw (e.g., Margari et al. [2010]). Determining the phase relationships of coregistered signals in a single core circumvents many of the problems associated with core-to-core correlation and developing age models that are accurate on millennial timescales.

4.5. North Atlantic thermohaline circulation

The most widely invoked explanation of past abrupt climate variability and its "asymmetrical" interhemispheric (Greenland vs. Antarctica) phasing is based on the occurrence of major perturbations to the AMOC (for a review, see Alley [2007]). Production of Northern Component Water is thought to have been stronger during the warmer, longer Greenland interstadials (e.g., IS 8, 12, and 14) and reduced during Greenland stadials, especially during Heinrich events (Hodell et al., 2010; Kissel et al., 2008; Piotrowski et al., 2008; Henry et al., 2016). Previous work using sediments from the Iberian margin has confirmed (with particularly firm chronostratigraphic constraints) the link between past interhemispheric climate change and perturbations to the deep Atlantic circulation system. Thus, changes in deepwater radiocarbon concentration (Skinner and Shackleton, 2004; Skinner et al., 2021), oxygenation (Martrat et al., 2007; Skinner et al., 2003), temperature (Skinner et al., 2003, 2007), remineralized nutrient content (Shackleton et al., 2000; Skinner et al., 2007; Willamowski and Zahn, 2000), and lateral export rates (Gherardi et al., 2005) have all been linked to abrupt climatic changes that occurred in the recent geological past. These reconstructions have marked out hydrographic changes on the Iberian margin as a highly sensitive gauge of changes in the deep overturning circulation, in particular because of their sensitivity to changes in the representation of northern- and southern-sourced deep waters in the northeast Atlantic (e.g., Martrat et al. [2007]; Skinner et al. [2007]). Indeed, it is precisely the tight connection between deepwater circulation on the Iberian margin and the bipolar seesaw that lies at the heart of Shackleton's initial observation of northern and southern signals recorded simultaneously in Core MD95-2042 (Shackleton et al., 2000).

There is clearly a compelling case to be made for extending the types of reconstructions noted above (including benthic $\delta^{13}C$ as a proxy for deepwater sourcing and "ventilation" in particular) beyond the last few glacial cycles to parallel the Antarctic ice core range and to extend still further back in time. Furthermore, by covering a range of water depths (1304–4686 mbsl), we will be able to analyze important aspects of past changes in the overturning circulation with especially strong stratigraphic constraints. For example, variations in the amplitude and rapidity of vertical displacements of water masses can be related to past changes in biogeochemical cycling.

We envisage that cores recovered during Expedition 397 together with those drilled during Expedition 339 will provide the basis for "reference" sections of temporal water column variability in the northeast Atlantic. This material will prove invaluable for assessing the expression and impacts of abrupt ocean circulation change in the past, especially as this relates to interhemispheric climate phasing and glacial–interglacial climate evolution.

4.6. Terrestrial changes

Marine archives recovered adjacent to the continents have the potential to link continental and marine climate records because they are influenced directly by continental inputs, such as sediment from rivers and winds. The western Iberian margin has emerged as a critical area for studying continent-ocean connections because of the combined effects of major river systems and a narrow continental shelf that lead to the rapid delivery of terrestrial material (e.g., pollen and organic biomarkers) to the deep-sea environment (Margari et al., 2014, 2020; Oliveira et al., 2017; Rodrigues et al., 2017; Sánchez Goñi et al., 2016; Tzedakis et al., 2015). In the southern Portuguese margin, eolian pollen transport is limited by the direction of the prevailing offshore winds and pollen is mainly transported to the abyssal sites by the sediments carried by the Tagus River (Margari et al., 2010, 2014, 2020; Naughton et al., 2007; Roucoux et al., 2001; Sánchez-Goñi et al., 2000). Comparison of modern marine and terrestrial samples along western Iberia has shown that the marine pollen assemblages provide an integrated picture of the regional vegetation on the adjacent continent. Moreover, modern biogeographical differences in the distribution of Atlantic and Mediterranean plant communities are reflected in the pollen signal of northern and southern marine pollen spectra, respectively (Naughton et al., 2007). Thus, the Portuguese margin provides a rare opportunity to (1) enhance the study of ocean-continent linkages by analyzing proxies for continental hydrology and vegetation (e.g., pollen, elemental ratio data in bulk sediments, and molecular and isotopic composition of leaf waxes) in marine sediment cores that can be precisely correlated to polar ice cores and (2) to construct the longest continuous record of late Miocene–Pleistocene vegetation changes available anywhere to date. A detailed pollen record from the Portuguese margin linked to the marine isotopic stratigraphy and record of millennial-scale variability will be a unique resource that can be used to place vegetation changes in the context of global and North Atlantic climate changes. Comparisons with terrestrial pollen reference sequences, such as Tenaghi Philippon, Greece (Tzedakis et al., 2006), and with International Continental Scientific Drilling Program (ICDP) sites from Lake Ohrid (Albania/Macedonia) and Lake Van (Turkey) will assess patterns of geographical variation. In addition, correlation of Iberian margin proxies to European speleothems offers the opportunity to tie marine records to a radiometric timescale using U-Th and U-Pb isotopes (e.g., Tzedakis et al., 2018; Bajo et al., 2020).

Questions to be addressed include the following:

- How do major vegetation changes over the course of the Pliocene–Pleistocene relate to shifts in climatic regimes (e.g., intensification of NHG, mid-Pleistocene transition)?
- Did the Mediterranean-type seasonal precipitation rhythm appear at ~3.6 Ma (Suc and Popescu, 2005; Suc, 1984) or intermittently during the course of the late Miocene and Pliocene (Tzedakis, 2007)?
- Did the intensification of NHG lead to an increase in species extinction rates?
- Are these changes in vegetation communities synchronous between the Eastern and Western Mediterranean?
- What was the phase relationship between terrestrial vegetation and marine-atmospheric parameters during periods of rapid climate change?

4.7. History of upwelling on the Portuguese margin

The location of Portugal on the western extreme of the European continent results in very specific oceanographic conditions. The upper ocean circulation is characterized by two completely different circulation regimes in Spring–Summer and Fall–Winter. During the upwelling season, the fairly strong and steady northerly winds induce coastal upwelling of nutrient-rich ENACW with the filaments of upwelled waters (off the capes) penetrating more than 200 km offshore into the open ocean (Fiúza, 1984; Fiúza et al., 1998; Sousa and Bricaud, 1992). These nutrient-rich waters generate a transition zone between the oligotrophic water offshore and the highly productive area near the coast.

This upwelling process leaves a clear imprint in the sediments covering the ocean bottom in the area, including physical properties, geochemistry, diatom and planktonic foraminiferal assemblage composition, and their geographic distribution (Abrantes, 1988; Abrantes and Moita, 1999;

Salgueiro et al., 2008). The past geological variability of the upwelling has been studied both on orbital and millennial timescales. At the glacial–interglacial scale, an increase in diatom accumulation rates, which is in good agreement with other independent productivity proxies, has been interpreted to represent an order of magnitude increase in productivity during the previous glacial periods, not only on the Portuguese margin but in both hemispheres of the eastern Atlantic (Abrantes, 1991, 2000). Abrantes et al. (1998) suggested increased primary production associated with Heinrich events off the Portuguese coast, whereas the high-resolution planktonic foraminifer study of three sites located along the Iberian margin indicates a more complex north–south pattern (Salgueiro et al., 2010). Primary productivity decreased markedly during stadials and Heinrich events on the northern margin but increased off Sines in the region of influence of the Cape da Roca filament and near the "Shackleton sites." The possibility of drilling this region will allow us to conduct a multiproxy study and determine the response of the local upwelling conditions as well as the biotic response to global climate change, including its resilience and recovery time, and address questions such as: How did the ecosystem respond to rapid climatic changes? What were the rates of change? Is it possible to identify a planktonic/benthic coupling? How did the upwelling system evolve with changing glacial boundary conditions in the Pliocene–Pleistocene?

5. Operations plan/Coring strategy

The drilling plan calls for quadruple to quintuple APC coring until refusal using nonmagnetic core barrels, followed by the half-length APC (HLAPC) system, and finally by triple extended core barrel (XCB) coring. Experience gained during Expedition 339 suggests that APC refusal will occur near 200 mbsf and the XCB will be effective (high recovery and good quality core) to at least 350 mbsf or deeper. These depths have been marked by horizontal dashed lines on the seismic profiles in Figures F9–F14. An APC/XCB bottom-hole assembly (BHA) with a polycrystalline diamond compact (PDC) bit was found to work best in clay-rich sediment encountered during Expedition 339. Emphasis will be placed on recovering complete composite sections in the depth range achievable using the APC system because the best quality cores are needed for establishing high-resolution stratigraphies. Once the full-length APC system has reached refusal, we intend to use the HLAPC system, which has a 4.7 m long core barrel. Use of the HLAPC system should significantly increase the depth to which the section can be recovered by APC. The superior core quality of the APC system compared to the XCB system is worth the extra wire time investment. Once the HLAPC system reaches refusal, we will switch to the XCB system and proceed to the maximum planned penetration depth if core quality remains good (Tables **T1**, **T2**). The deepest hole at each site will be logged with the triple combo tool.

In anticipation of the high sampling demand for these cores, we propose to drill four or five holes per site using the APC system for the Quaternary and produce two complete composite sections to meet immediate and future sampling needs. High-resolution sampling is required to capture MCV even in regions of high sediment accumulation rates such as the Portuguese margin. We will need to acquire more sediment than is normally considered necessary to accommodate the high sample demand as well as archiving core material for future studies. This is a lesson learned from Site U1385 where the four APC holes recovered were insufficient to fully meet the sample demand. In the absence of wider diameter cores, this can only be achieved by drilling many parallel holes at each site and making detailed (bed-to-bed) correlations among them (Hodell et al., 2015). For the deeper part of each site, we will use a triple XCB strategy to obtain a single spliced stratigraphic section.

The operations plan includes ~55 days of ship time that is divided into approximately 4 days of transit, 49 days of drilling, and 2 days of downhole logging. Because transit times between sites are short there will be little time for catching up with core processing between sites; thus, we will have to adhere to a strict schedule of core flow in the laboratory during drilling and logging operations.

5.1. Proposed drill sites

The sites are described from deepest (Proposed Site SHACK-11B) to shallowest (Proposed Site SHACK-10B), which is the proposed order of drilling during Expedition 397. The rationale for the

Table T1. Operations plan and time estimates for primary sites, Expedition 397. Maximum penetration depth approved by Environmental Protection and Safety Panel (EPSP) is shown under each site number. mbrf = meters below rig floor. APC = advanced piston corer, HLAPC= half-length APC, XCB = extended core barrel, APCT-3 = advanced piston corer temperature.

Site	Location (latitude, longitude)	Seafloor depth (mbrf)	Operations description		Transit (days)	Drilling/ Coring (days)	Logging (days)
Lisbon			Start of Expedition	5.0	Port call days		
			Transit ~98 nmi to SHACK-11B @ 10.5 kt		0.4		
SHACK-11B	37°37.3110'N	4697	Hole A - APC/HLAPC/XCB to 350 mbsf - Orientation and APCT-3		0.0	3.8	0.0
EPSP	10°42.5982'W		Hole B - APC/HLAPC/XCB to 350 mbsf - Orientation		0.0	2.9	0.0
to 350 mbsf			Hole C - APC/HLAPC/XCB to 350 mbsf - Orientation - Log with triple combo		0.0	2.9	0.6
			Hole D - APC/HLAPC to 250 mbsf - Orientation		0.0	2.1	0.0
			Hole E - APC/HLAPC to 250 mbsf - Orientation		0.0	2.5	0.0
			Subtotal days on site:	14.8			
			Transit ~17 nmi to SHACK-14A @ 8.0 kt		0.1		
SHACK-14A	37°34.8600'N	3467	Hole A - APC/HLAPC/XCB to 500 mbsf - Orientation and APCT-3		0.0	3.9	0.0
EPSP	10°21.5400'W		Hole B - APC/HLAPC/XCB to 500 mbsf - Orientation		0.0	3.5	0.0
to 500 mbsf			Hole C - APC/HLAPC/XCB to 500 mbsf - Orientation		0.0	3.5	0.0
			Hole D - APC/HLAPC/XCB to 500 mbsf - Orientation - Log with triple combo		0.0	3.9	0.4
			Subtotal days on site:	15.4			
			Transit ~11 nmi to SHACK-04C @ 10.0 kt		0.0		
SHACK-04C	37°34.0002'N	2596	Hole A - APC/HLAPC/XCB to 400 mbsf - Orientation		0.0	2.7	0.0
EPSP	10°7.6644'W		Hole B - APC/HLAPC/XCB to 400 mbsf - Orientation		0.0	2.4	0.0
to 400 mbsf			Hole C - APC/HLAPC/XCB to 400 mbsf - Orientation		0.0	2.4	0.0
			Hole D - APC/HLAPC/XCB to 400 mbsf - Orientation - Log with triple combo		0.0	2.7	0.5
			Subtotal days on site:	10.7			
			Transit ~37 nmi to SHACK-10B @ 10.0 kt		0.2		
SHACK-10B	37°57.6042'N	1315	Hole A - APC/HLAPC/SCB to 500 mbsf - Orientation and APCT-3		0.0	2.9	0.0
EPSP	9°30.9954'W		Hole B - APC/HLAPC/XCB to 500 mbsf - Orientation		0.0	2.4	0.0
to 500 mbsf			Hole C - APC/HLAPC/XCB to 500 mbsf - Orientation - Log with triple combo		0.0	2.4	0.5
			Hole D - APC/HLAPC to 250 mbsf - Orientation		0.0	1.1	0.0
			Hole E - APC/HLAPC to 250 mbsf - Orientation		0.0	1.3	0.0
			Subtotal days on site:	10.6			
			Transit ~776 nmi to Tarragona @ 10.5 kt		3.1		
Tarragona			End of Expedition		3.7	49.4	2.1

Port call days:	5.0	Total operating days:	55.2
Subtotal days on site:	51.5	Total expedition days:	60.2

Table T2. Operations plan and time estimates for alternate sites, Expedition 397. Maximum penetration depth approved by Environmental Protection and Safety Panel (EPSP) is shown under each site number. mbrf = meters below rig floor. APC = advanced piston corer, HLAPC= half-length APC, XCB = extended core barrel, APCT-3 = advanced piston corer temperature.

Site	Location (latitude, longitude)	Seafloor depth (mbrf)	Operations description		Drilling/ Coring (days)	Logging (days)
SHACK-16B	37°31.8000'N	2742	Hole A - APC/HLAPC to 250 mbsf - Orientation and APCT-3		1.9	0.0
EPSP	10°8.5200'W		Hole B - APC/HLAPC to 250 mbsf - Orientation		1.6	0.0
to 450 mbsf			Hole C - APC/HLAPC/XCB to 450 mbsf - Orientation		2.8	0.0
			Hole D - APC/HLAPC/XCB to 450 mbsf - Orientation		2.8	0.0
			Hole E - APC/HLAPC/XCB to 450 mbsf - Orientation - Log with triple combo		3.1	0.4
			Subtotal days on site:	12.6		
SHACK-17A	37°48.1746'N	3208	Hole A - APC/HLAPC to 250 mbsf - Orientation and APCT-3		2.1	0.0
EPSP	10°10.7772'W		Hole B - APC/HLAPC to 250 mbsf - Orientation		1.7	0.0
to 550 mbsf			Hole C - APC/HLAPC/XCB to 550 mbsf - Orientation		3.7	0.0
			Hole D - APC/HLAPC/XCB to 550 mbsf - Orientation		3.7	0.0
			Hole E - APC/HLAPC/XCB to 550 mbsf - Orientation - Log with triple combo		4.0	0.5
			Subtotal days on site:	15.8		

order is the fact that the shallowest Site SHACK-10B (1315 m) is the lowest priority one because of the many sites drilled during Expedition 339 that targeted sites at intermediate water depths beneath the MOW. In addition, the time between cores on deck will be greatest at the deepest site which will provide more time for scientists to train at the beginning of the expedition.

5.1.1. Site SHACK-11B

The primary scientific objective of Proposed Site SHACK-11B is to recover a deep distal record from 4686 mbsl near the toe of the PPA under the influence of LDW (i.e., modified Antarctic Bottom Water). Because the site is both the deepest and furthest from shore, the sedimentation rates will be lower than the other sites and are estimated to be ~5 cm/ky. As a result, we should recover a complete latest Miocene–Quaternary sequence to 350 mbsf. This site will provide a history of deepwater circulation through the Pliocene warm period and during the intensification of NHG at 2.9 Ma. The great depth of this site may result in dissolution of carbonate microfossils, although the piston core recovered at the same location has continuous preservation of foraminifers. We are also expecting to obtain the latest Miocene at this site, which will be important for studying the deep circulation during the Messinian salinity crisis.

Site SHACK-11B is located on Cruise JC089 Line 2 near the intersection of Line 3 (Figure **F9**). The targeted depth (upper Miocene; around 6.6 s TWT) corresponds to a high-amplitude reflection. There are some potentially disturbed intervals beneath the target depth; however, we do not intend to penetrate to these deeper levels. Some of the disturbed features may be related to air gun source timing issues during data acquisition, which also cause the seabed to appear as a double reflection in Lines 1 and 2. Because of its location, there is a possibility for this site to be affected by thin distal turbidites, although they are not apparent on the seismic profiles.

5.1.2. Site SHACK-14A (primary)/Site SHACK-17A (alternate)

Proposed Site SHACK-14A is in a water depth of 3467 mbsl (Figure **F10**), and OMPA indicates a mixture of 25% LDW and 75% NEADW at the site today (Jenkins et al., 2015). The main objective is to reconstruct the Pliocene–Pleistocene history of circulation change in the deep North Atlantic near the boundary between NEADW and LDW (Figure **F5**). Sedimentation rates are estimated to be ~10 cm/ky to the top of the upper Pliocene. We have permission from the EPSP to drill to 500 mbsf (beyond the orange reflector, upper Pliocene; ~3.6 Ma), which would capture the entire Quaternary and much of the Pliocene to ~4 Ma. Proposed Site SHACK-17A serves as an alternate site to Site SHACK-14A.

5.1.3. Site SHACK-17A (alternate)

Proposed Site SHACK-17A is in 3197 m of water (Figure **F11**) and is mostly influenced by NEADW today but was sensitive to past changes in the mixing ratio of southern and northern component water throughout the Pleistocene. The upper Pliocene to lower Quaternary sequence is exceptionally thick at this location and will provide a very high resolution record. The piston core (JC089-07) at this site is 10.2 m long and has a sedimentation rate of 17 cm/ky. The site is close to piston Cores MD95-2042 and MD99-2334K, which have become important reference sections for millennial-scale paleoceanographic reconstruction (Margari et al., 2010; Shackleton et al., 2000, 2004; Skinner and Shackleton, 2006; Skinner and Elderfield, 2007). Core MD95-2042 is 32.5 m long and covers the period from the Holocene to MIS 6 (194 ka) with a sedimentation rate of 18 cm/ky.

The proposed penetration depth is 550 mbsf, which will include the entire Quaternary and late Pliocene to the time of intensification of NHG (2.9 Ma).

Site SHACK-17A serves as an alternate site to Site SHACK-14A.

5.1.4. Site SHACK-4C (primary)/Site SHACK-16B (alternate)

Proposed Site SHACK-4C is in a water depth of 2585 mbsl and is located 1 km southwest of Site U1385 and piston Core MD01-2444 (Figure **F12**). With 4 days of drilling at Site U1385, we were able to drill to a maximum depth of 156 mbsf (1.45 Ma) in four holes (Expedition 339 Scientists, 2013b). The section is largely undisturbed except for a few minor deformation features (microfaults and contorted strata) that do not extend across holes (see Table T5 of Expedition 339 Scientists [2013b]). The sediment lithology consists of uniform nannofossil muds and clays, with varying proportions of biogenic carbonate and terrigenous sediment (Expedition 339 Scientists, 2013b). The mean sedimentation rate is 11 cm/ky over the last 1.45 My, and we expect the sedimentation rates to be similar throughout the Quaternary.

The objective of Site SHACK-4C is to recover the deeper part of the section below Site U1385 to the base of the upper Pliocene (orange reflector) at 400 mbsf (Figure F8), which will more than

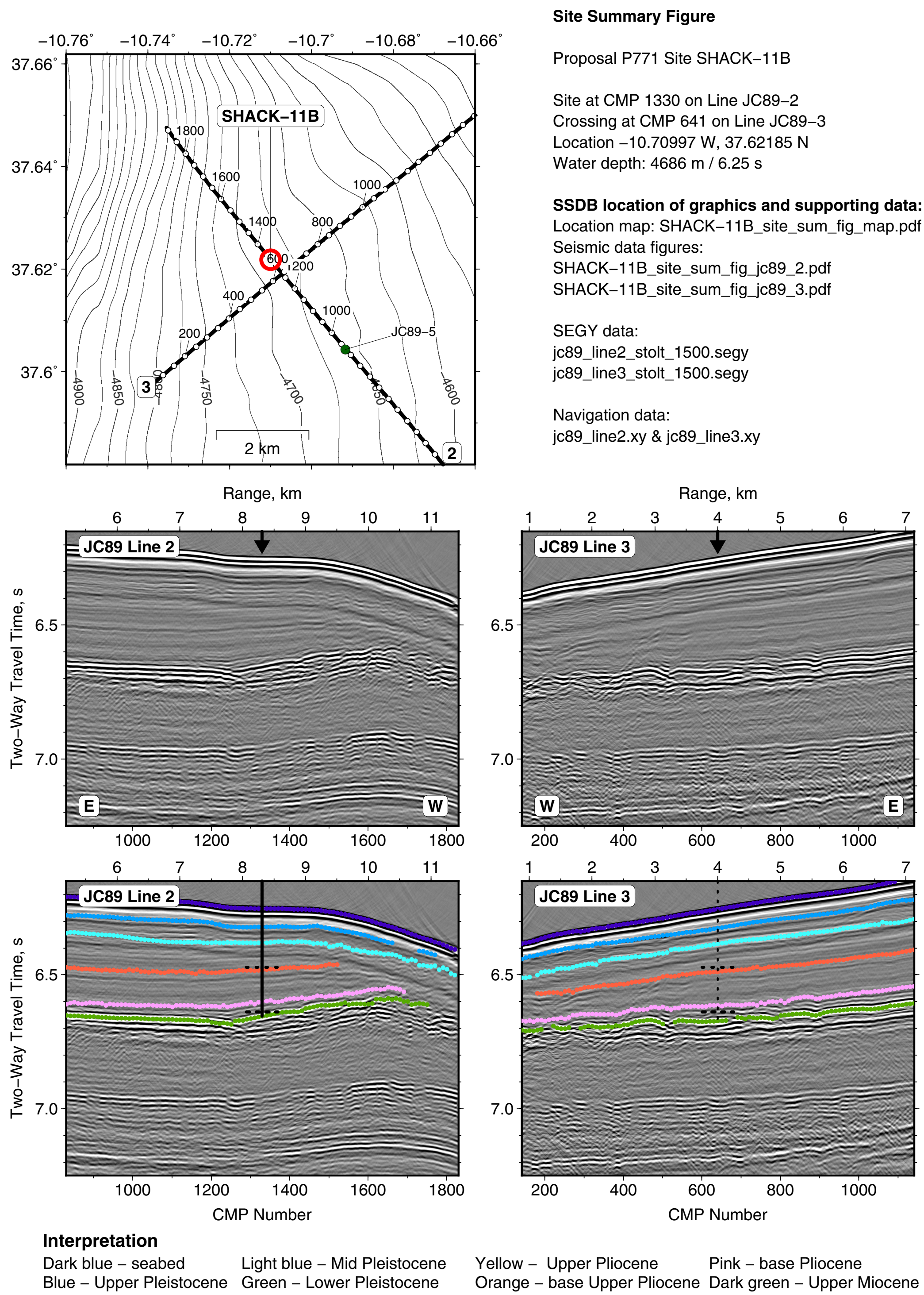

Figure F9. Location and seismic lines, Site SHACK-11B (deepest and furthest offshore site to be drilled during Expedition 397). Objective is to drill to dark green reflector (~350 m) estimated to correspond to upper Miocene. Dashed horizontal lines = estimated penetration by APC (~200 mbsf) and XCB (350 mbsf). CMP = common midpoint.

double the section recovered at Site U1385. The uppermost 150 m of Site SHACK-4C will duplicate the record from Site U1385, which is necessary because the existing working halves of the cores were completely sampled and no material remains for future studies. Drilling at Site SHACK-4C will extend the record of Site U1385 through the entire Quaternary and into the upper Pliocene (~3.6 Ma) prior to the intensification of NHG. The water depth of the site (2585 mbsl) places it in the core of NEADW today (Figure **F5**).

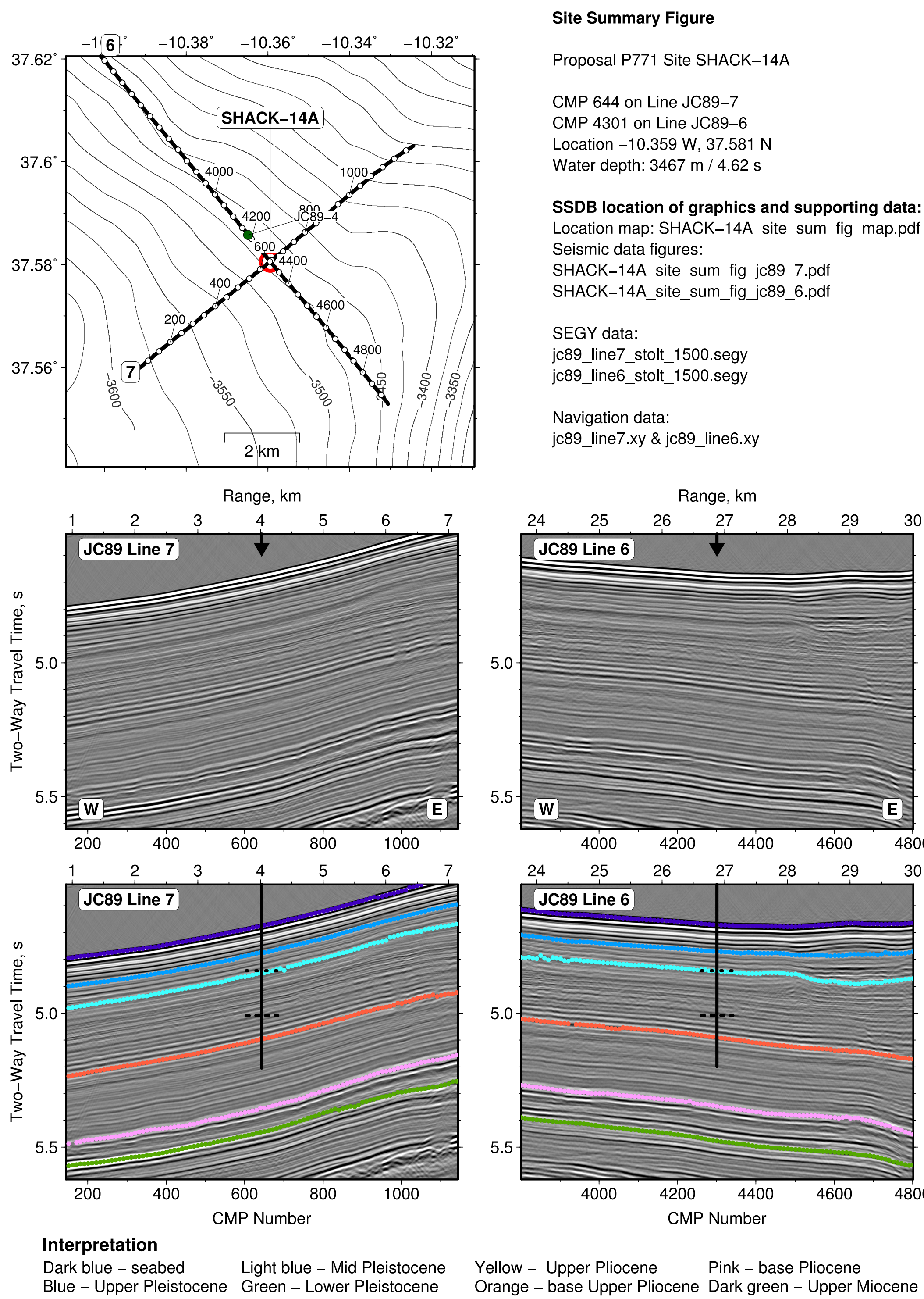

Figure F10. Location map and seismic lines, Site SHACK-14A. We have permission to drill to 500 mbsf, which is below orange reflector estimated to correspond to base of upper Pliocene. Dashed horizontal lines = estimated penetration by APC (~200 mbsf) and XCB (350 mbsf).

5.1.5. Site SHACK-16B (alternate)

Proposed Site SHACK-16B is the alternate site to Proposed Site SHACK-4C and is located 5.3 km south of Site SHACK-4C in a water depth of 2731 mbsl (Figure F13).

The objectives are the same as Site SHACK-4C.

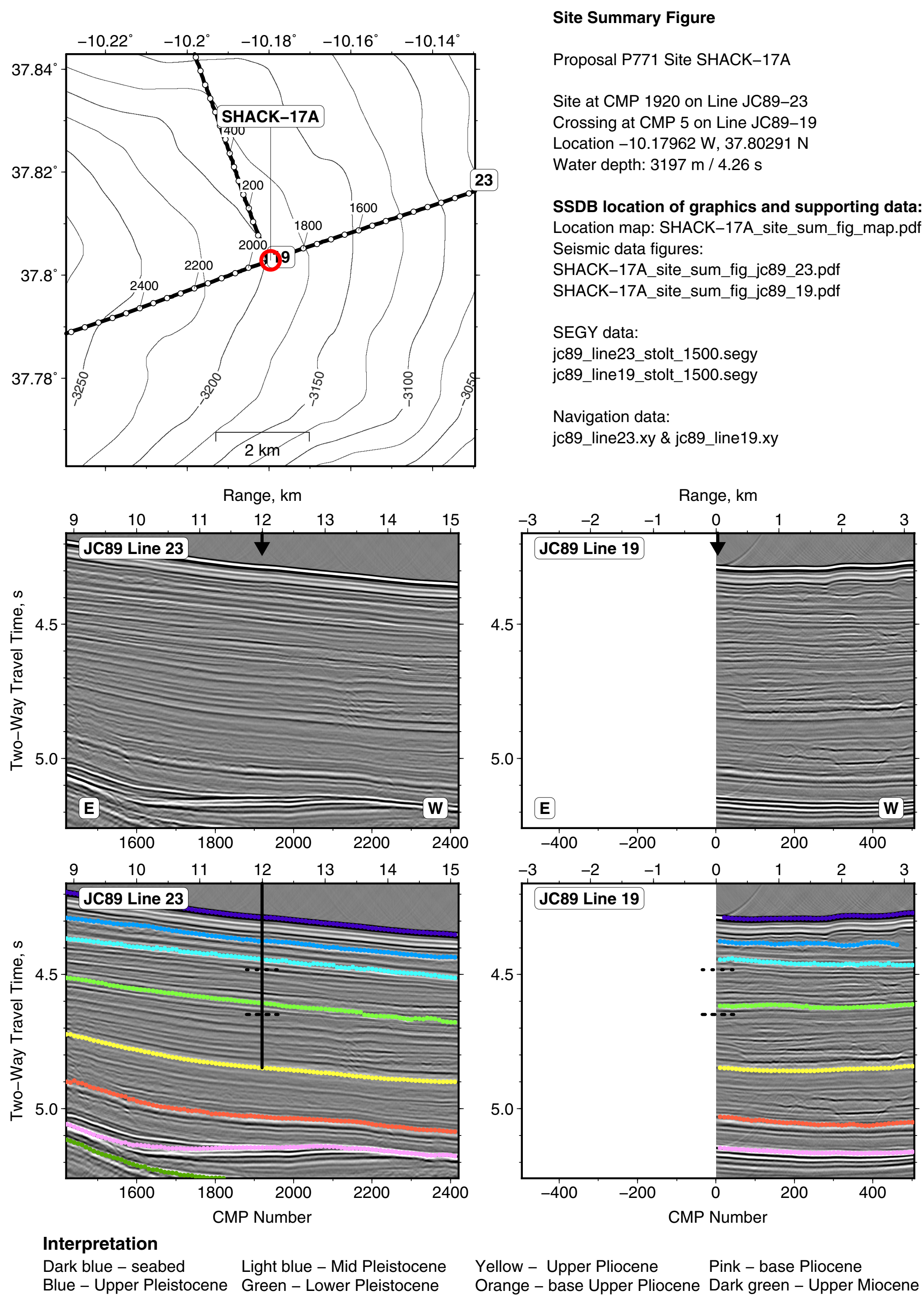

Figure F11. Location map and seismic lines, Site SHACK-17A. Alternate site to Site SHACK-14A and would provide an ultra-high resolution record from upper Pliocene (yellow reflector) to recent. Dashed horizontal lines = estimated penetration by APC (~200 mbsf) and XCB (350 mbsf).

5.1.6. Site SHACK-10B

Proposed Site SHACK-10B is closest to the coast and the shallowest of the proposed depth transect (1304 mbsl). The site is located on a drift deposit formed under the influence of the lower MOW and lies on the broad, gently inclined middle-slope region of the PPA (Figures F2, F6), on which the seismic data indicate an extensive plastered drift deposit (Figure F14).

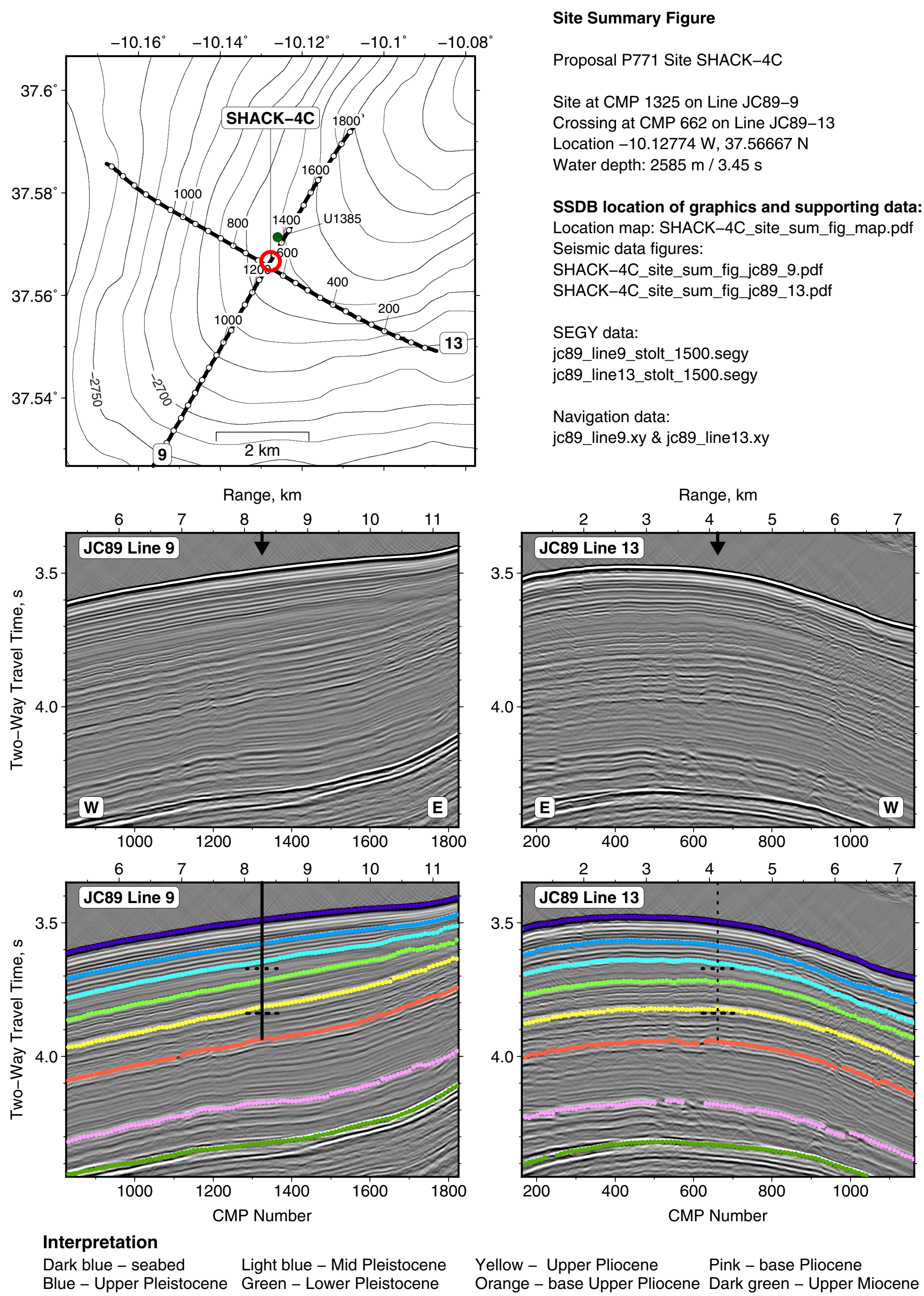

Figure F12. Location map and seismic lines, Site SHACK-4C (near Site U1385). Objective is to extend 1.5 My record of Site U1385 to base of upper Pliocene (3.6 Ma; orange reflector) prior to intensification of NHG. Dashed horizontal lines = estimated penetration by APC (~200 mbsf) and XCB (350 mbsf).

Site SHACK-10B is located on the distal part of the contourite system (southwest Iberian margin), and complements Sites U1386–U1391 drilled during Expedition 339. We expect to recover a continuous late Miocene to Quaternary sedimentary record at high sedimentation rates. The primary objective is to drill to 500 mbsf and recover a Pliocene–Pleistocene sedimentary succession formed under the influence of lower MOW (Hernández-Molina et al., 2014). The piston core from Site SHACK-10B indicates a sedimentation rate of 20 cm/ky, which is the highest rate of the sites.

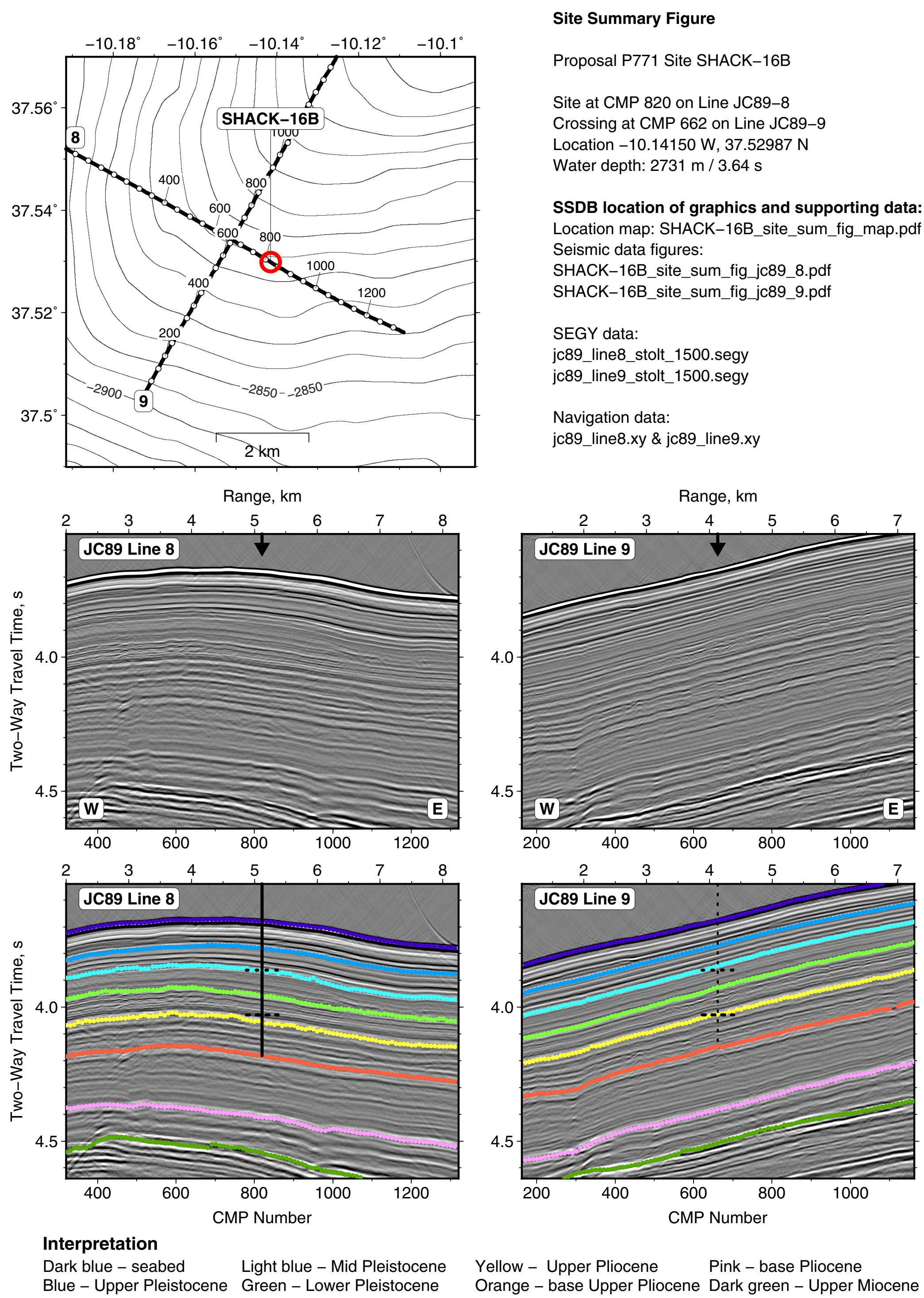

Figure F13. Location map and seismic lines, Site SHACK-16B. Alternate site to Site SHACK-4C. Objective is to extend 1.5 My record of Site U1385 to base of upper Pliocene (3.6 Ma; orange reflector). Dashed horizontal lines = estimated penetration by APC (~200 mbsf) and XCB (350 mbsf).

The high accumulation rates associated with contourite deposition provide an expanded sedimentary record that will permit detailed examination of paleocirculation patterns linked to past environmental change. The record at this site will provide a direct comparison with hemipelagic sedimentation at the deeper sites, which are removed from contourite input and under the influence of NEADW and LDW.

The section at Site SHACK-10B is expected to be similar to Site U1391, which was drilled in a water depth of 1085 mbsl and located 70 km south-southeast of Site SHACK-10B (Figure **F3**). At

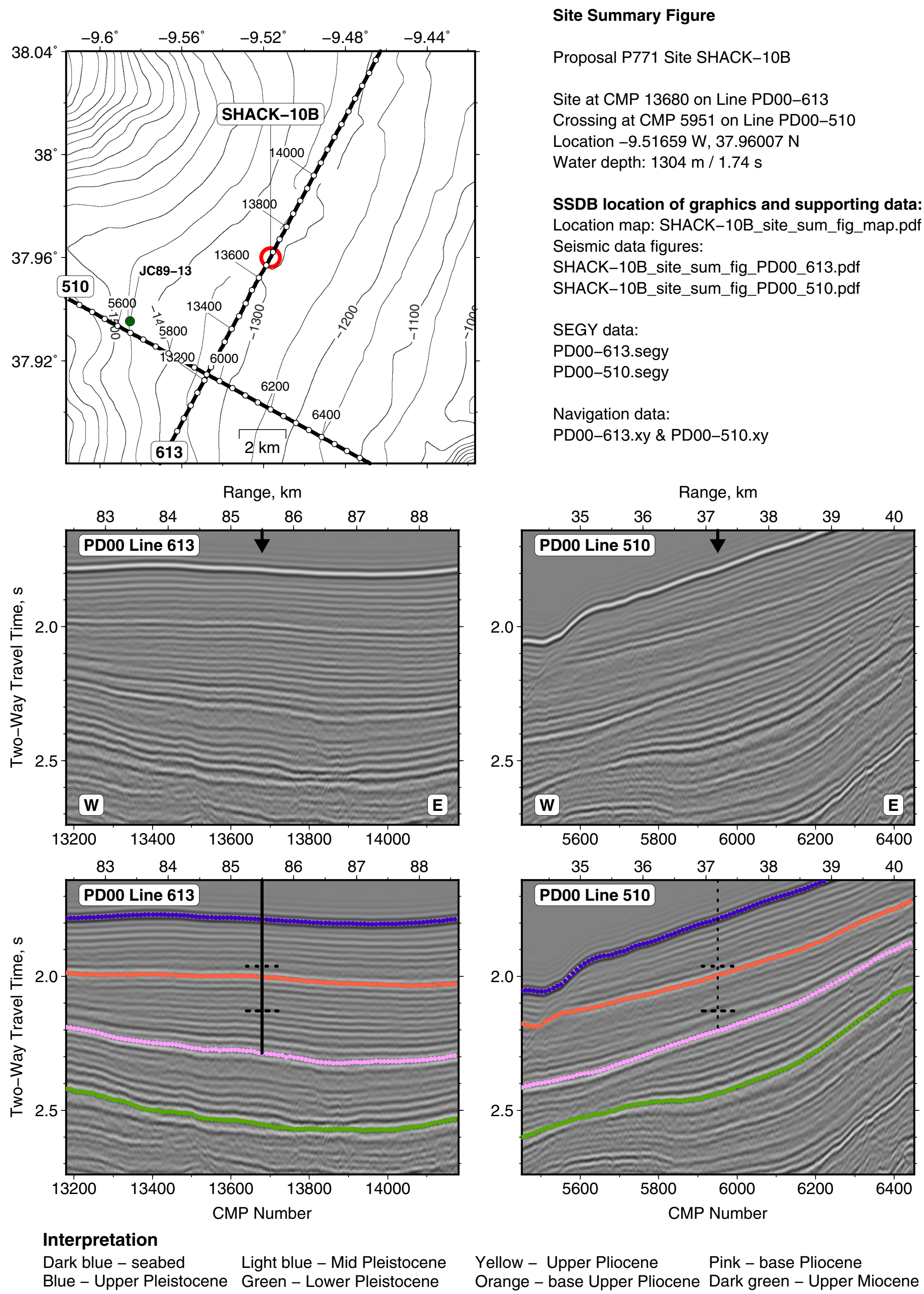

Figure F14. Location map and seismic lines, Site SHACK-10B. Objective is to drill to 500 mbsf corresponding to base of Pliocene (pink reflector). Dashed horizontal lines = estimated penetration by APC (~200 mbsf) and XCB (350 mbsf).

Site U1391, three holes were drilled and cored using the APC, XCB, and rotary core barrel (RCB) systems, reached a total depth of 672 mbsf. The sedimentary succession extends from the mid-Pliocene to Holocene and is represented by a thick, very uniform series of mud-rich contouritic sediment, with rapid rates of sedimentation during the late Quaternary (Expedition 339 Scientists, 2013a).

6. Wireline logging/Downhole measurements strategy

The primary operations plan includes deployment of the advanced piston corer temperature (APCT-3) tool to record formation temperature measurements at all sites except for Site SHACK-4C. Formation temperature measurements were recorded at this site's location during Expedition 339 (Site U1385).

We plan to use the triple combo tool string at each site. The triple combo tool string measures density, natural gamma radiation (NGR), porosity, and resistivity, along with borehole diameter (caliper log). The caliper log will allow an assessment of hole conditions and the potential for success of subsequent logging runs. NGR data gathered by the triple combo will enable correlation with NGR measurements collected from the cores. Integration of wireline logging data with core data will allow for core-log-seismic integration and correlation to the regional lithostratigraphy. For more information on the downhole logging tools, see **http://iodp.tamu.edu/tools/logging**.

7. Risks and contingency

We identified the following potential risks associated with Expedition 397 that have been mitigated to the extent possible:

- Man-made hazards/risks: Numerous underwater communication cables exist in the region, which required interaction with cable companies to verify approved operating distances. All sites have been located at a minimum distance of 1.3 km (i.e., Site Shack-10B) from the known position of all cables in the area.
- Shipping lanes: Site SHACK-10B is located in the shipping management area off Portugal. During the site survey cruise, we provided our area of operations 72 h in advance to the Instituto Hidrografico (IHPT) who provides Notices to Mariners by NAVTEX broadcast in both English and Portuguese. Security messages from the ship were also relayed on VHF Channel 72.
- Natural hazards: The seismic lines do not show consistent evidence of fluid flow affecting the sedimentary sequence at the proposed sites; thus, we consider shallow drilling hazards to be minimal.
- High recovery: More than 6 km of core is expected to be recovered during Expedition 397. Such high core recovery and handling poses a risk of injury to drillers, technicians, and scientists because of the physical demands required to recover and process that much core. There is also little transit time between sites leaving very little time for catch up or downtime.

No contingency time is allocated in the operations plan, but sites will be drilled in order of priority with the last site (SHACK-10B) being the lowest priority. Any delays to the schedule will be accommodated by decreasing the penetration depth at Site SHACK-10B.

The drilling sites are in Portugal's Exclusive Economic Zone, and obtaining clearance to drill will be necessary.

COVID-19 continues to be a significant risk, and contingency plans are in place for a reduced science and technical party should conditions warrant. It may involve reduced core processing and analysis during the expedition with a shift toward increased shore-based activities during and/or after the expedition.

8. Sampling and data sharing strategy

Shipboard and shore-based researchers should refer to the IODP Sample, Data, and Obligations Policy and Implementation Guidelines posted on the Web at **http://www.iodp.org/top-resources/program-documents/policies-and-guidelines**. This document outlines the policy for distributing IODP samples and data to research scientists, curators, and educators. The document also defines the obligations that sample and data recipients incur. The Sample Allocation Committee (SAC; composed of Co-Chief Scientists, Staff Scientist, and IODP Curator on shore and curatorial representative on board the ship) will work with the entire scientific party to formulate a formal expedition-specific sampling plan for shipboard and postcruise sampling.

Every member of the science party is obligated to carry out scientific research for the expedition and publish the results. Shipboard scientists are expected to submit sample requests (at **http://iodp.tamu.edu/curation/samples.html**) ~6 months before the beginning of the expedition. Based on sample requests (shore based and shipboard) submitted by this deadline, the SAC will prepare a tentative sampling plan, which will be revised on the ship as dictated by core recovery and cruise objectives. The sampling plan will be subject to modification depending upon the actual material recovered and collaborations that may evolve between scientists during the expedition. Modification of the strategy during the expedition must be approved by the Co-Chief Scientists, Staff Scientist, and curatorial representative on board the ship.

Given the specific objectives of Expedition 397, great care will be taken to maximize shared sampling to promote integration of data sets and enhance scientific collaboration among members of the scientific party so that our scientific objectives are met and each scientist has the opportunity to contribute. All sample sizes and frequencies must be justified on a scientific basis and will depend on core recovery, the full spectrum of other requests, and the expedition objectives. Some redundancy of measurement is unavoidable, but minimizing the duplication of measurements among the shipboard party and identified shore-based collaborators will be a major factor in evaluating sample requests. If critical intervals are recovered, there may be considerable demand for samples from a limited amount of cored material. These intervals may require special handling, a higher sampling density, reduced sample size, or continuous core sampling by a single investigator. A sampling plan coordinated by the SAC may be required before critical intervals are sampled. Substantial collaboration and cooperation will be required. The SAC may require an additional formal sampling plan before critical intervals are sampled, and a special sampling plan will be developed to maximize scientific return and scientific participation and to preserve some material for future studies. The SAC can decide at any stage during the expedition or during the 1 y moratorium period which recovered intervals should be considered critical.

Shipboard sampling will be restricted to acquiring ephemeral data types and shipboard measurements. Whole-round samples may be taken for interstitial water measurements and physical property measurements as dictated by the shipboard sampling plan that will be finalized during the first few days of the expedition. The majority of the sampling for postcruise research will be postponed until a shore-based sampling party that will be implemented approximately 4–6 months after the end of the expedition at the Bremen Core Repository (BCR) in Bremen, Germany. All shipboard and approved shore-based scientists, students, and collaborators will be invited to help collect the thousands of anticipated samples.

The data collected during the expedition will be used to produce stratigraphic spliced sections and age models for each site, which are critical to the overall objectives of the expedition and for planning for higher resolution sampling postexpedition. The minimum permanent archive will be the standard archive half of each core and will not be sampled on board the ship. Following the expedition, the IODP Curator will finalize the selection of archive halves designated as permanent over any intervals recovered from multiple holes at a site.

Following Expedition 397, the core working halves will be delivered to the BCR. However, the archive halves may be shipped to the IODP Gulf Coast Repository in College Station, Texas (USA), the Center for Marine Environmental Sciences (MARUM) at the University of Bremen (Germany), the University of Cambridge (United Kingdom), the Portuguese Institute for the Sea and Atmosphere (IPMA) in Lisbon (Portugal), and possibly other facilities for postcruise programmatic XRF core scanning. XRF core scanning of cores from Site U1385 proved invaluable for constructing the composite section and provided the first record of millennial variability in sediment lithology (Hodell et al., 2015). XRF data will also be important for correlation from site-to-site along the depth transect (Figure **F8**). Upon completion of these measurements, the archive halves of the cores will be sent to the BCR for permanent storage.

All collected data and samples will be protected by a 1 y moratorium period following the completion of the postexpedition sampling party. During this time, data and samples will be available only to the Expedition 397 shipboard participants and approved shore-based scientists.

9. Expedition scientists and scientific participants

The current list of participants for Expedition 397 can be found at **http://iodp.tamu.edu/science-ops/expeditions/iberian_margin_paleoclimate.html**.

10. Acknowledgments

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Site summaries

Site SHACK-4C

Priority:	Primary
Position:	37°34.0002′N; 10°7.6644′W
Water depth (m):	2585
Target drilling depth (mbsf):	400
Approved maximum penetration (mbsf):	400
Survey coverage (track map; seismic profile):	Common midpoint (CMP) 1325 on JC089 Line 9 CMP 662 on JC089 Line 13 (nearest crossing)
Objective(s):	• Recover millennial-scale marine reference section for the Quaternary and late Pliocene • Extend the record of Site U1385 to the late Pliocene prior to the intensification of NHG • Provide marine sediment analog to the polar ice cores • Surface hydrography and upwelling • Reconstruct deepwater circulation changes from the core of NEADW (i.e., mixing ratio of southern and northern component water) • Facilitate marine-terrestrial correlations • Astronomically-tuned timescale for the Pliocene–Pleistocene
Coring program:	4 holes: APC/HLAPC/XCB to 400 mbsf; orientation PDC bit
Downhole measurements program:	Triple combo tool string
Nature of rock anticipated:	Hemipelagic sediments

Site SHACK-10B

Priority:	Primary
Position:	37°57.6042′N; 9°30.9954′W
Water depth (m):	1304
Target drilling depth (mbsf):	500
Approved maximum penetration (mbsf):	500
Survey coverage (track map; seismic profile):	CMP 13680 at PD00 on Line 613 CMP 5951 at PD00 Line 510 (nearest crossing)
Objective(s):	• Late Miocene–Quaternary history of lower MOW • Significance of MOW on thermohaline circulation • Variability in the strength and depth of the MOW during Pliocene–Pleistocene, including the intensification of NHG • History of MOW at this distal deep site compared to that inferred at more proximal sites to Gibraltar (Hernandez-Molina et al., 2014)?
Coring program:	3 holes: APC/HLAPC/XCB to 500 mbsf; orientation 2 holes: APC/HLAPC to 250 mbsf PDC bit
Downhole measurements program:	Triple combo tool string
Nature of rock anticipated:	Hemipelagic sediments to contourite sequence

Site SHACK-11B

Priority:	Primary
Position:	37°37.3110′N; 10°42.5982′W
Water depth (m):	4686
Target drilling depth (mbsf):	350
Approved maximum penetration (mbsf):	350
Survey coverage (track map; seismic profile):	CMP 1330 at JC089 Line 2 CMP 836 at JC089 Line 1 (nearest crossing)
Objective(s):	• Late Miocene–Pleistocene reference section • History of deep overturning circulation; monitor the influence of northern and southern source deep waters through the late Miocene–Quaternary • Interglacial conditions including Pliocene warm period • History of the intensification of NHG and mid-Pleistocene transitions • late Miocene–Pleistocene record of terrestrial vegetation changes • History of the Atlantic lysocline and carbonate ion variations • Date and identify the nature of acoustic transition at ~6.6 s TWT
Coring program:	3 holes: APC/HLAPC/XCB to 350 mbsf; orientation 2 holes: APC/HLAPC PDC bit
Downhole measurements program:	Triple combo tool string
Nature of rock anticipated:	Hemipelagic sediments

Site SHACK-14A

Priority:	Primary
Position:	37°34.8600′N; 10°21.5400′W
Water depth (m):	3467
Target drilling depth (mbsf):	400
Approved maximum penetration (mbsf):	500
Survey coverage (track map; seismic profile):	CMP 644 on JC089 Line 7 CMP 4301 on JC089 Line 6
Objective(s):	• Pliocene–Pleistocene marine reference section • Reconstruct deepwater circulation changes (i.e., mixing ratio of southern and northern component water) from a site near the mixing zone between LDW and NEADW • History of the intensification of NHG and mid-Pleistocene transition • Pliocene–Pleistocene record of terrestrial vegetation changes
Coring program:	4 holes: APC/HLAPC/XCB to 500 mbsf; orientation PDC bit
Downhole measurements program:	Triple combo tool string
Nature of rock anticipated:	Hemipelagic sediments

Site SHACK-16B

Priority:	Alternate
Position:	37°31.8000′N; 10°8.5200′W
Water depth (m):	2731
Target drilling depth (mbsf):	430
Approved maximum penetration (mbsf):	450
Survey coverage (track map; seismic profile):	CMP 820 on JC089 Line 8 CMP 662 on JC089 Line 9 (nearest crossing)
Objective(s):	• Recover millennial-scale marine reference section for the Quaternary • Provide marine sediment analog to the polar ice cores • Surface hydrography and upwelling • Reconstruct deepwater circulation changes from the core of NEADW (i.e., mixing ratio of southern and northern component water) • Facilitate marine-terrestrial correlations • Astronomically-tuned timescale for the Pliocene–Pleistocene
Coring program:	5 holes: APC/HLAPC/XCB to 450 mbsf; orientation PDC bit
Downhole measurements program:	Triple combo tool string
Nature of rock anticipated:	Hemipelagic sediments

Site SHACK-17A

Priority:	Alternate
Position:	37°48.1746′N; 10°10.7772′W
Water depth (m):	3197
Target drilling depth (mbsf):	550
Approved maximum penetration (mbsf):	550
Survey coverage (track map; seismic profile):	CMP 1920 on JC089 Line 23 CMP 5 on JC089 Line 19
Objective(s):	• Pliocene–Pleistocene marine reference section • Reconstruct deepwater circulation changes (i.e., mixing ratio of southern and northern component water) • History of the intensification of NHG • Pliocene–Pleistocene record of terrestrial vegetation changes
Coring program:	2 holes: APC/HLAPC/XCB to 250 mbsf 3 holes: APC/HLAPC/XCB to 550 mbsf; orientation PDC bit
Downhole measurements program:	Triple combo tool string
Nature of rock anticipated:	Hemipelagic sediments