Integrated Ocean Drilling Program
Expedition 339 Scientific Prospectus

Mediterranean Outflow

Environmental significance of the Mediterranean Outflow Water and its global implications

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Abstract

Integrated Ocean Drilling Program (IODP) Expedition 399 combines IODP Proposal 644-Full2 and ancillary proposal letter (APL)-763 and focuses on the broader significance of Mediterranean Outflow Water (MOW) on North Atlantic circulation and climate. The expedition will address important questions highlighted in the IODP Initial Science Plan related to paleocirculation and climate, the influence of oceanic gateways, and sea level and neotectonic control on sediment architecture along continental margins. In order to answer these questions, we propose targeted drilling of a late Neogene continental margin sequence in the Gulf of Cádiz and off West Iberia. The high rates of accumulation associated with contourite depositional system (CDS) deposits in this region provide an expanded sedimentary record that permits detailed examination of paleocirculation patterns linked to past environmental change. Expedition 339 offers a unique opportunity to understand the global link between paleoceanographic, climatic, and sea level changes from Messinian to recent time. The Gulf of Cádiz and off-West Iberia CDS form an extensive compound sedimentary body, which has been developing along the midslope over the past 5 m.y. under the direct influence of MOW. It therefore holds an unmistakable signal of MOW through the Gibraltar Gateway, reopened following tectonic adjustments at the end of the Messinian Salinity Crisis, and hence a clear record of Mediterranean Sea and MOW influence on the North Atlantic Ocean.

The importance of the Gulf of Cádiz is clearly reflected in the large number of regional studies and multinational interest shown over the past 40 y. An extensive array of high-quality data exists for the region, and a detailed seismic stratigraphic framework has recently been proposed. But, despite such extensive surveying, the region has not yet been drilled for scientific purposes, even though the Gibraltar Gateway clearly has major implications for global climate and oceanography. We have identified the following five broad scientific objectives, which require seven drill sites through the Pliocene to Quaternary sedimentary record:

1. Understand the opening of the Gibraltar Gateway an onset of MOW,
2. Determine MOW paleoceanography and global climate significance,
3. Establish a marine reference section of Pleistocene climate change,
4. Identify sea level changes and sediment architecture of the Cádiz CDS and Iberian margin, and
5. Ascertain synsedimentary neotectonic control on architecture and evolution of the CDS.

To achieve these major scientific objectives, it is essential to integrate the results of the proposed drill sites with a dense network of existing high-resolution seismic reflection profiles. Interpretation of this seismic network is already well established, although the inferred ages require drilling confirmation.

Seven primary sites (and two alternates sites) have been selected that will allow us to identify and calibrate the third- and fourth-order depositional units and associated widespread erosive discontinuities across the CDS. This is of great significance, both regionally and globally, for

1. Monitoring the long-term variability of MOW and its global climatic significance;
2. Constraining the main paleoceanographic events from late Miocene to recent time, including high-resolution focus on late Pleistocene and Holocene rapid climate events;
3. Evaluating the influence of opening of the Gibraltar Gateway on North Atlantic oceanography and climate and monitoring the effects of sea level change on MOW flux;
4. Understanding the architecture of a complex CDS and the nature of its unit stacking pattern related to allogenic and autogenic controls; and
5. Investigating the dramatic large-scale asymmetric cycles of seismic character evident on high-resolution records, thereby elucidating their link with Quaternary–Pliocene climate/sea level and paleoceanographic changes.

In addition, drilling proposed Site SHACK-04 on the western Iberian margin is expected to recover a continuous sediment record with high sedimentation rates that preserves a signal of millennial-scale climate variability throughout the Pleistocene. This record will constitute a marine reference section of Pleistocene climate variability that can be correlated confidently to polar ice core and European terrestrial archives. The site will be used to document suborbital climate variability over numerous Pleistocene glacial–interglacial cycles; determine interhemispheric phasing (lead/lag) of the climate system; and correlate terrestrial, marine, and ice core records.

Expedition schedule

Expedition 339 is based on Integrated Ocean Drilling Program drilling Proposal 644-Full2 and ancillary proposal letter APL-763 (available at **iodp.tamu.edu/scienceops/**

expeditions/mediterranean_outflow.html). Following ranking by the IODP Scientific Advisory Structure, the expedition was scheduled for the research vessel *JOIDES Resolution*, operating under contract with the US Implementing Organization. At the time of publication of this *Scientific Prospectus*, the expedition is scheduled to start in Ponta Delgada, Azores Islands (Portugal), on 17 November 2011 and to end in Lisbon, Portugal, on 17 January 2012. A total of 56 days will be available for the drilling, coring, and downhole measurements described in this report (for the current detailed schedule, see **iodp.tamu.edu/scienceops/**). Further details about the facilities aboard the *JOIDES Resolution* and the USIO can be found at **www.iodp-usio.org/.** Supporting site survey data for Expedition 339 are archived at the IODP-Management International Site Survey Data Bank (**ssdb.iodp.org**).

Introduction

Integrated Ocean Drilling Program (IODP) Expedition 339, which combines IODP Proposal 644-Full2 and ancillary proposal letter (APL)-763, is primarily paleoceanographic in nature, focusing mainly on the broader significance of Mediterranean Outflow Water (MOW) on North Atlantic circulation and climate. This expedition offers a rare opportunity to understand the global link between paleoceanographic, climatic, and sea level changes from Messinian to recent time and will address the importance of ocean gateways in regional and global ocean circulation and climate by coring and logging seven sites on the Gulf of Cádiz and the West Iberian margin (Figs. **F1, F2**).

The overarching aims of Expedition 339 are

- To study the contourite depositional system (CDS) generated by MOW influence and its evolution and environmental implications (IODP Proposal 644-Full2). This CDS has been developed with very high rates of accumulation over the past 5 m.y. as the direct result of MOW, which provides an expanded sedimentary record that permits detailed examination of paleocirculation patterns linked to past environmental change; and
- To produce a marine reference section of Pleistocene millennial-scale climate variability and changes in surface and deepwater circulation along the Portuguese margin (APL-763). Climate signals from this reference section will constrain the temporal relationships of abrupt climate change recorded in the northeast Atlantic Ocean, the polar ice cores, and European terrestrial records.

Expedition 339 will address the following key elements of the IODP Initial Science Plan (ISP) through targeted drilling of a Neogene and Quaternary continental margin sequence in the Gulf of Cádiz and off West Iberia (Figs. **F1, F2**).

Oceanic gateways and their influence

Tectonically induced changes are highlighted in the ISP as one of the principal internal forcing mechanisms for environmental change (ISP, pages 36–38). By drilling in the Gulf of Cádiz, we seek to document the effects of opening the Gibraltar Gateway around 5 Ma and therefore initiating the major influx of warm, saline, Intermediate Water into the North Atlantic Ocean.

Paleocirculation and climate

One of the fundamental scientific questions identified in the ISP under *Environmental Change, Processes, and Effects* (page 35) is "How did the Earth system respond to climatic change and at what timescales?" A key response of the ocean system to climate forcing is significant reorganization of global circulation and adjustment in the thermohaline conveyor belt model. Hence, the record of paleocirculation and paleoclimate is further identified as a specific target in the ISP (pages 35–36). Expedition 339 will address changes in and effects of MOW as a component of North Atlantic circulation in the post-Miocene time period.

Rapid climate change

Rapid climate change is highlighted as a special initiative in the ISP under *Environmental Change, Processes, and Effects*. Future advances in our understanding of the causes of abrupt change will rely on our ability to correlate high-resolution sedimentary archives from the oceans, ice cores, and terrestrial sequences and to interpret these records in the context of novel Earth system modeling approaches. A challenge for IODP, and the broader drilling community, is to identify sequences from appropriate locations with adequate temporal resolution to study processes of the integrated climate system. Expedition 339 will recover sediment records deposited at high accumulation rates containing high-fidelity signals of Pleistocene climate variability and rapid climate change, which can be correlated to polar ice core and terrestrial archives.

Sea level change and sediment architecture

The response of sediment architecture, especially along continental margins, to sea level change is highlighted in the ISP as the second principal internal forcing mechanism for environmental change (ISP, pages 40–41). Whereas considerable attention and several past ODP drilling legs have been directed toward placing turbidites and other downslope systems within a sequence stratigraphic context, there is no generally accepted understanding of how and where the alongslope sedimentary system, driven by bottom water circulation, fits within these models. Fundamental questions regarding the timing and extent of hiatuses and condensed sequences and the corollary periods of alongslope deposition, drift development, and paleodepth reconstruction have yet to be answered. Expedition 339 will address precisely these aspects of sediment architecture within the Gulf of Cádiz and West Iberian marginal sequences in relation to changes in sea level and other forcing mechanisms.

Neotectonic activity

Margin evolution anywhere is controlled by complex interactions of many different forcing variables, most importantly sea level and climate, sediment supply, and tectonics. Expedition 339 will reconstruct the timing of neotectonic activity that has had a significant impact on submarine topography and, consequently, controlled the flow path of the two branches of MOW and their influence in the North Atlantic.

Expedition 339 is certainly ambitious in scope and scientifically very exciting. It has been carefully crafted by a broad spectrum of scientists over an 8 y gestation period. The expedition reflects an intense international interest in the region and its global significance, building on a research database accumulated over 35 y. Furthermore, the study of the CDS should be of great interest to the international community not only because of the stratigraphic, sedimentologic, paleoceanographic, and paleoclimatologic significance, but also because of its close relationship with possible specific deep-marine geohabitats and/or mineral and energy resources (Rebesco and Camerlenghi, 2008).

Background

Gulf of Cádiz and West Iberian margin: geological and oceanographic setting

Tectonic framework

The southwestern margin of the Iberian Peninsula, at the eastern end of the Azores-Gibraltar zone, is the location of the diffuse plate boundary between Eurasia and Africa. The present plate convergence between the African and Eurasian plates in the Gulf of Cádiz area is ~4 mm/y with a northwest–southeast trend and is accommodated over that broad diffuse deformation zone (Olivet, 1996; Argus et al., 1989). Distinct periods of crustal deformation, fault reactivation, and halokinesis related to the movement between Eurasia and Africa (Malod and Mauffret, 1990; Srivastava et al., 1990; Maldonado et al., 1999; Gutscher et al., 2002; Alves et al., 2003; Medialdea et al., 2004, 2009; Lopes et al., 2006; Terrinha et al., 2009; Zitellini et al., 2009) are known to have controlled the tectonostratigraphic evolution of this part of the Iberian Peninsula. The tectonic structure of this area is a consequence of the distinct phases of rifting since the late Triassic to the Early Cretaceous caused by the opening of the central and North Atlantic basin (Murillas et al., 1990; Pinheiro et al., 1996; Wilson et al., 1996; Srivastava et al., 2000; Borges et al., 2001) and its later deformation during the Cenozoic, especially in the Miocene (Ribeiro et al., 1990; Zittellini et al., 2009). The Gulf of Cádiz Cenozoic evolution was controlled by the Alpine tectonic phases that affected the southern part of Europe. During the Pliocene and Quaternary, the effect of glacio-eustatic variations have rather overprinted structural effects on the margin and resulted in erosion, sedimentary progradation, and incision of major submarine canyons (Mougenot, 1988; Alves et al., 2003; Terrinha et al., 2003, 2009).

The Gulf of Cádiz straddles this oblique-compressive zone between the Eurasian and African plates, extending from the Gloria transform fault zone to the Gibraltar arc, which marks the western front of the Betic-Rif collisional orogen. Since the late Miocene, the northwest–southeast compressional regime has been developed simultaneously with the extensional collapse of the Betic-Rif orogenic front, by westward emplacement of a giant "olistostrome," the Cádiz Allochthonous Unit (CAU), and by very high rates of basin subsidence coupled with strong diapiric activity. At the end of the Messinian, a transtensional regime caused the reopening of the connection between the Atlantic and the Mediterranean through the Strait of Gibraltar (Maldonado et al., 1999). By the end of the early Pliocene, subsidence decreased and the margin evolved toward its present, more stable, condition (Maldonado et al., 1999; Maestro et al., 2003; Medialdea et al., 2004), although the CAU provides an unstable substratum for late Miocene, Pliocene, and Quaternary sedimentation (Medialdea et al., 2004; Zitellini et al., 2009). Some neotectonic reactivation is also evident, as expressed by the occurrence of mud volcanoes, diapiric ridges (Diaz-del-Río et al., 2003; Somoza et al., 2003; Fernández-Puga, et al., 2007; Zitellini et al., 2009), and fault reactivation (Maestro et al., 1998; Gràcia et al., 2003a, 2003b; Lobo et al., 2003; Terrinha et al., 2009). Tectonics have represented a key long-term factor in affecting seafloor morphology, which has exerted strong control on the pathways of MOW and, therefore, on the architecture of the CDS.

Oceanographic setting

The present-day circulation pattern is dominated by exchange of water masses through the Strait of Gibraltar (Fig. F3). This exchange is driven by the highly saline and warm MOW near the bottom and the turbulent, less saline, cool-water mass of Atlantic water at the surface. MOW forms a strong bottom current flowing toward the west and northwest above North Atlantic Deep Water (NADW) (Madelain, 1970; Melières, 1974; Zenk, 1975; Thorpe, 1976; Ambar and Howe, 1979).

After it exits through the Gibraltar Gateway, MOW represents an intermediate water mass, which is warm and very saline, that flows to the northwest along the middle slope (Fig. F3) under Atlantic Inflow and above NADW (Zenk, 1975; Thorpe, 1976; Gardner and Kidd, 1983; Ochoa and Bray, 1991; Baringer and Price, 1999). MOW also represents a flux of ~1.78 Sv through the Gibraltar Gateway, composed of both Levantine Intermediate Water (LIW) and Western Mediterranean Deep Water (WMDW) (Bryden and Stommel, 1984; Bryden et al., 1994; Millot, 1999, 2009), and generates important alongslope sedimentary processes along the Atlantic margin (Serra et al., 2010a, 2010b). In the Gulf of Cádiz, MOW flows between 500 and 1400 meters below sea level (mbsl) with a velocity close to 300 cm/s at the Strait of Gibraltar (Ambar and Howe, 1979) and ~80–100 cm/s at the latitude of Cape San Vicente (Cherubin et al., 2000). Its distribution is conditioned by the complex morphology of the continental slope, which generates two main cores, between 500 and 700 mbsl (upper core or Mediterranean upper water [MUW]) and 800 and 1400 mbsl (lower core or Mediterranean lower water [MLW]). MLW is further divided into three branches (Fig. F3) (Madelain, 1970; Zenk, 1975; Ambar and Howe, 1979; Johnson and Stevens, 2000; Borenäs et al., 2002). In the western sectors, the interaction of these branches with the seafloor generates big meddies (Richardson et al., 2000).

After exiting the Gulf of Cádiz, MOW has three principal branches (Fig. **F4**): the main branch flows to the north, the second to the west, and the third to the south, reaching the Canary Islands and then veering toward the west (Iorga and Lozier, 1999; Slater, 2003). The northern branch flows along the middle slope of the Portuguese margin and is further divided into two branches by the influence of the Galicia Bank (Fig. **F4**). These two branches return to converge and subsequently circulate to the east in the Gulf of Biscay following the continental slope contour (Fig. **F4**). MOW reaches Porcupine Bank and partly circulates to the north along Rockall Trough until reaching the Norwegian Sea (Iorga and Lozier, 1999; Slater, 2003).

Between ~500 and 1500 mbsl, the water column along the West Iberian margin is dominated by the warm, salty MOW, the two cores of which are centered at ~800 and 1200 mbsl (Ambar and Howe, 1979), and flow as undercurrents northward along the margin and also spread westward. Below MOW at ~1600 mbsl, Labrador Sea Water (LSW) can be found on the margin north of 40.5°N (Fiuza et al., 1998). Below 2000 mbsl, recirculated Northeast Atlantic Deep Water (NEADW) prevails, which represents a mixture of LSW, Iceland Scotland Overflow Water (ISOW), Denmark Strait Overflow Water (DSOW), and to a lesser extent MOW and Lower Deep Water (LDW) (van Aken, 2000). Abyssal water in the region consists of a lower fringe of NEADW that obtains an increasing component of southern-sourced LDW with depth until ~4000 mbsl, where LDW dominates.

Morphosedimentary and stratigraphic framework

The major part of the Gulf of Cádiz comprises a giant outward bulge sloping to the west with irregular surface relief (Fig. **F5**). The principal physiographic features of this broad slope are

- A shelf-break located between 100 and 140 mbsl,
- A steeper (2°–3°) upper slope between 150 and 400 mbsl,
- Two gently dipping (>1°) wide terraces at 500–750 and 800–1200 mbsl on the middle slope crossed by channels and ridges that trend northeast, and
- A smooth lower slope (0.5°–1°).

For the most part, this slope lacks submarine canyons, except in the western area of the Algarve margin (Hernández-Molina et al., 2006; Mulder et al., 2006; Marchès et al., 2007). The West Iberian margin is characterized by a steeper slope (~4.5°), which is crossed by several major submarine canyons, but there is also a middle slope terrace (Alves et al., 2003; Terrinha et al., 2003; Llave et al., 2007).

The interaction of MOW with the Gulf of Cádiz margin has resulted in the development of one of the most extensive and complex CDSs ever described. Many authors have highlighted this interaction and have characterized its erosive and depositional features along the middle slope (e.g., Madelain, 1970; Gonthier et al., 1984; Nelson et al., 1993, 1999; Llave et al., 2001, 2006, 2007, 2010, submitted; Habgood et al., 2003; Hernández-Molina et al., 2003, 2006, submitted; Mulder et al., 2003, 2006; Hanquiez et al., 2007; Marchès et al., 2007). This CDS has both large depositional and erosional features (Fig. F2), conditioned by a strong current with speeds reaching nearly 300 cm/s close to the Strait of Gibraltar, slowing to ~80 cm/s at Cape St. Vincent (Kenyon and Belderson, 1973; Ambar and Howe, 1979; Cherubin et al., 2000). The main depositional features are sedimentary wave fields, sedimentary lobes, mixed drifts, plastered drifts, elongated mounded and separated drifts, and sheeted drifts. The main erosional features are contourite channels, furrows, marginal valleys, and moats. All of these features have a specific location along the margin, and their distribution defines five morphosedimentary sectors within the CDS (details can be found in Hernández-Molina et al. [2003, 2006] and Llave et al. [2007]). The development of each of these five sectors at any time is related to a systematic deceleration of MOW as it flows westward from the Strait of Gibraltar, caused by its interaction with margin bathymetry and the effects of Coriolis force. In general, the drifts are composed mainly of muddy, silty, and sandy sediments, with a mixed terrigenous (dominant component) and biogenic composition (Gonthier et al., 1984; Stow et al., 1986, 2002). In contrast, sand and gravel are found in the large contourite channels (Nelson et al., 1993, 1999), as are many erosional features (Hernández-Molina et al., 2006; García et al., 2009). In the proximal sector close to the Strait of Gibraltar, an exceptionally thick (~815 m) sandy-sheeted drift occurs, with sand layers averaging 12–15 m thick (minimum thickness = 1.5 m; maximum thickness = 40 m) (Buitrago et al., 2001).

Four major depositional sequences have been recognized in large contourite systems of the Pliocene and Quaternary sedimentary record, which must be related to MOW paleoceanographic changes. The depositional sequences are separated by four major regional discontinuities (Fig. F6), which from bottom to top are late Miocene (M), intra-lower Pliocene (LPR), base quaternary discontinuity (BQD), and mid-Pleistocene revolution (MPR) (Llave et al., 2001, 2007, 2010, submitted; Hernández-Molina et al., 2002, 2009; Stow et al., 2002). Together, these discontinuities constitute an impressive record of changes in water mass circulation and of the tectonic and/or environmental changes that have affected the evolution of the margin.

Portuguese margin sediments, by contrast, are dominated by hemipelagic muds, with variable admixtures of terrigenous silt and sand, and biogenic components (Baas et al., 1997). Pelagic sedimentation prevailed during interglacial periods. The input of terrigenous material is enhanced during glacial periods because of lowered sea level and input from local sources such as density-driven slope lateral advection and low-concentration turbidity currents, as well as minor influence from bottom currents and ice rafting. High sedimentation rates are typical in this region because of elevated fluxes in both glacial (clay) and interglacial (silt) material; however, distinct climate control results in enhanced sedimentation during colder periods at both orbital and millennial timescales. This pattern is observed in water depths between 2500 and 4600 m (Hall and McCave, 2000; Lebreiro et al., 2009). 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 does not affect open slope deposition. Ice-rafted detritus occasionally reached the Iberian margin during the last glacial period, especially during Heinrich events when sea-surface temperatures were very low (Lebreiro et al., 1996; Baas et al., 1997; Cayre et al., 1999; Thouveny et al., 2000; de Abreu et al., 2003).

Neotectonic implications

Tectonism during the Pliocene and Quaternary caused by the broad northwest–southeast compressional regime has determined in the short term the local thickness, geometry, and present position of various depositional bodies and in the long term has also contributed to new paleoceanographic changes. Several features of the CDS in the Gulf of Cádiz and west of Portugal can be related to this recent tectonic activity, which has involved the reactivation of faults and diapiric structures related to local movements (Maldonado et al., 1999; Fernández-Puga, 2004; Medialdea et al., 2004, 2009; Fernández-Puga et al., 2007; Neves et al., 2009; Terrinha et al., 2009; Zitellini et al., 2009). The most recent tectonic activity has directly conditioned several features (Llave et al., 2001, 2003; Hernández-Molina et al., 2003; García et al., 2009), including

- The recent configuration of the channels and ridges sector,
- The inactivity of several fossil mounded and sheeted drifts identified in Sectors 3 and 4,
- The recent genesis of the Diego Cão Channel, and
- The recent overexcavation and northward migration of the Cádiz Channel.

On the West Iberian margin, recent tectonic activity is variable from north to south. The Lisbon margin in the north has undergone significant subsidence through the

Pliocene and Quaternary. The Alentejo margin further south has undergone moderate subsidence during the early Pliocene but evolved to a region of mixed transpression-transtension during the late Pliocene and Quaternary, in association with uplift of the Gorringe Bank. Neotectonic activity is recognized in this area at the present time (Alves et al., 2003; Gràcia et al., 2003a, 2003b; Terrinha et al., 2003; Zitellini et al., 2009).

Seismic studies/Site survey data

A broad database of Gulf of Cádiz and the West Iberian margin information collected over the past 40 y by many different nations and cruises provides a superb template for drilling. This data is composed of

- Bathymetric data, including swath bathymetry of the middle slope using the Simrad EM12S-120 and EM300 multibeam echo-sounder systems;
- Side-scan sonar image data from the Seamap, OKEAN, Gloria, and TOBI systems;
- An extensive seismic data grid, including low-resolution multichannel seismic profiles from oil companies (mainly REPSOL and TGS-NOPEC), medium-resolution seismic profiles from Sparker, air gun, Geopulse, and Uniboom systems, high-resolution seismic profiles using a 3.5 kHz system, and ultrahigh-resolution seismic profiles using TOPAS;
- A variety of core data, ranging from box cores and short gravity cores to giant piston cores;
- Over 3000 submarine photographs taken with a BENTHOS-372 camera; and
- Physical oceanographic information.

Scientific objectives

Drilling in the Gulf of Cádiz and off the West Iberian margin offers a unique opportunity to tackle key scientific goals enumerated in the IODP ISP related to

- Oceanic gateways and their global influence,
- Paleocirculation and climate,
- Rapid climate change,
- Sea level and related controls on sediment architecture, and
- Neotectonic activity and controls on continental margin sedimentation.

The extensive CDS that has been developing within the Gulf of Cádiz and extending around the West Iberian margin over the past 5 m.y. has directly resulted from MOW (e.g., Madelain, 1970; Gonthier et al., 1984; Faugères et al., 1985; Nelson et al., 1993, 1999; Llave et al., 2001, 2006, 2007, 2010, submitted; Stow et al., 2002; Habgood et al., 2003; Hernández-Molina et al., 2003, 2006, submitted; Mulder et al., 2003, 2006; Hanquiez et al., 2007; Marchès et al., 2007). The high rates of accumulation and expanded sedimentary records of drift deposits permit high-resolution examination of past environmental change (Llave et al., 2005; Voelker et al., 2006). The CDS deposits, therefore, hold the very best signal of MOW flow through the Gibraltar Gateway and a clear record of its influence on the oceanography and climate of the North Atlantic Ocean and on NADW variability (Bigg and Wadley, 2001a, 2001b; Bigg et al., 2003). However, the region has not yet been drilled for scientific purposes, even though the Gibraltar Gateway clearly has major implications for global climate and oceanography. The deeper target off western Portugal (APL-763) lies outside the direct influence of MOW but contains an expanded record of primarily hemipelagic sediment with which we can develop a Pleistocene marine archive of climate change.

We identify five broad scientific objectives for the proposed drilling program.

1. Understanding the opening of the Gibraltar Gateway and onset of MOW.

Tectonic adjustments along the suture line between the African and Eurasian plates could have lead to the opening of the Gibraltar Gateway at the end of the Miocene at 5.3 Ma (Berggren and Hollister, 1974; Mulder and Parry, 1977; Maldonado et al., 1999; Blanc, 2002; García-Castellanos et al., 2009). Other authors stressed that the cut into the threshold of Gibraltar was due more to the regressive erosion of a stream that was flowing toward the desiccated Mediterranean basin, resulting in the opening of the strait (Blanc, 2002; Loget and Van Den Driessche, 2006). Reopening of the Gibraltar Gateway marked the end of complete isolation of the Mediterranean Sea and global effects of the Messinian salinity crisis (Ryan et al., 1973; Hsü et al., 1978; Comas et al., 1999; Duggen et al., 2003). Immediately following this initial opening, the gateway depth was most likely insufficient to allow any very significant outflow of deep MOW into the Gulf of Cádiz. Therefore, the onset of deep MOW, the initiation of contourite drift sedimentation in the gulf, and the broader influence of warm saltwater influx in the North Atlantic lagged behind gateway opening. However, the actual timing of this event is uncertain.

Our first objective is to drill through the drift succession and into late Miocene sediments at several different sites and therefore date the basal age of drift sedimentation in the Gulf of Cádiz. We also aim to evaluate the nature of change in the patterns of sedimentation and microfauna/microflora from the end of the Miocene through the early to middle Pliocene, from proximal regions closest to the Gibraltar Gateway to distal regions on the West Iberian margin. This will allow us to determine any downstream variation in the onset of contourite deposition and of MOW bottom water signature.

2. Determine MOW paleocirculation and global climate significance.

The present-day flux of MOW through the Gibraltar Gateway is nearly 2 Sv (i.e., 2×10^6 m^3/s), carrying warmer waters and more than 300,000 tons of excess salt every second into the North Atlantic. The consequent increase in density of the NADW may stabilize, or in cases of decreased MOW flux, destabilize thermohaline circulation and therefore trigger climate change (Johnson, 1997; Rahmstorf, 1998; Bigg and Wadley, 2001a; Bigg et al., 2003). The importance of MOW in the North Atlantic Ocean circulation and climate is now widely recognized. MOW millennial to long-term variability and its effects on the thermohaline circulation is an active and prolific line of research at present. It has been inferred that the rate of deepwater formation reached its highest level in the Mediterranean during glacial stages, when contribution of NADW was at a minimum and Antarctic Bottom Water (AABW) at a maximum, but there are still many questions to resolve in this regard (e.g., Duplessy et al., 1988; Abrantes, 1988; Caralp, 1988, 1992; Sarnthein et al., 1994; Schönfeld, 1997, 2002; Cayre et al., 1999; Flower et al., 2000; Sierro et al., 2000, 2005; Shackleton et al., 2000; Schönfeld and Zahn, 2000; Cacho et al., 2000, 2001; Moreno et al., 2002; de Abreu et al., 2003; Schönfeld et al., 2003; Slater, 2003; Löwemark et al., 2004; Raymo et al., 2004; Voelker et al., 2006; Llave et al., 2006; Lebreiro et al., 2009; Lebreiro, 2010; Voelker and Lebreiro, 2010; among others).

Our second objective is to date the principal unconformities and minor discontinuities identified on seismic records, thereby calibrating the seismic stratigraphic framework. We will then be able to assess their link to paleocirculation variation and events and to evaluate their global correlation and significance. Detailed reconstruction of paleoceanographic conditions over centennial, millennial, and longer timescales at high resolution will disclose their evolution through time and help elucidate the background driving forces.

3. Establish marine reference section of Pleistocene climate (rapid climate change).

Few marine sediment cores have played such a pivotal role in paleoclimate research as those from the Portuguese margin Shackleton sites, so called to honor Nick Shackleton's seminal work in highlighting the global importance of these sections. (Shackleton et al., 2000). These cores preserve a high-fidelity record of millennial-scale climate variability for the last glacial cycle that can be correlated precisely to polar ice cores in both hemispheres (Fig. F7). Moreover, the narrow continental shelf off Portugal results in the rapid delivery of terrestrial material (e.g., pollen) to the deep-sea environment, thereby permitting correlation of marine and ice core records to European terrestrial sequences. IODP drilling of proposed Site SHACK-04 (location of piston Core MD01-2444) on the Iberian margin during Expedition 339 provides a rare opportunity to recover a marine reference section of Pleistocene climate variability that can be correlated confidently to polar ice core and terrestrial archives.

Our third objective (and the principal objective of proposed Site SHACK-04 [APL-763]) is to recover a Pleistocene sediment archive offshore Portugal that will greatly improve the precision with which marine sediment records of climate change are correlated to and compared with ice core and terrestrial records. By yielding multiproxy records that can be placed on an integrated stratigraphy, drilling of proposed Site SHACK-04 will result in major advances in our ability to reconstruct millennial-scale climate variability during the Pleistocene and understand its underlying causes.

4. Identify external controls on sediment architecture of the Gulf of Cádiz CDS and West Iberian margin.

The effects of sea level change on Pliocene–Quaternary sedimentary architecture in the Gulf of Cádiz and along the West Iberian margin have been considerably amplified by the direct influence of the Gibraltar Gateway cross-sectional area (see above). Detailed analysis of sedimentary architecture of the CDS drift deposits is essential to distinguish between climate and sea level change and to the further development of the global sequence stratigraphic model. In particular, the global role of bottom currents and evolution of alongslope depositional systems have not been adequately considered as a major component of the generalized sequence stratigraphic framework for continental margins. Furthermore, the cyclicity of MOW flux and resultant deposits has a relationship to eustatic influences on the Gibraltar sill that needs to be defined as a control on the entire North Atlantic circulation.

Our fourth objective is to establish the nature of sedimentation and the timing of associated hiatuses by first-order drilling, dating, facies analysis, and correlation between all drill sites. This will further allow us to determine the stacking pattern and evolution of the Pliocene–Quaternary drift deposits and evaluate contourite cyclicity at seismic to sediment scales. Combining facies analysis and sedimentation rates with detailed compositional studies should allow a more complete understanding of sediment supply and remobilization within the bottom-current system and quantification of a sedimentary budget and flux for the CDS in the gulf.

5. Ascertain synsedimentary neotectonic control on architecture and evolution of the CDS.

Charting the chronology of neotectonic activity that has had significant effect on development and architecture of the CDS is essential to a more complete understanding of the margin system in this region. Margin evolution anywhere is controlled by complex interaction of many different forcing variables, most importantly sea level and climate, sediment supply, and tectonics. The Gulf of Cádiz provides an excellent example of how recent tectonic activity has markedly affected submarine topography (Medialdea et al., 2004; Hernández-Molina et al., 2006; Fernández-Puga et al., 2007; Llave et al., 2007; García et al., 2009; Terrinha et al., 2009; Zittellini et al., 2009) and, consequently, controlled changes in the distribution of branches of MOW and their influence in the North Atlantic (Llave et al., 2007). The initiation and early history of MOW with regard to timing and tectonic control of the Gibraltar Gateway is the focus of Objective 1 (above).

Our fifth objective is to chart the chronology of neotectonic activity that has had significant effect on development and architecture of the CDS and to identify the principal morphological changes that have resulted from this tectonic activity. We will thus be able to evaluate the direct influence of recent diapiric activity on the evolution of the CDS, particularly with regard to the erosion of channels and moats through the softer cores of diapir strings. There is also an excellent opportunity to determine the rate of diapiric movement and its change through time.

Operations plan/Drilling strategy

The drilling program targets seven primary and two alternate sites, all located in either Portuguese or Spanish territorial waters (Tables **T1, T2, T3**), two of which are on the southwest Portuguese continental margin and the remaining five in the Gulf of Cádiz (Fig. **F2**). However, the final operations plan and number of sites to be cored is contingent upon changes to the R/V *JOIDES Resolution* operations schedule, operational risks (see below), review by the Environmental Protection and Safety Panel, and the outcome of a request for permission to occupy these sites.

The coring strategy will consist of advanced piston coring (APC) in two holes (A and B) at each site to refusal, except at proposed Site SHACK-04 where four holes are planned. Multiple holes will allow us to build a composite section at each site. If a complete composite record of the APC section cannot be achieved by double coring, a third hole (C) may be spot-cored to complete the splice or fill any desirable gaps. The "drillover" technique will be employed to maximize APC penetration where desirable. For planning purposes, the APC refusal depth for most sites is estimated at 100 meters below seafloor (mbsf), although we anticipate that this may be exceeded at some of the more mud rich sites. APC refusal will be followed by extended core barrel (XCB) coring at each site to ~350 mbsf (150 mbsf at proposed Site SHACK-04) and then by rotary core barrel (RCB) coring to total depth.

Proposed Site SHACK-04 will be drilled at a depth of 2578 mbsl. The water depth range is mostly below the influence of MOW, which is confined to depths shallower than 1600 mbsl during interglacials and shallower than ~2200 mbsl during glacial periods (Schönfeld and Zahn, 2000). Other Expedition 339 sites are located in the core of MOW and thus, combined with proposed Site SHACK-04, will provide a detailed history of both intermediate and deep water. Proposed Site SHACK-04 was chosen to obtain a continuous Pleistocene sequence with the highest resolution while avoiding disturbance by downslope transport (i.e., turbidites and mass flow deposits). The site is located at the crossing point of seismic lines Steam 9406 and BS-09 (Fig. **F4**) at the same position as Core MD01-2444, which has been studied extensively as part of the Pole-Ocean-Pole (POP) project (e.g., Fig. **F3;** Skinner and Shackleton, 2006; Vautravers et al., 2006; Martrat et al., 2007; Margari et al., 2010).

The drilling program at proposed Site SHACK-04 will consist of APC coring using nonmagnetic core barrels until refusal depth (if less than 150 m) and then, if necessary, using magnetic core barrels to the target depth of 150 mbsf (Table **T1**). Emphasis will be placed on recovering complete composite sections in the depth range achievable using APC drilling techniques (generally as deep as 200–300 mbsf) because high-quality cores will be vital for establishing high-resolution stratigraphies. In anticipation of the high sample demand for these Quaternary reference sections, four holes are required to produce multiple copies of the composite sections to meet immediate and future sampling needs.

In accordance with routine drilling procedures, downhole temperature measurements will be obtained with the advanced piston corer temperature tool (APCT-3) and, where warranted, with the Sediment Temperature Tool (SET). Temperature measurements will allow reconstruction of the thermal gradient at each site. This information will help constrain the history of burial diagenesis of the sediments encountered.

Logging/Downhole measurement strategy

The downhole measurement plan aims to provide characterization of in situ formation properties and establish the link between features in the borehole and reflectors in the seismic sections. Identifying the nature and depths of the main seismic reflectors and unconformities will be key to understanding the depositional history of the sediment sequences drilled during the expedition.

Wireline logging is planned for the deepest hole at all but one of the sites of Expedition 339. Logging is not currently planned for proposed Site SHACK-04A, which is to be quadruple-cored to 150 mbsf, although logging the site would become feasible if the target depth was deeper. Standard IODP tool strings will be deployed at each logged site. The first run will be the triple combination (triple combo) tool string, which logs formation resistivity, density, porosity, natural gamma radiation (NGR), and borehole diameter. The diameter log provided by the caliper on the density tool will allow assessment of hole conditions (e.g., any washouts of sandy beds), log quality, and the potential for success of the following runs. The second run will be the Formation MicroScanner (FMS)-sonic tool string, which provides an oriented 360° resistivity image of the borehole wall and logs of formation acoustic velocity, NGR, and borehole diameter. The third run will be a check shot survey using the Versatile Seismic Imager (VSI) tool at ~25 m station spacing. The seismic source for the check shots will be a generator-injector air gun, and its deployment is subject to the IODP marine mammal policy; the check shot survey would have to be postponed or cancelled if policy conditions are not met. Details of the logging tools are available at **iodp.ldeo.columbia.edu/TOOLS_LABS/tools.html.**

Proposed Site GC-04B will be cored to 1139 mbsf. Sites this deep take longer to drill; therefore, there is increased risk that the logging hole will partially collapse and that only part of the hole can be logged. To reduce the risk of incomplete site characterization and provided there is sufficient time available, proposed Site GC-04B will be logged in two steps. The upper part will be logged in one of the APC/XCB holes and the lower part in the RCB hole.

Downhole logging data will provide the only stratigraphic data where core recovery is incomplete, especially in the lower part of the sites where they are single-cored with RCB. To provide the link between the borehole stratigraphy and the seismic section, check shot surveys will give depth to seismic traveltime conversions and sonic velocity and density data will be combined to generate synthetic seismograms for detailed well-seismic correlations.

Formation temperature measurements

Temperature measurements are planned for all sites to reconstruct the thermal gradient at each location. Typically, ~4–5 measurements are made at one hole per site using the APCT-3 and potentially supplemented by the SET if necessary where sediments are more consolidated.

Risks and contingency

The principal risks identified include

- Sandy lithologies alternating with silt/clay, leading to a potential for hole instability;
- MOW flows between 500 and 1400 mbsl with variable but high bottom-current velocity, which is close to 300 cm/s at the Strait;
- The presence of gas-prone sediments at some sites and depths, leading to a potential for core expansion on deck;
- The presence of submarine cables on the seafloor (or partially buried by sediment drift) that might be damaged during drilling operations;
- Commercial marine fishing and shipping traffic, military training operations (Army submarines) area, disused explosive dumping areas; and
- Adverse weather conditions.

All of these factors may affect coring and drilling operations, but most are considered of minor significance or are away from the proposed locations.

Plans for mitigation of effects and for contingency include the possibility of using heavy mud or casing to increase the stability of the hole and keep the hole from collapsing. A TV survey of the seafloor before coring is planned for all sites to prevent the hitting a submarine cable accidentally.

The drilling sites are within Portugal and Spain's Exclusive Economic Zones and obtaining clearances to drill will be necessary.

Sampling and data sharing strategy

Shipboard and shore-based researchers should refer to the IODP Sample, Data, and Obligations Policy (**www.iodp.org/program-policies/**). This document outlines the policy for distributing IODP samples and data. It also defines the obligations incurred by sample and data recipients. All requests for data and core samples must be approved by the Sample Allocation Committee (SAC). The SAC is composed of the Co-Chief Scientists, Staff Scientist, and IODP Curator on shore and curatorial representatives in place of the Curator onboard the ship. For proposed Site SHACK-04A, the APL main proponent will act as an additional SAC member.

Every member of the science party is obligated to carry out scientific research for the expedition and publish it. For this purpose, shipboard scientists are expected to submit sample requests (at **smcs.iodp.org/**) detailing their science plan 3 months before the beginning of the expedition. Based on sample requests (shore based and shipboard) submitted by this deadline and input from the scientific party, the SAC will prepare a tentative sampling plan that will be revised on the ship as dictated by 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. This planning process is necessary to coordinate the research to be conducted and to ensure that the scientific objectives are achieved. Modifications to the sampling plan and access to samples and data during the expedition and the 1 y postexpedition moratorium period require the approval of the SAC.

All sample frequencies and sizes 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 factor in evaluating sample requests. Success will require collaboration, integration of complementary data sets, and consistent methods of analysis. Substantial collaboration and cooperation are highly encouraged.

Shipboard sampling will be restricted to acquiring ephemeral data types and to low-resolution sampling (e.g., biostratigraphic sampling and toothpick-sized samples for bulk carbonate isotopes), mainly so that we can rapidly produce age model data critical to the overall objectives of the expedition and for planning for higher resolution sampling postcruise. Sampling for the bulk of individual scientist's personal research will be postponed until a shore-based sampling party to be implemented ~4 months after the expedition at the Bremen Core Repository (BCR) in Bremen, Germany. The BCR houses cores collected from the Atlantic and Arctic Oceans (north of the Bering Strait).

There may be considerable demand for samples from a limited amount of cored material for some critical intervals. Critical intervals may require special handling, a higher sampling density, reduced sample size, or continuous core sampling for a set of particular high-priority research objectives. 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 as critical.

For proposed Site SHACK-04, a highly coordinated sampling effort will be undertaken by shipboard and shore-based scientists to produce a multiproxy data set on samples from the same stratigraphic horizons, similar to that achieved by the ice core community. Ice core samples from the same depth are typically divided among multiple investigators, and results are often replicated among laboratories. We will adopt a similar sampling strategy for proposed Site SHACK-04 that emphasizes a genuine multiproxy approach with acute attention to resolution, replication, and time control. This monumental task is well beyond the capabilities of any individual or laboratory group. The sampling strategy will consist of a highly coordinated effort by shipboard and shore-based participants to produce the widest range of proxy measurements possible on the same set of samples. Close coordination among shipboard and nonshipboard participants will be established early in the planning process in order to develop a sampling scheme that meets the needs of all investigators. Because of the exceptionally high demand for samples anticipated at proposed Site SHACK-04, sample sharing will be encouraged where appropriate to maximize the use of the core material.

All collected data and samples will be protected by a 1 y postcruise moratorium, during which time data and samples are available only to the Expedition 339 Science Party and approved shore-based participants. This moratorium will extend 1 y following the completion of the sampling party.

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Table T1. Primary and alternate proposed sites, Expedition 339. (**See table note.**)

Site	Latitude	Longitude	Water depth (mbsl)	Penetration (mbsf)	Estimated age
Primary					
SHACK- 4A	37°34.29′N	10°7.57′W	2578	150	Pleistocene
GC-01A	36°49.69′N	7°45.33′W	566	526	Quaternary
GC-09A	36°48.32′N	7°43.14′W	567	784	Pliocene
GC-04B	36°15.42′N	6°48.27′W	686	1139 (1548)	Pliocene
GC-05B	36°25.67′N	7°14.24′W	660	650 (938)	Pliocene
GC-02B	36°19.04′N	7°43.08′W	980	433	late Pliocene
WI-01B	37°21.54′N	9°24.66′W	1074	675	Pliocene
Alternate					
GC-10A	36°15.27′N	6°48.00′W	686	991	Pliocene
GC-11A	36°25.52′N	7°16.68′W	660	650 (991)	Pliocene

Note: All penetration depths are pending approval from the Environmental Protection and Safety Panel. Penetration depths in parentheses refer to maximum target depths at the site and are also dependent on time availability during the expedition. These maximum target depths are not included in the primary operations plan (Table **T2**).

Table T2. Operations plan and additional logging, Expedtion 339. (**See table notes**).

Expedtion:	339	Proposal Number:	644 Full2
Start Date & Time:	11/17/11 06:00	Proposal Name:	Med Outflow
End Date & Time:	01/17/12 03:28	Last Edited By:	grout

Expedition 339 Operations Plan with Additional Logging

Site No.	Location (Latitude Longitude)	Sea Floor Depth (mbrf)	Operations Description	Transit (days)	Drilling Coring (days)	LWD/MWD Log (days)
Ponta Delgada, Azores			**Begin Expedition** 5.0	port call days		
			Transit ~737 nmi to SHACK-04A (Portugal) @ 10.0	3.1		
SHACK-04A (Portugal)	37° 34.29' N	2589	Hole A - APC to 100 mbsf and XCB to 150 mbsf. 4-APCT and 2 SET Measurements. Conduct TV survey before coring.		1.8	
	10° 7.57' W		Hole B - APC to 100 mbsf and XCB to 150 mbsf		0.7	
Pending EPSP			Hole C - APC to 100 mbsf and XCB to 150 mbsf		0.7	
approval to 150 mbsf			Hole D - APC to 100 mbsf and XCB to 150 mbsf.		1.0	
			Sub-Total Days On-Site: 4.2			
			Transit ~122 nmi to GC-01A (Portugal) @ 10.0	0.6		
GC-01A (Portugal)	36° 49.69' N	577	Hole A - APC to 100 mbsf and XCB to 350 mbsf. 4-APCT and 2 SET Measurements. Conduct TV survey before coring.		1.8	
	7° 45.33' W		Hole B - APC to 100 mbsf and XCB to 350 mbsf		1.2	
Pending EPSP			Hole C - Drill to 350 mbsf and RCB core to 526 mbsf. Log Triple combo, FMS-sonic, and VSP.		2.2	0.9
approval to 526 mbsf						
			Sub-Total Days On-Site: 6.1			
			Transit ~2 nmi to GC-09A (Portugal) @ 10.0	0.0		
GC-09A (Portugal)	36° 48.32' N	578	Hole A - APC to 100 mbsf and XCB to 350 mbsf. 4 APCT and 2 SET Measurements. Conduct TV survey before coring.		1.7	
	7° 43.14' W		Hole B - APC to 100 mbsf and XCB to 350 mbsf		1.2	
Pending EPSP			Hole C - Drill to 350 mbsf and RCB core to 784 mbsf. Log with Triple combo, FMS-sonic, and VSP.		3.4	1.2
approval to 784 mbsf						
			Sub-Total Days On-Site: 7.5			
			Transit ~55 nmi to GC-04B (Spain) @ 10.0	0.2		
GC-04B (Spain)	36° 15.42' N	697	Hole A - APC to 100 mbsf and XCB to 350 mbsf. 4-APCT and 2 SET Measurements. Conduct TV survey before coring.		1.8	
	6° 48.27' W		Hole B - APC to 100 mbsf and XCB to 400 mbsf. Log upper part with Triple combo, FMS-sonic, and VSP.		1.6	0.8
Pending EPSP			Hole C - Drill to 350 mbsf and RCB core to 1139 mbsf. Log lower part with Triple combo, FMS-sonic, and VSP.		5.9	1.3
approval to 1139 mbsf						
			Sub-Total Days On-Site: 11.4			
			Transit ~23 nmi to GC-05B (Spain)@ 10.0	0.1		
GC-05B (Spain)	36° 25.67' N	671	Hole A - APC to 100 mbsf and XCB to 350 mbsf. 4-APCT and 2 SET Measurements. Conduct TV survey before coring.		1.9	
	7° 14.24' W		Hole B - APC to 100 mbsf and XCB to 350 mbsf		1.2	
Pending EPSP			Hole C - Drill to 350 mbsf and RCB core to 650 mbsf. Log Triple combo, FMS-sonic, and VSP.		2.9	1.0
approval to 650 mbsf						
			Sub-Total Days On-Site: 7.0			
			Transit ~24 nmi to GC-02B (Portugal)@ 10.0	0.1		
GC-02B (Portugal)	36° 19.04' N	991	Hole A - APC to 100 mbsf and XCB to 350 mbsf. 4-APCT and 2 SET Measurements. Conduct TV survey before coring.		2.0	
	7° 43.08' W		Hole B - APC to 100 mbsf and XCB to 350 mbsf		1.4	
Pending EPSP			Hole C - Drill to 350 mbsf and RCB core to 433 mbsf. Log with Triple combo, FMS-sonic, and VSP.		2.0	1.0
approval to 650 mbsf						
			Sub-Total Days On-Site: 6.4			
			Transit ~103 nmi to WI-01B (Portugal)@ 10.0	0.4		
WI-01B (Portugal)	37° 21.54' N	1085	Hole A - APC to 100 mbsf and XCB to 350 mbsf. 4-APCT and 2 SET measurements. Conduct TV survey before coring.		1.6	
	9° 24.66' W		Hole B - APC to 100 mbsf and XCB to 350 mbsf		1.5	
Pending EPSP			Hole C - Drill to 350 mbsf and RCB core to 675 mbsf. Log with Triple combo, FMS-sonic, and VSP.		3.2	1.0
approval to 675 mbsf						
			Sub-Total Days On-Site: 7.3			
			Transit ~82 nmi to Lisbon, Portugal@ 10.0	0.3		
Lisbon, Portugal			**End Expedition**	4.8	42.7	7.2

Port Call:	5.0	Total Operating Days:	54.7
Sub-Total On-Site:	49.9	Total Expedition:	59.7

Notes: LWD/MWD = logging while drilling/measurement while drilling. EPSP = Environmental Protection and Safety Panel, APC = advanced piston corer, XCB = extended core barrel, APCT = advanced piston corer temperature tool, SET = Sediment Temperature Tool, RCB = rotary core barrel, triple combo = triple combination tool string, FMS-sonic = Formation MicroScanner-sonic tool string, VSP = vertical seismic profile.

Table T3. Logging plan for alternate sites, Expedition 339. (**See table notes**).

Expedtion: 339
Start Date & Time: 11/17/11 06:00
End Date & Time: 01/17/12 03:28

Proposal Number: 644 Full2
Proposal Name: Med Outflow
Last Edited By: grout

Alternate Sites

Site No.	Location (Latitde Longitude)	Sea Floor Depth (mbrf)	Operations Description	Transit (days)	Drilling Coring (days)	LWD/MWD Log (days)
GC-11A (Spain)	36° 25.52' N	671	Hole A - APC to 100 mbsf and XCB to 350 mbsf. 4 APCT and 2 SET Measurements. Conduct TV survey before coring.		1.8	
	7° 16.68' W		Hole B - APC to 100 mbsf and XCB to 350 mbsf		1.2	
Pending EPSP			Hole C - Drill to 350 mbsf and RCB core to 650 mbsf. Log with Triple combo, FMS-sonic, and VSP.		2.8	1.0
approval to 650 mbsf						
			Sub-Total Days On-Site: 6.8			
GC-10A (Spain)	36° 15.27' N	697	Hole A - APC to 100 mbsf and XCB to 350 mbsf. 4-APCT and 2 SET Measurements. Conduct TV survey before coring.		1.8	
	6° 48.00' W		Hole B - APC to 100 mbsf and XCB to 350 mbsf		1.2	
Pending EPSP			Hole C - Drill to 350 mbsf and RCB core to 991 mbsf. Log with Triple combo, FMS-sonic, and VSP.		4.9	1.4
approval to 991 mbsf						
			Sub-Total Days On-Site: 9.3			

Notes: EPSP = Environmental Protection and Safety Panel, APC = advanced piston corer, XCB = extended core barrel, APCT = advanced piston corer temperature tool, SET = Sediment Temperature Tool, RCB = rotary core barrel, triple combo = triple combination tool string, FMS-sonic = Formation MicroScanner-sonic tool string, VSP = vertical seismic profile.

Figure F1. Expedition 339 sites in the Gulf of Cádiz (GC) and West Iberian (WI) margin.

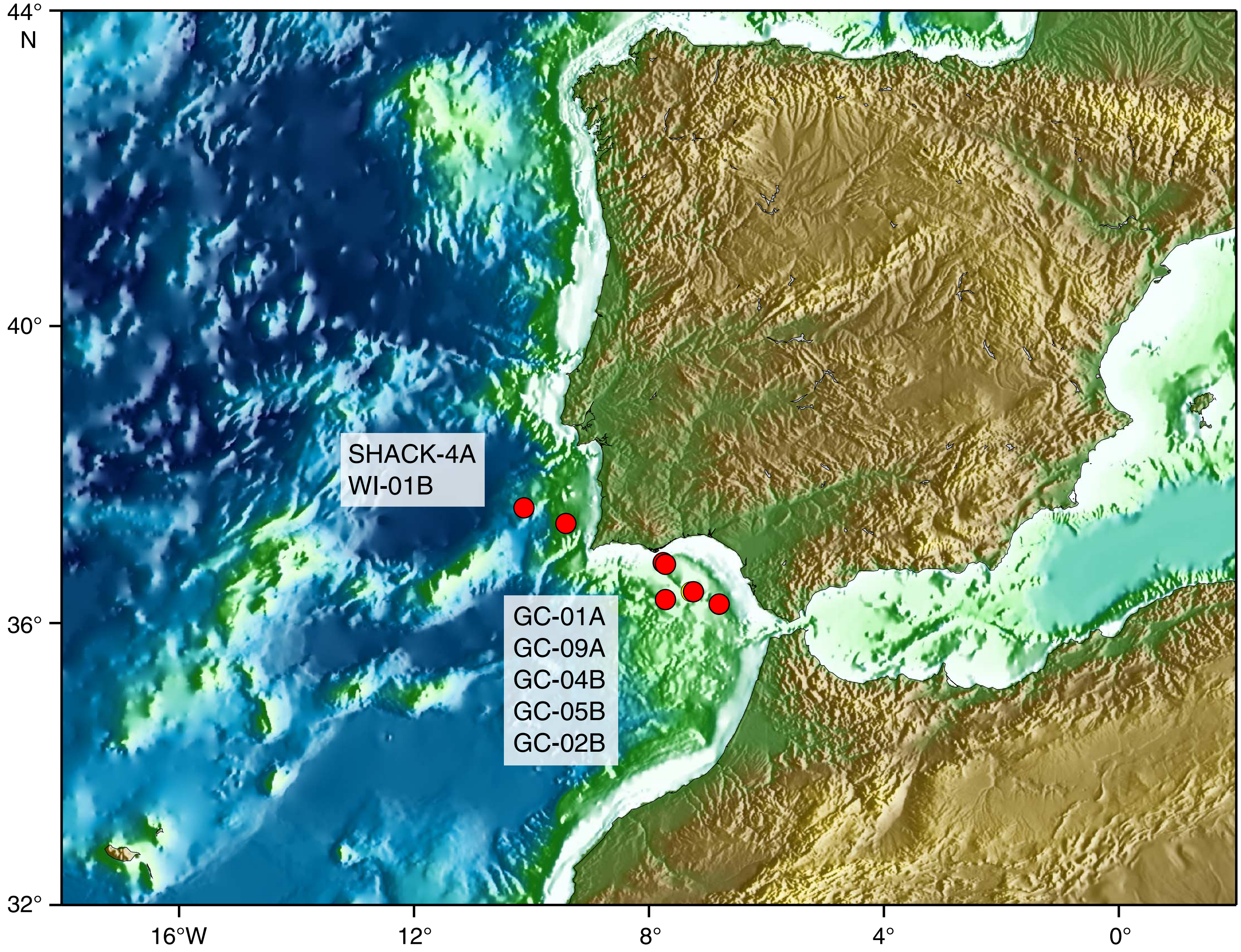


Figure F2. Regional map of the contourite depositional system on the middle slope of the Gulf of Cádiz and West Iberian margin with proposed site locations. Morphosedimentary sectors (1–5) based on Hernández-Molina et al. (2003, 2006) and S. Lebreiro (pers. comm., 2006).

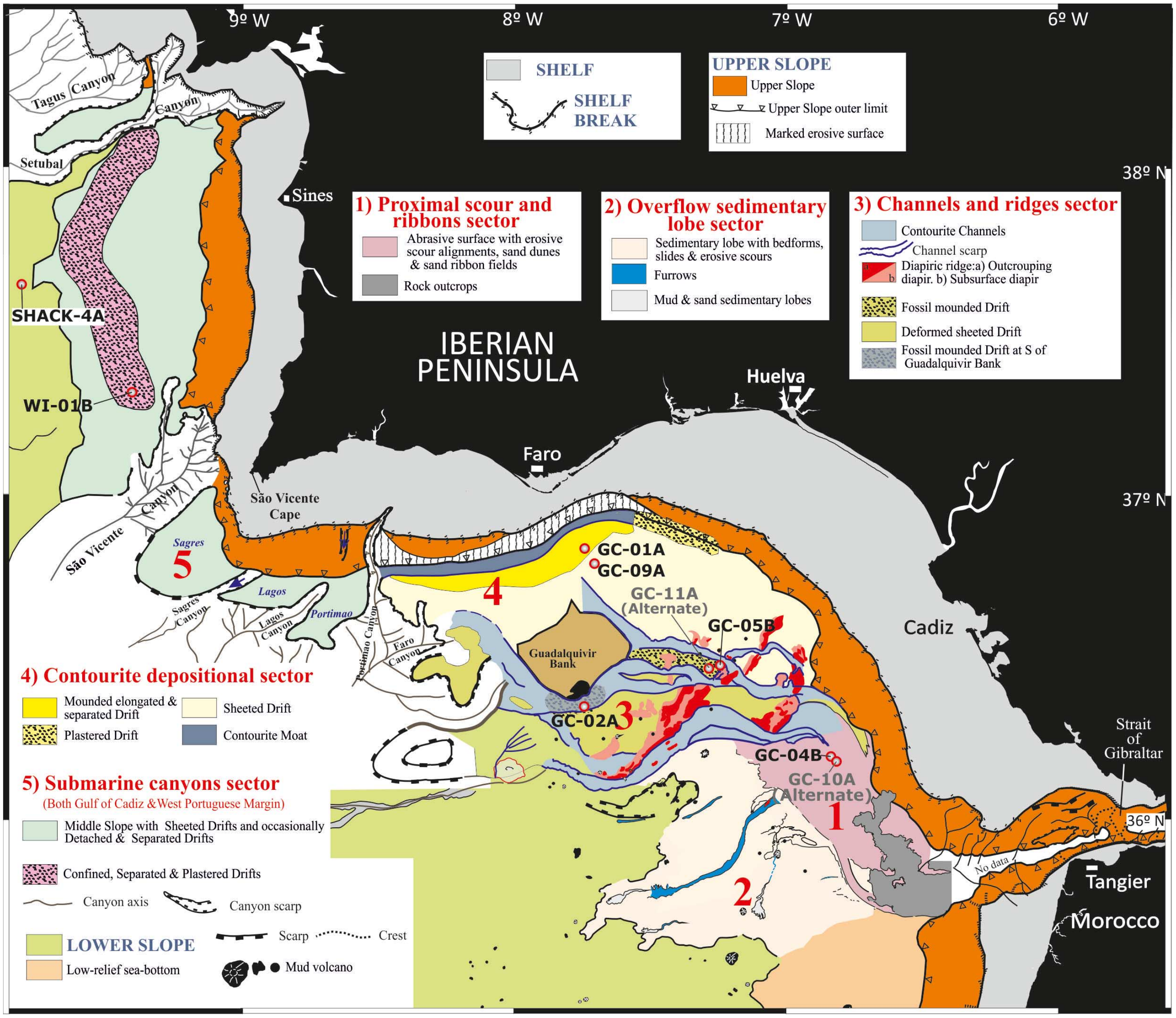


Figure F3. Location sketch with main water-mass circulation along the margin (modified from Hernández-Molina et al., 2006).

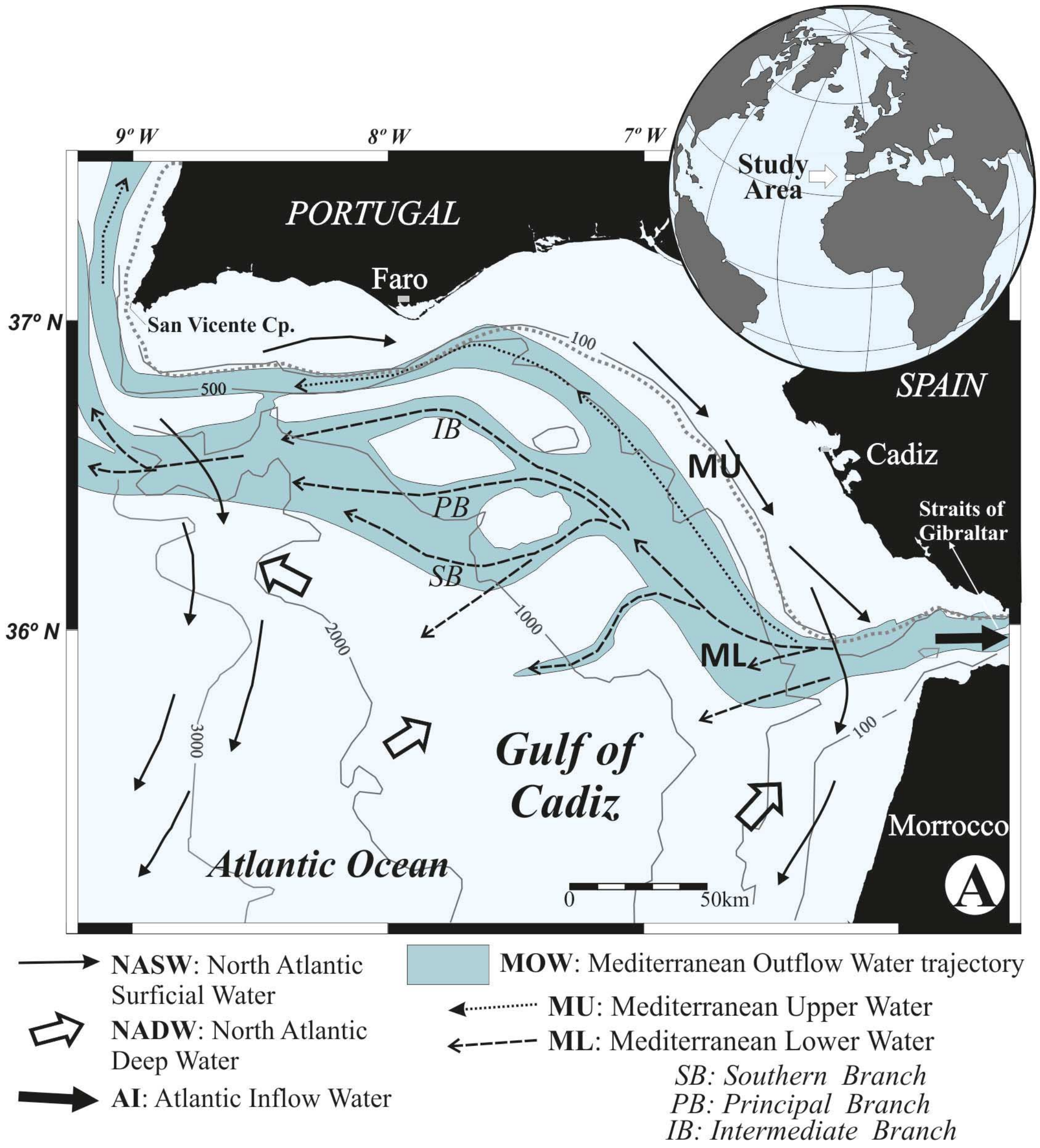


Figure F4. General circulation pattern of the Mediterranean Outflow Water (MOW) pathway in the North Atlantic (modified from Iorga and Lozier, 1999). Red circles filled with yellow indicate relative location of proposed sites. AB = Agadir Basin, BAP = Biscay Abyssal Plain, BB = Bay of Biscay, EP = Extremadura Promontory, GaB = Galicia Bank, GoB = Gorringe Bank, HAP = Horseshoe Abyssal Plain, MAP = Madeira Abyssal Plain, MI = Madeira Island, PAP = Porcupine Abyssal Plain, RC = Rockall Channel, SAP = Seine Abyssal Plain, St.V = Cape Sant Vicent, TAP = Tagus Abyssal Plain.

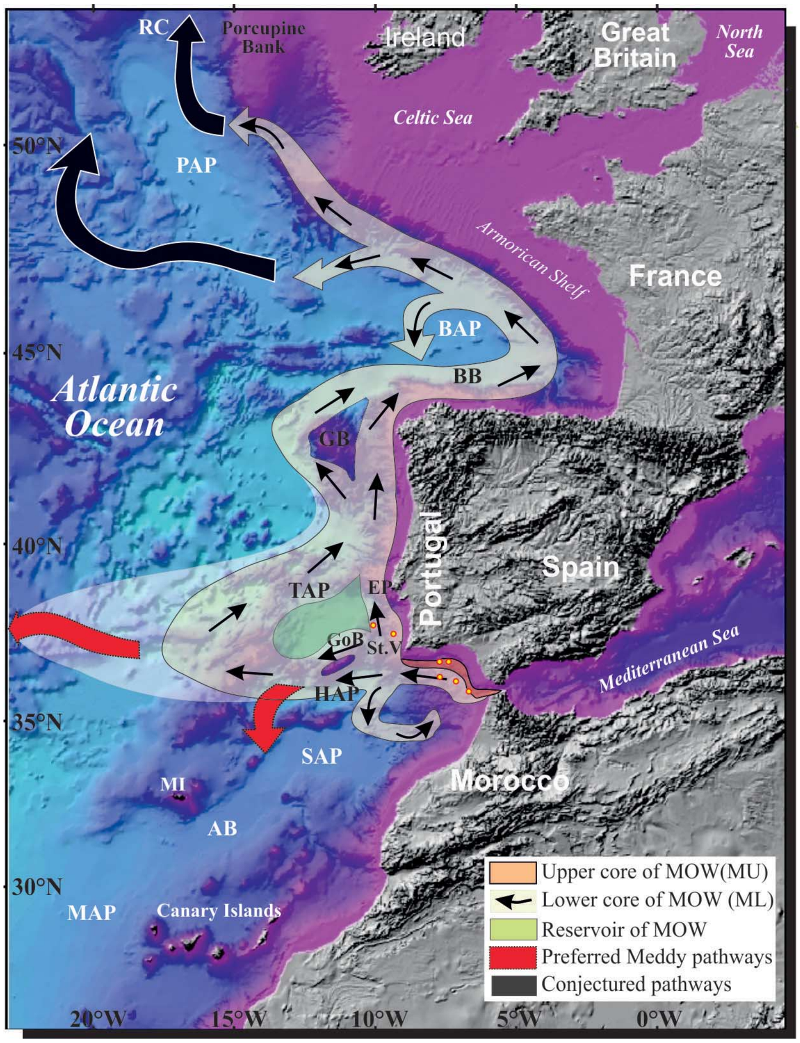


Figure F5. Three-dimensional regional bathymetric map of the Gulf of Cádiz (realized J.T. Vázquez (IEO) from satellite data from Smith and Sandwell, 1997). CC = Cascais canyon, GB = Guadalquivir Bank, NC = Nazaré canyon, PC = Portimao canyon, St. VC = São Vicente canyon, SC = Setúbal canyon, TC = Tagus canyon. AlM = Algarve margin; BLM = Beira litoral margin, BM = Betic domain margin, GM = Guadalquivir margin, LM = Lisbon margin, SM = Sudiberic margin.

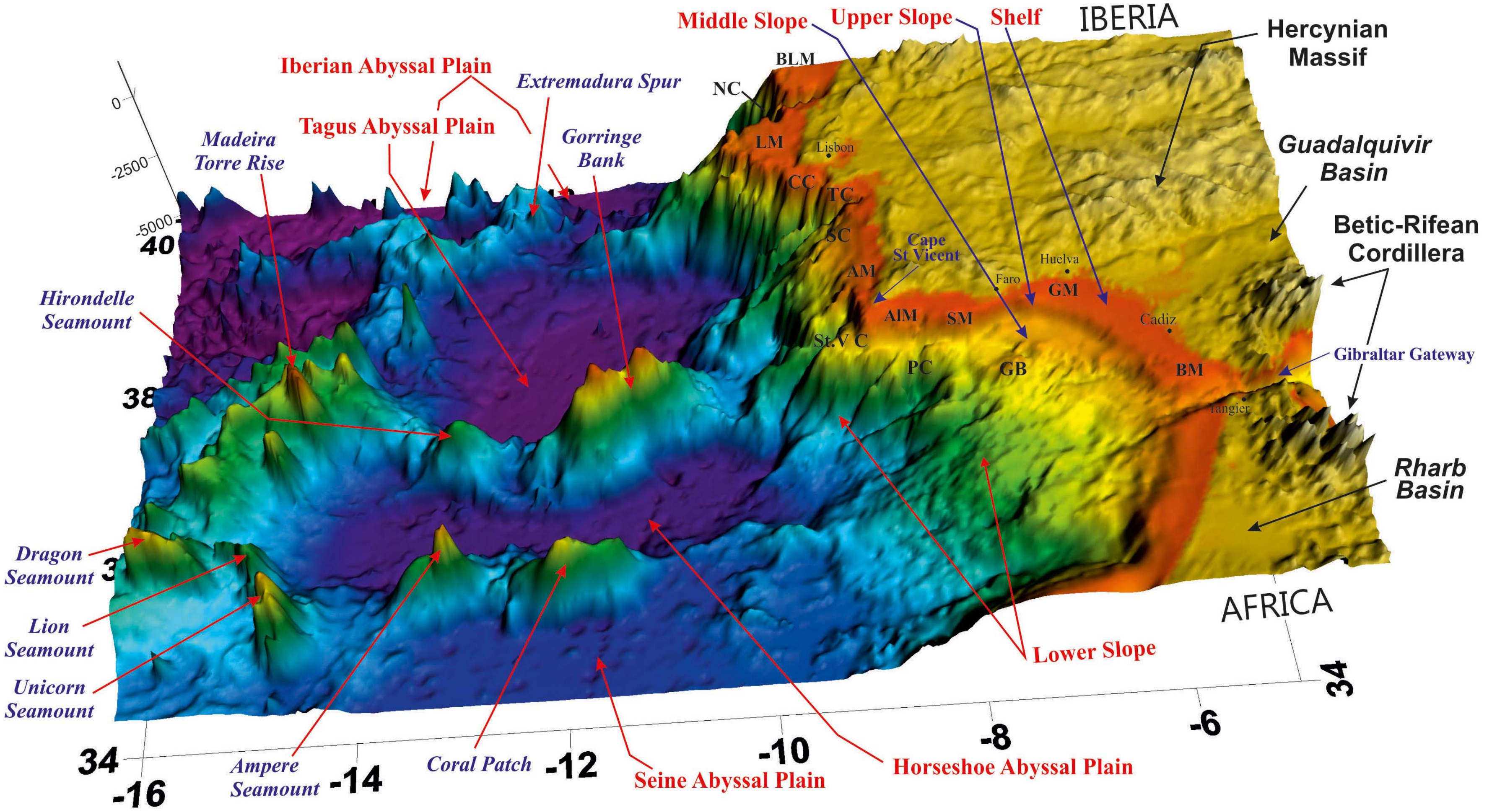


Figure F6. Multichannel seismic (MCS) reflection profile (Line P74-45) across the Faro-Albufeira Drift on the middle slope showing the location of proposed Site GC-09A (MCS lines provided by REPSOL Oil Company). Four major low-resolution depositional sequences have been recognized in the Pliocene and Quaternary sedimentary record (Llave et al., 2001; Hernández-Molina et al., 2002, 2006) and are separated by four relevant discontinuities: M (late Messinian), LPR (early Pliocene?), QBD (base of the Quaternary?), and MPR (mid-Pleistocene?). LPR erosive discontinuity could represent the onset of drift formation. TWT = two-way traveltime. MOW = Mediterranean Outflow Water.

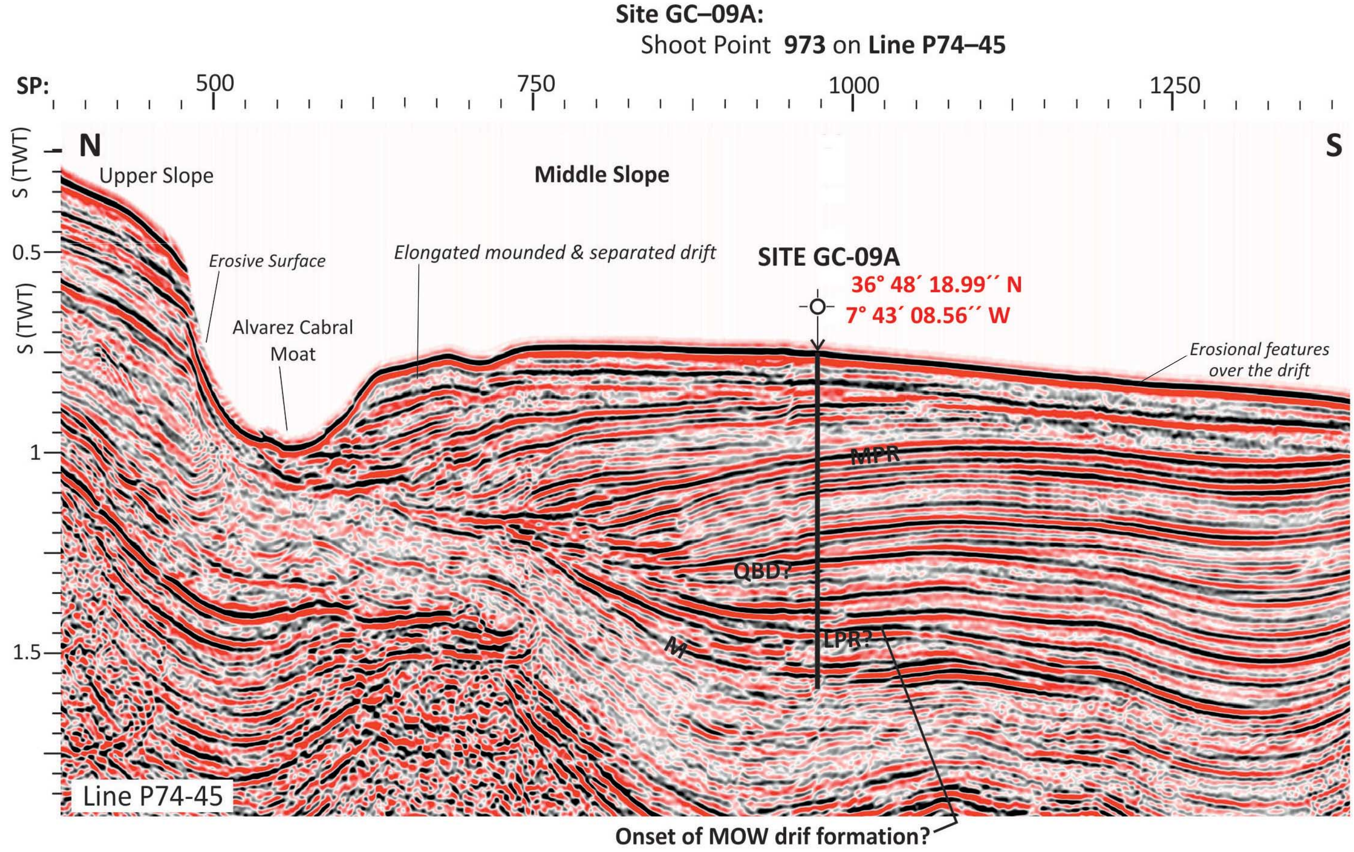
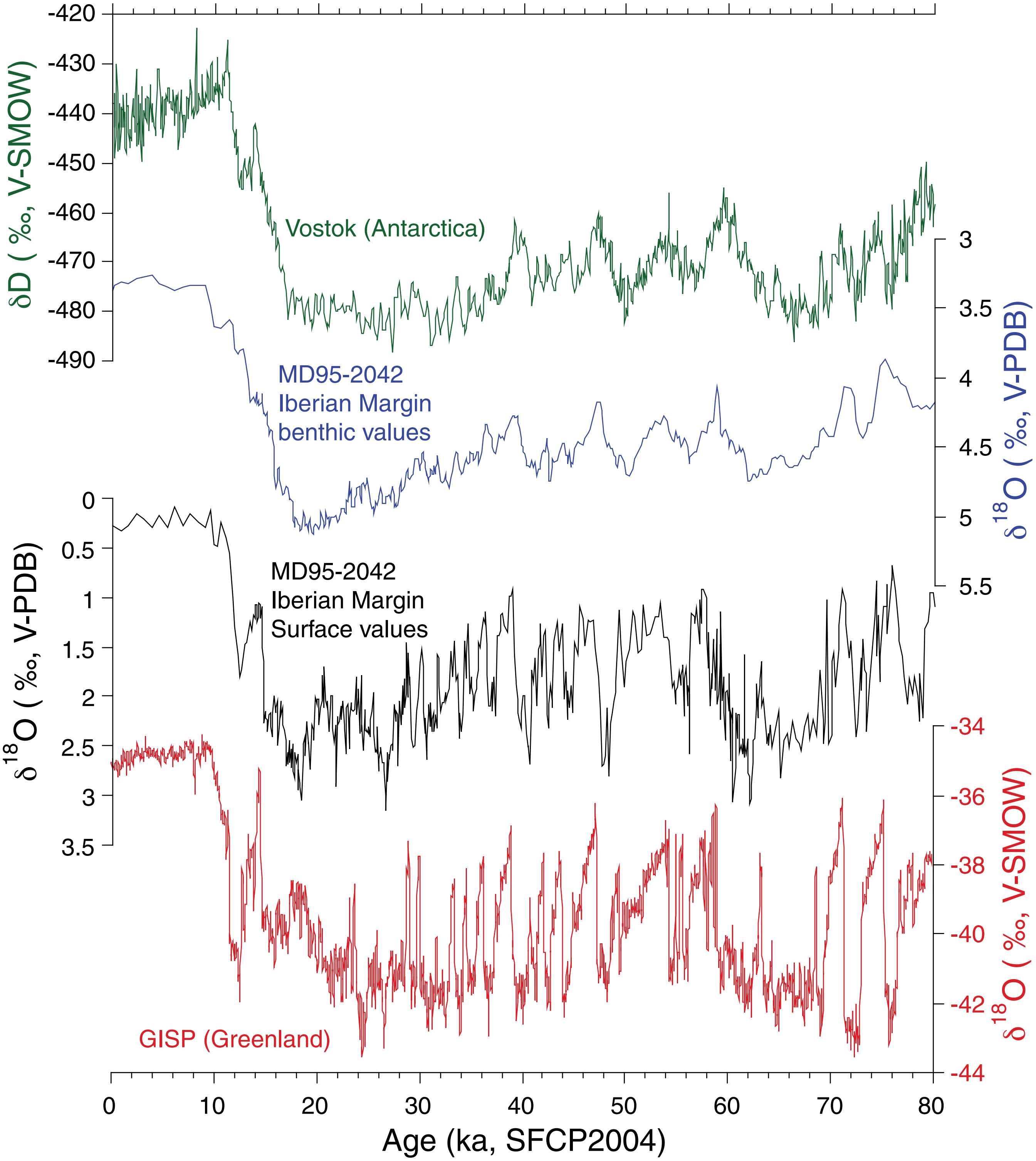


Figure F7. Rapid climate changes during the last glaciation. Correlation of δ^{18}O record of GISP ice core (red record) to δ^{18}O of *Globigerina bulloides* (lower black record) in Core MD95-2042. Resulting correlation of Vostok δD (green) and benthic δ^{18}O of Core MD95-2042 (upper black record). V-PDB = Vienna Peedee belemnite, V-SMOW = Vienna standard mean ocean water, SFCP2004 = Shackleton et al. (2004).



Site summaries

Site GC-01A

Priority:	High
Position:	Lat 36°49′41.29″N (36°49.688), Long 7°45′19.63″W (–7°45.327) (WGS 84)
Water depth (m)	566
Target depth (mbsf):	526
Approved maximum penetration (mbsf):	Pending EPSP/TAMU Safety Panel approval
Previous drilling in area:	None
Comments:	Jurisdiction: Portugal Potential hazards: shallow gas, shallow-water flow, soft seabed, strong currents
Survey coverage (track map, seismic profile)	• Bathymetric sketch and site location with seismic lines position on the contourite depositional system (Fig. **AF1**) • Sparker seismic reflection profile (Line FADO L-38) across the Faro-Albufeira Drift (Fig. **AF2**).
Objectives (see text for complete details):	• Recover complete Quaternary sedimentary record. • MOW upper core • Related to scientific objectives (1) Influence of the Gibraltar Gateway, (2) MOW paleoceanography and global climate significance, (3) sea level changes and sediment architecture
Drilling/coring program:	Double APC to refusal, then single XCB/RCB to 475 mbsf Temperature measurements: APCT-3
Downhole logging program:	Standard tools: triple combo, FMS-sonic, VSI
Anticipated lithology:	Sands, silts, and clays

Site summaries (continued)

Site GC-09A

Priority:	High
Position:	Lat 36°48′18.99″N (36°48.316), Long 7°43′08.56″W (–7°43.142) (WGS 84)
Water depth (m)	567
Target depth (mbsf):	784
Approved maximum penetration (mbsf):	Pending EPSP/TAMU Safety Panel approval
Previous drilling in area:	None
Comments:	Jurisdiction: Portugal Potential hazards: shallow gas, shallow-water flow, soft seabed, strong currents
Survey coverage (track map, seismic profile)	• Bathymetric sketch and site location with seismic lines position on the contourite depositional system (Fig. **AF1**) • Multichannel seismic reflection (MCS) profile (Line P74-45) across the Faro-Albufeira Drift (Fig. **AF3**).
Objectives (see text for complete details):	• Recover complete Pliocene sedimentary record. • MOW upper core • Related to scientific objectives (1) Influence of the Gibraltar Gateway, (2) MOW paleoceanography and global climate significance, (3) sea level changes and sediment architecture
Drilling/coring program:	Double APC to refusal, then single XCB/RCB hole to 784 mbsf Temperature measurements: APCT-3
Downhole logging program:	Standard tools: triple combo, FMS-sonic, VSI
Anticipated lithology:	Sands, silts, clays, and marls

Site summaries (continued)

Site GC-04B

Priority:	High
Position:	Lat 36°15′24.96″N (36°15.416), Long 6°48′16.4″W (–6°48.273) (WGS 84)
Water depth (m)	686
Target depth (mbsf):	1548 (primary operation plan based on 1139 m penetration)
Approved maximum penetration (mbsf):	Pending EPSP/TAMU Safety Panel approval
Previous drilling in area:	None
Comments:	Jurisdiction: Spain Potential hazards: shallow gas, shallow-water flow, soft seabed, strong currents
Survey coverage (track map, seismic profile)	• Bathymetric sketch with site location and seismic lines on the contourite depositional system on the middle slope of the Gulf of Cádiz (Close to the Strait of Gibraltar) (Fig. **AF4**) • Multichannel seismic reflection (MCS) profile (Line S81A-16) across the middle slope (Fig. **AF5**).
Objectives (see text for complete details):	Influence of the Gibraltar Gateway on MOW during the Quaternary and late Pliocene
Drilling/coring program:	Double APC to refusal, then single XCB/RCB hole to 1139 mbsf Temperature measurements: APCT-3
Downhole logging program:	Standard tools: triple combo, FMS-sonic, VSI
Anticipated lithology:	Mainly sands, but also silts and clays

Site summaries (continued)

Site GC-05B

Priority:	High
Position:	Lat 36°25′40.01″N (36°25.666), Long 7°14′14.11″W (–7°14.235) (WGS 84)
Water depth (m)	660
Target depth (mbsf):	938 (primary operations plan based on 650 m penetration)
Approved maximum penetration (mbsf):	Pending EPSP/TAMU Safety Panel approval
Previous drilling in area:	None
Comments:	Jurisdiction: Spain Potential hazards: shallow gas, shallow-water flow, soft seabed, strong currents
Survey coverage (track map, seismic profile)	• Bathymetric sketch with site location and seismic lines position around proposed Sites GC-05B and GC-11A (alternate) on the contourite depositional system on the middle slope of the Gulf of Cádiz (Fig. **AF6**) • Multichannel seismic reflection (MCS) profile (Line HE91-20) across the sheeted Drifts (Fig. **AF7**)
Objectives (see text for complete details):	MOW lower core (complete Pliocene and Quaternary record)
Drilling/coring program:	Double APC to refusal, then single XCB/RCB hole to 650 mbsf Temperature measurements: APCT-3
Downhole logging program:	Standard tools: triple combo, FMS-sonic, VSI
Anticipated lithology:	Sands, silts, and clays

Site summaries (continued)

Site GC-02B

Priority:	High
Position:	Lat 36°19′02.38″N (36°19.039), Long 7°43′04.89″W (–7°43.081) (WGS 84)
Water depth (m)	980
Target depth (mbsf):	433
Approved maximum penetration (mbsf):	Pending EPSP/TAMU Safety Panel approval
Previous drilling in area:	None
Comments:	Jurisdiction: Portugal Potential hazards: shallow gas, shallow-water flow, soft seabed, strong currents
Survey coverage (track map, seismic profile)	• Bathymetric sketch with proposed Site GC-02B and seismic lines position on the contourite depositional system on the middle slope of the Gulf of Cádiz (Fig. **AF8**) • Multichannel seismic reflection (MCS) profile (Line Tasyo L-8) of the western area of the central sector of the middle slope (Fig. **AF9**)
Objectives (see text for complete details):	Synsedimentary neotectonic control on architecture and evolution of the countorite depositional system
Drilling/coring program:	Double APC to refusal, then single XCB/RCB hole to 433 mbsf Temperature measurements: APCT-3
Downhole logging program:	Standard tools: triple combo, FMS-sonic, VSI
Anticipated lithology:	Sands, silts, clays, and marls

Site summaries (continued)

Site WI-01B

Priority:	High
Position:	Lat 37°21′32.53″N (37°21.542), Long 9°24′39.41″W (–9°24.656) (WGS 84)
Water depth (m)	1074
Target depth (mbsf):	675
Approved maximum penetration (mbsf):	Pending EPSP/TAMU Safety Panel approval
Previous drilling in area:	None
Comments:	Jurisdiction: Portugal Potential hazards: shallow gas, shallow-water flow, soft seabed, strong currents
Survey coverage (track map, seismic profile)	• Bathymetric sketch with site and seismic lines positions on the contourite depositional system on the western Portuguese middle slope (Fig. **AF10**) • Multichannel seismic reflection (MCS) profile (Line PD00-522) across the plastered drift on the middle slope (Fig. **AF11**)
Objectives (see text for complete details):	Quaternary and Pliocene sedimentary record due to MOW in a distal part of the contourite system (West Iberian margin)
Drilling/coring program:	Double APC to refusal, then single XCB/RCB hole to 675 mbsf Temperature measurements: APCT-3
Downhole logging program:	Standard tools: triple combo, FMS-sonic, VSI
Anticipated lithology:	Sands, silts, and clays

Site summaries (continued)

APL Site SHACK-04A

Priority:	High
Position:	Lat 37°34.29′N (37.571475), Long 10°7.57′W (–10.12616) (WGS 84)
Water depth (m)	2578
Target depth (mbsf):	150
Approved maximum penetration (mbsf):	150
Previous drilling in area:	None
Comments:	Jurisdiction: Portugal Potential hazards: shallow gas, shallow-water flow, soft seabed, strong currents
Survey coverage (track map, seismic profile)	• Track lines for seismic Lines Steam-9407 and BS-09 indicating position of proposed Site SHACK-04A (Fig. AF12). • Seismic Line BS09 indicating the position of proposed Site SHACK-04A at shotpoint 3950 (Fig. AF13) • Seismic Line Steam-9407 showing the position of proposed Site SHACK-04A and depth of penetration (~150 mbsf) (Fig. AF14)
Objectives (see text for complete details):	• Recover millennial-scale marine reference section for the Pleistocene • Provide marine sediment analog to the polar ice cores • Reconstruct deep water circulation changes (i.e., mixing ratio of southern and northern component water) • Facilitate marine-terrestrial correlations • Construct an integrated stratigraphy
Drilling/coring program:	Quadruple APC to refusal, drillover Temperature measurements: APCT-3
Downhole logging program:	None
Anticipated lithology:	Hemipelagic muds

Site summaries (continued)

Site GC-10A

Priority:	Alternate 1
Position:	Lat 36°15′16″N (36°15.266), Long 6°48′W (–6°48) (WGS 84)
Water depth (m)	686
Target depth (mbsf):	991
Approved maximum penetration (mbsf):	Pending EPSP/TAMU Safety Panel approval
Previous drilling in area:	None
Comments:	Jurisdiction: Portugal Alternate to proposed Site GC-04B
Survey coverage (track map, seismic profile)	• Bathymetric sketch of alternate proposed Site GC-10A and seismic lines position on the contourite depositional system on the middle slope of the Gulf of Cádiz (close to the Strait of Gibraltar) (Fig. **AF15**). • Airgun seismic reflection (MCS) profile (Line CADIZ-21) across the middle slope (Fig. **AF16**)
Objectives (see text for complete details):	Influence of the Gibraltar Gateway on MOW during the Quaternary and late Pliocene
Drilling/coring program:	Double APC to refusal, then single XCB/RCB hole to 991 mbsf Temperature measurements: APCT-3
Downhole logging program:	Standard tools: triple combo, FMS-sonic, VSI
Anticipated lithology:	Sands, silts ,and clays

Site summaries (continued)

Site GC-11A

Priority:	Alternate 2
Position:	Lat 36°25′31.058″N (36°25.517), Long 7°16′41.312″W (–7°16.688) (WGS 84)
Water depth (m)	660
Target depth (mbsf):	991 (primary operations plan based on 650 m penetration)
Approved maximum penetration (mbsf):	Pending EPSP/TAMU Safety Panel approval
Previous drilling in area:	None
Comments:	Jurisdiction: Portugal Alternate to proposed Site GC-05B
Survey coverage (track map, seismic profile)	• Bathymetric sketch with site location and seismic lines position around proposed Sites GC-05B and GC-11A (slternate) on the contourite depositional system on the middle slope of the Gulf of Cádiz (Fig. **AF6**) • Multichannel seismic reflection (MCS) profile (Line HE91-20) across the sheeted Drifts (Fig. **AF7**)
Objectives (see text for complete details):	MOW lower core (Pliocene and Quaternary record)
Drilling/coring program:	Double APC to refusal, then single XCB/RCB hole to 650 mbsf Temperature measurements: APCT-3
Downhole logging program:	Standard tools: triple combo, FMS-sonic, VSI
Anticipated lithology:	Sands, silts, and clays

Figure AF1. Bathymetric sketch with proposed Sites GC-01A and GC-09A on the contourite Depositional System on the middle slope of the Gulf of Cádiz.

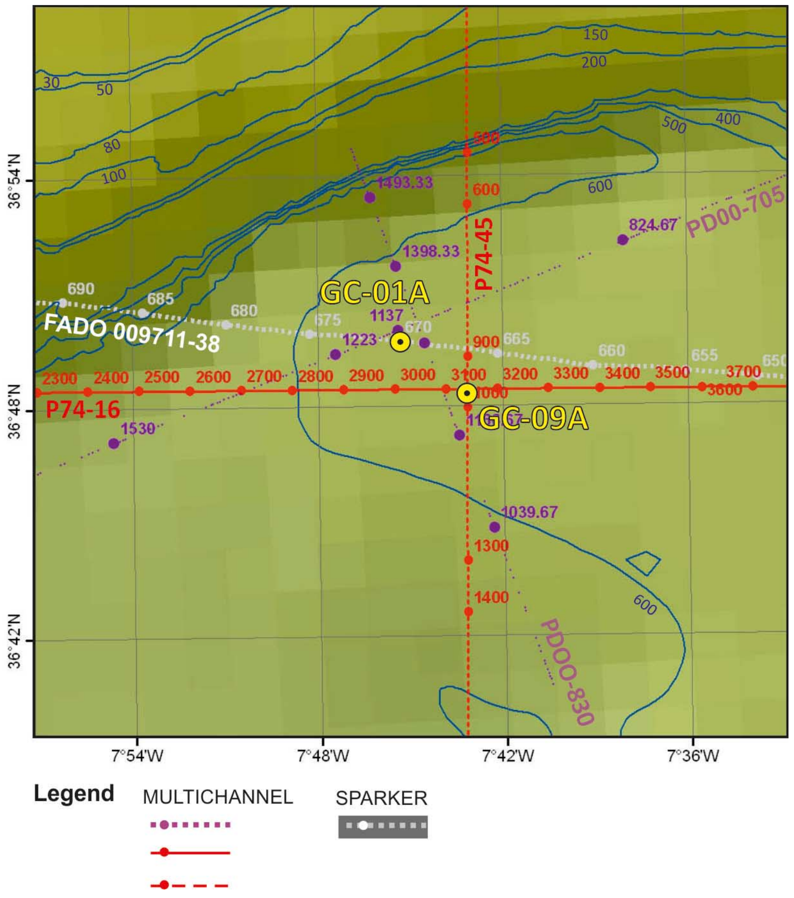


Figure AF2. Sparker seismic reflection profile (Line FADO L-38) across the Faro-Albufeira drift on the middle slope showing location of proposed Site GC-01A. Four major low-resolution depositional sequences have been recognized in the Pliocene and Quaternary sedimentary record (Llave et al., 2001; Hernández-Molina et al., 2002, 2006) and are separated by four relevant discontinuities: LPR (early Pliocene?), QBD (base of the Quaternary?), and MPR (mid-Pleistocene?). LPR erosive discontinuity could represent the onset of drift formation.

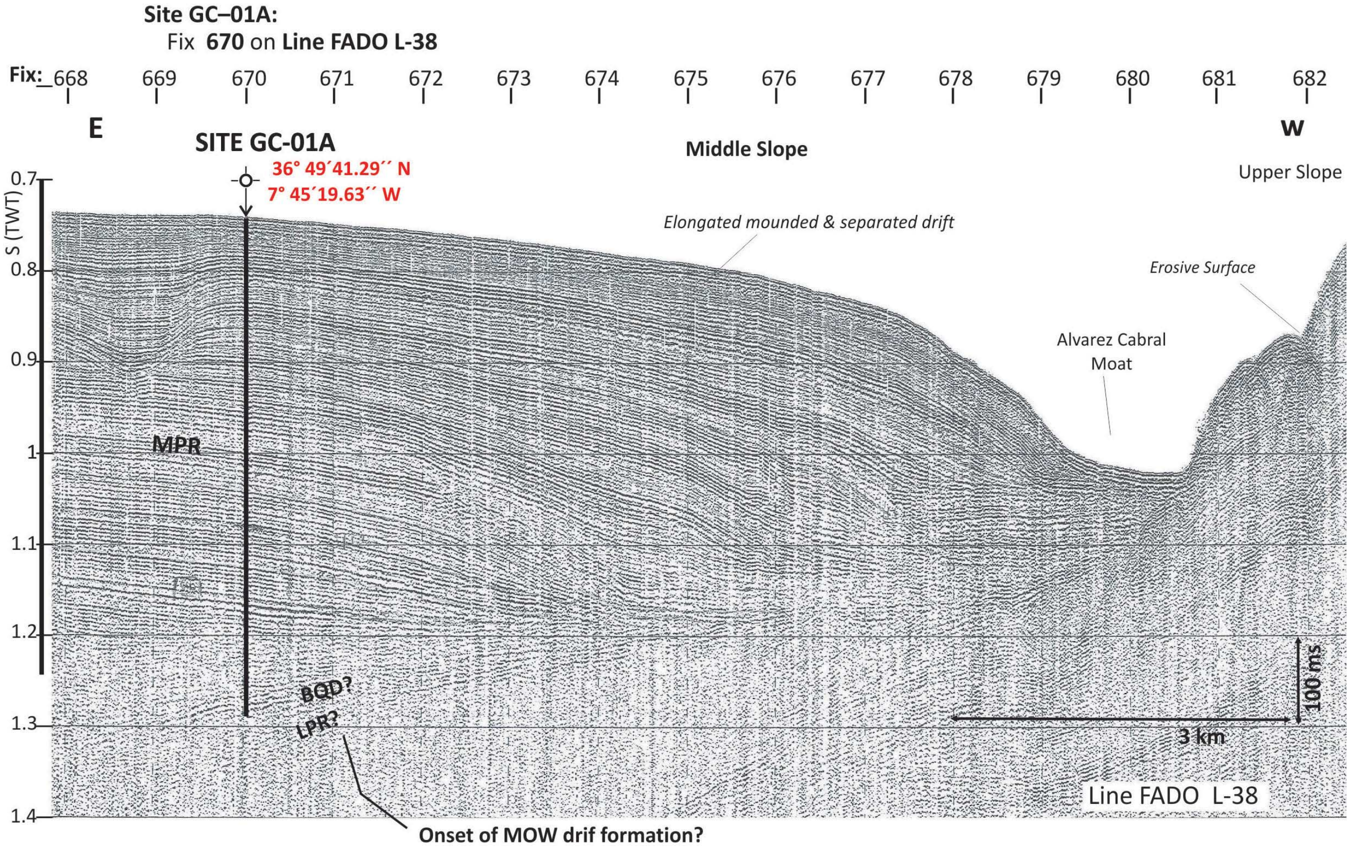


Figure AF3. Multichannel seismic (MCS) reflection profile (Line P74-45) across the Faro-Albufeira drift on the middle slope showing location of proposed GC-09A (MCS lines provided by REPSOL Oil Company). Four major low-resolution depositional sequences have been recognized in the Pliocene and Quaternary sedimentary record (Llave et al., 2001; Hernández-Molina et al., 2002, 2006) and are separated by four relevant discontinuities: M (late Messinian) LPR (early Pliocene?), QBD (base of the Quaternary?), and MPR (mid-Pleistocene?). LPR erosive discontinuity could represent the onset of drift formation. TWT = two-way traveltime. MOW = Mediterranean Outflow Water.

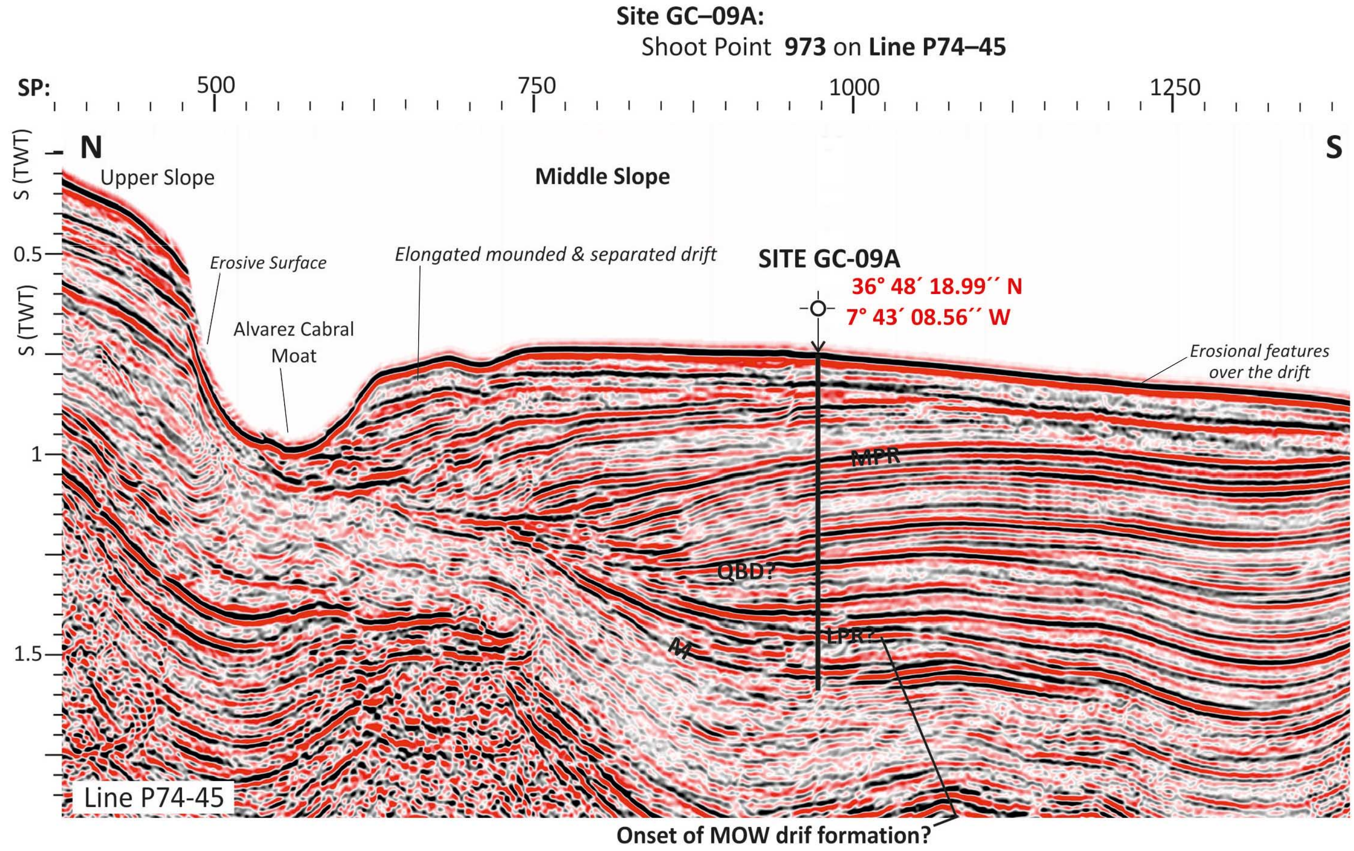


Figure AF4. Bathymetric sketch with proposed Site GC-04B on the contourite Depositional System on the middle slope of the Gulf of Cádiz (close to the Strait of Gibraltar).

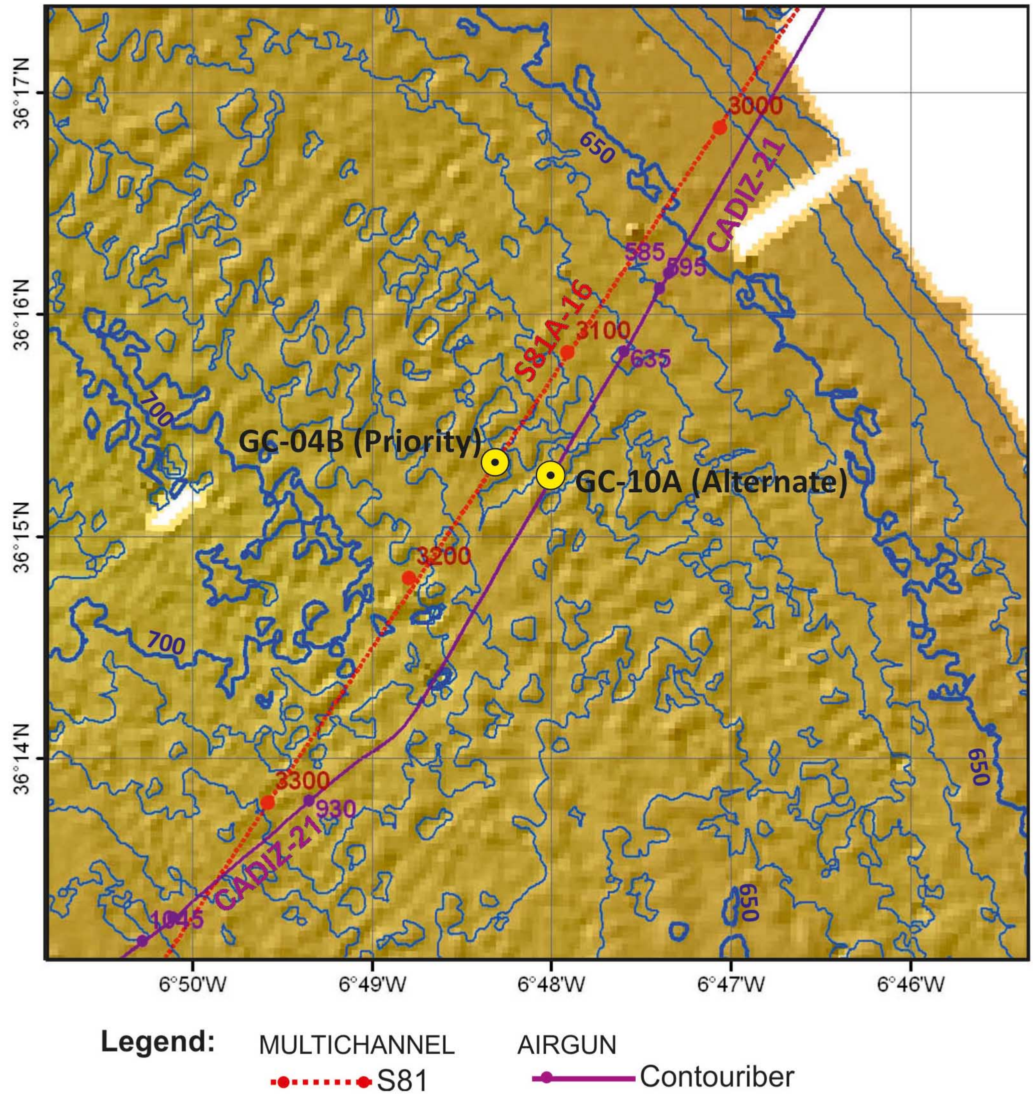


Figure AF5. Multichannel seismic (MCS) reflection profile (Line S81A-16) across the middle slope showing the location of proposed Site GC-04A (MCS lines provided by REPSOL-YPF Oil Company). Four major low-resolution depositional sequences have been recognized in the Pliocene and Quaternary sedimentary record (Llave et al., 2001; Hernández-Molina et al., 2002, 2006) and are separated by four relevant discontinuities: LPR (early Pliocene?), QBD (base of the Quaternary?), and MPR (mid-Pleistocene?). LPR erosive discontinuity could represent the onset of drift formation. TWT = two-way traveltime.

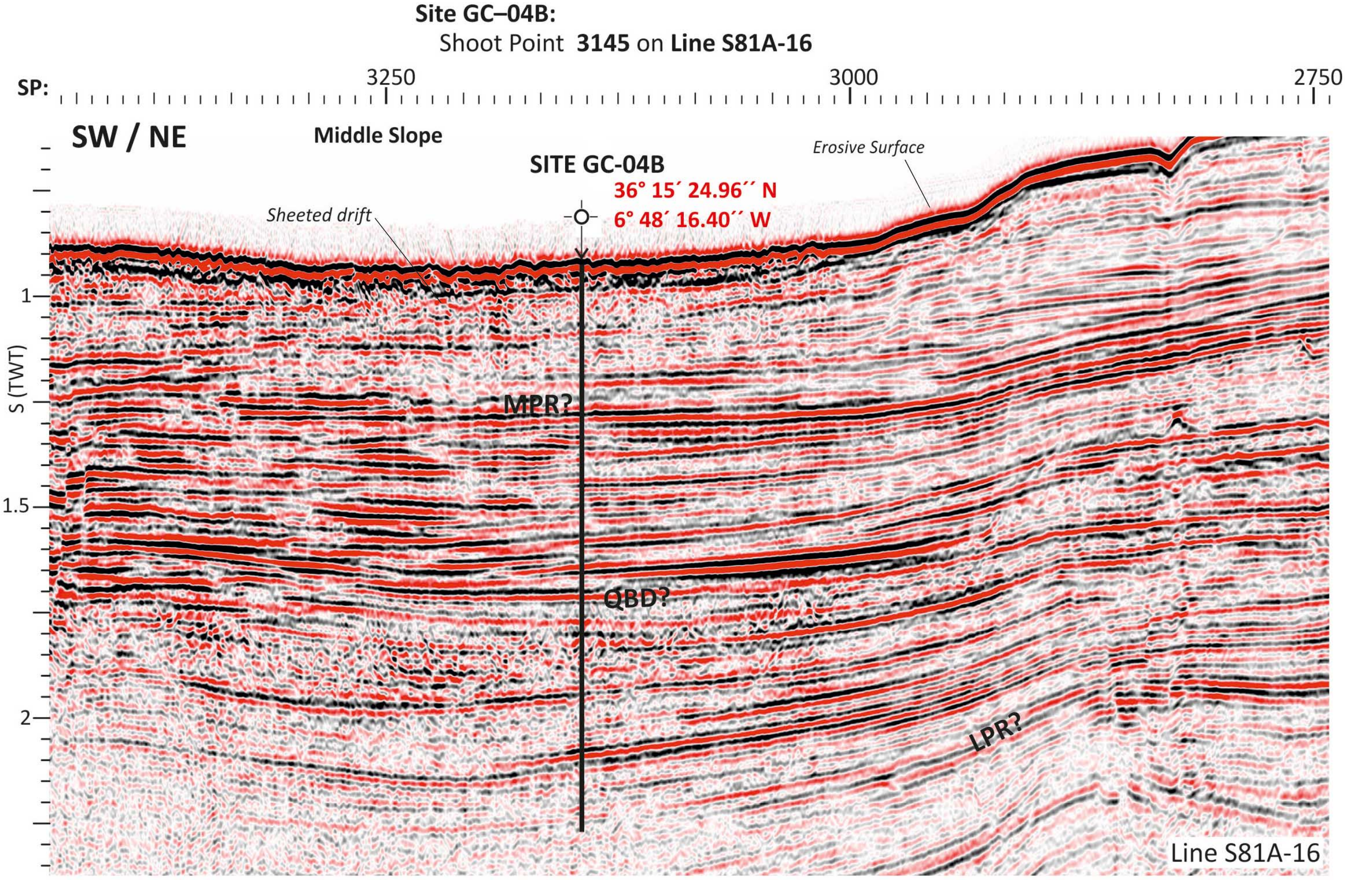


Figure AF6. Bathymetric sketch with proposed Sites GC-05B and GC-11A (alternate) on the contourite Depositional System on the middle slope of the Gulf of Cádiz.

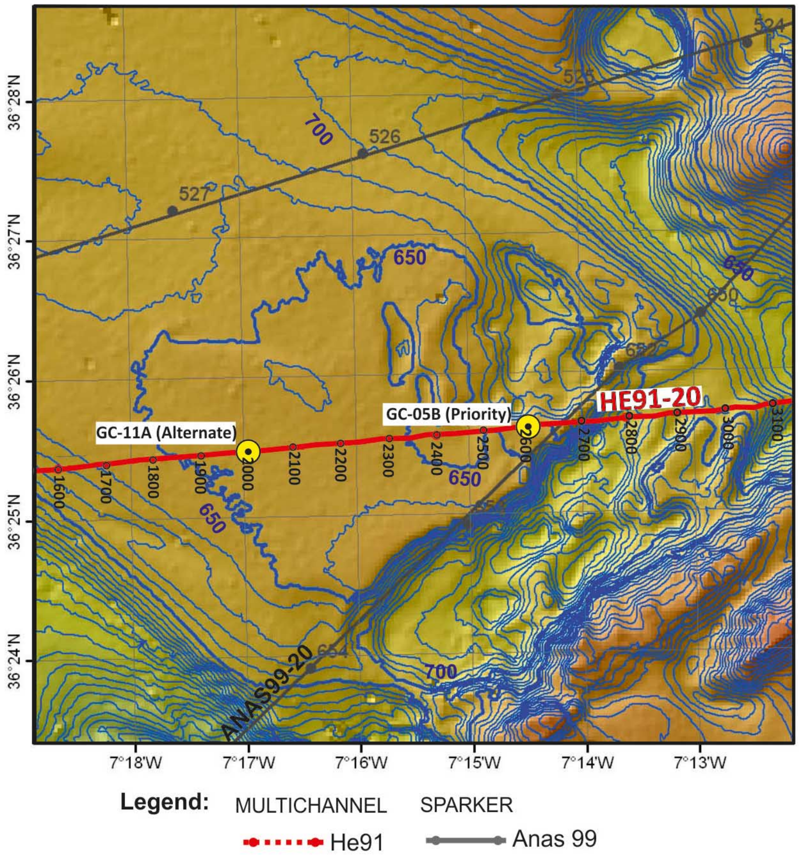


Figure AF7. Multichannel seismic (MCS) reflection profile (Line HE91-20) across the sheeted drifts showing the location of proposed Sites GC-05B and GC-11A (alternate) (MCS lines provided by REPSOL Oil Company). Four major low-resolution depositional sequences have been recognized in the Pliocene and Quaternary sedimentary record (Llave et al., 2001; Hernández-Molina et al., 2002, 2006) and are separated by four relevant discontinuities: LPR (early Pliocene?), QBD (base of the Quaternary?) and MPR (mid-Pleistocene?). LPR erosive discontinuity could represent the onset of drift formation. TWT = two-way traveltime.

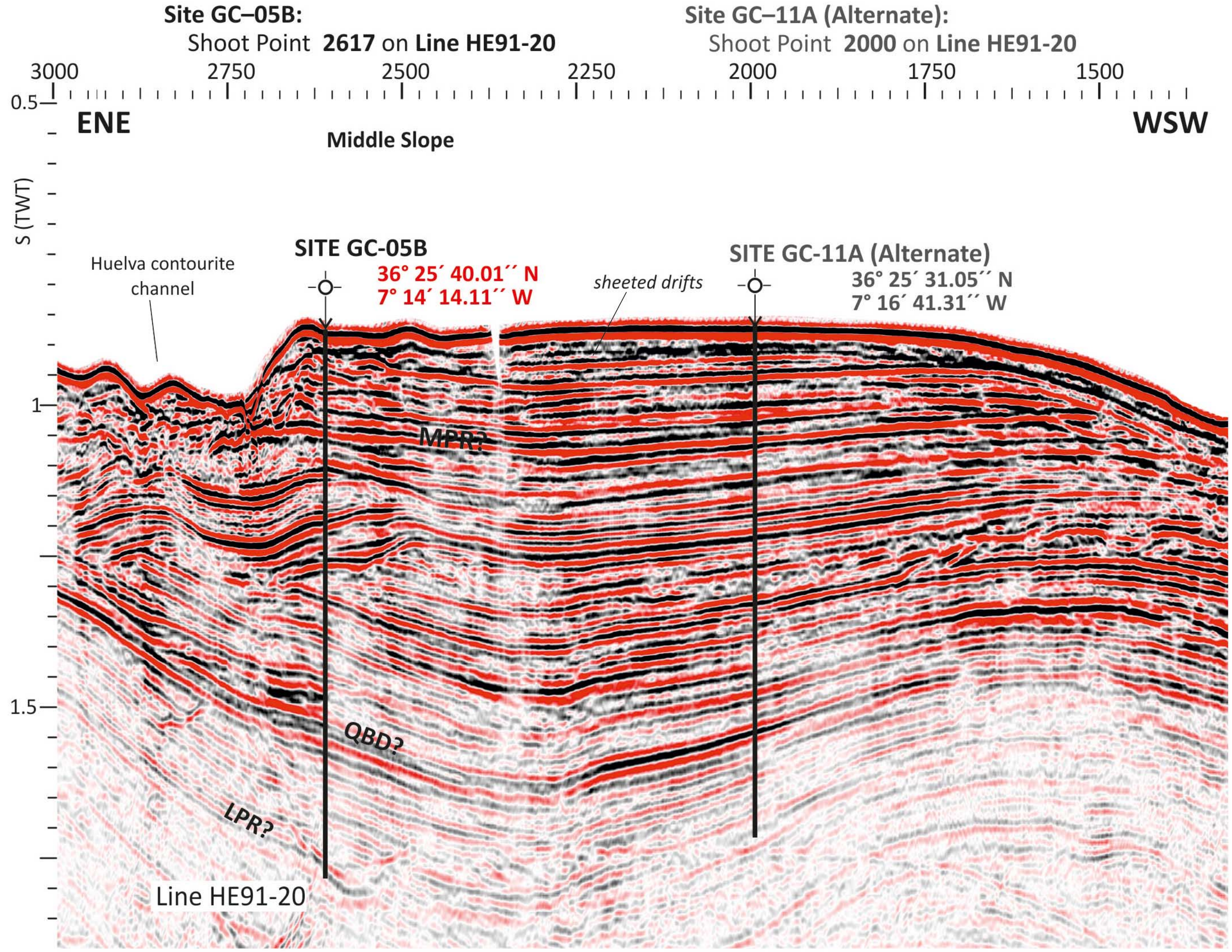


Figure AF8. Bathymetric sketch with proposed Site GC-02B on the contourite Depositional System on the middle slope of the Gulf of Cádiz.

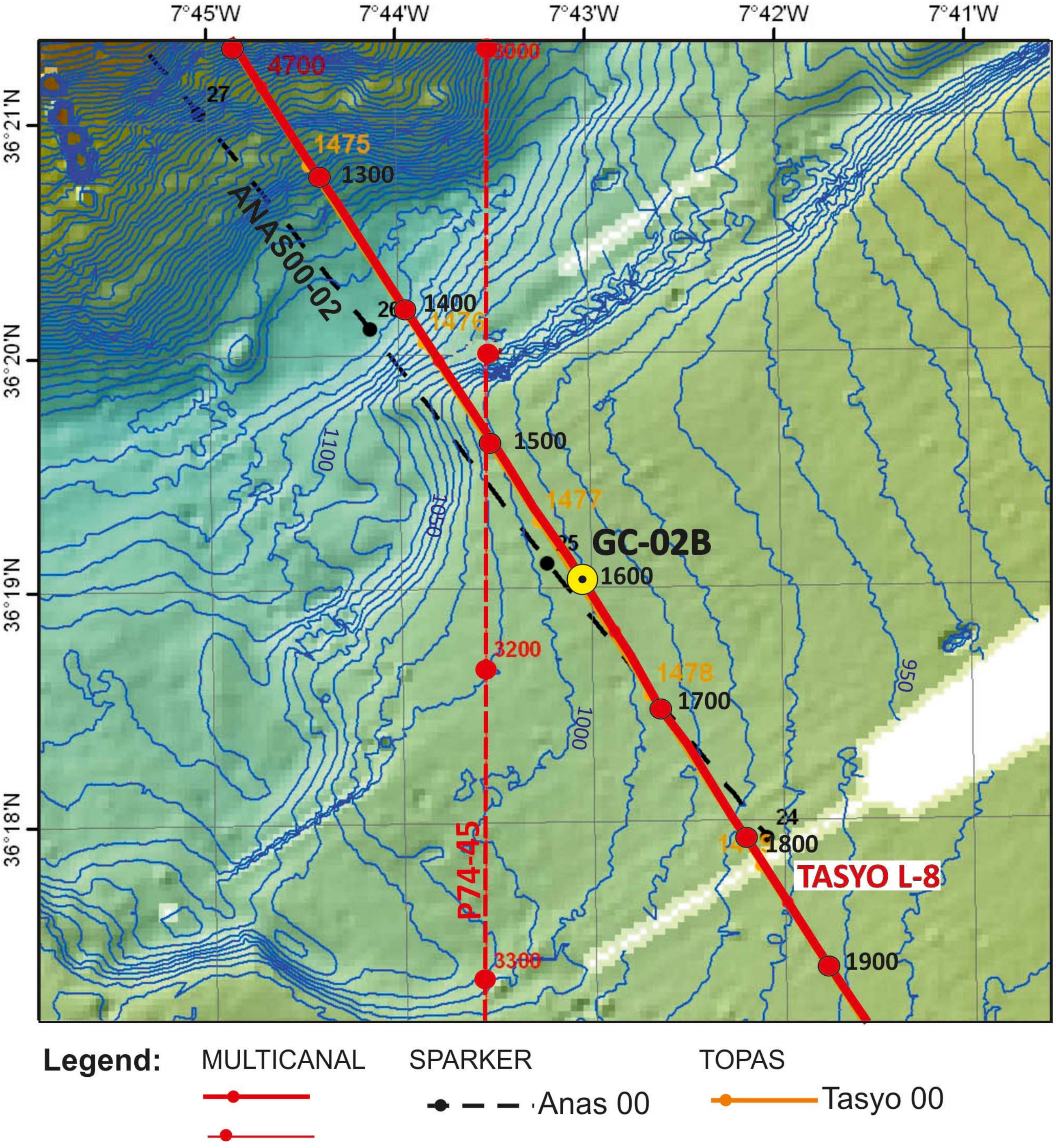


Figure AF9. Multichannel seismic (MCS) reflection profile (Line Tasyo L-8) of the western area of the central sector of the middle slope showing the location of proposed Site GC-02A (TASYO Project). Four major low-resolution depositional sequences have been recognized in the Pliocene and Quaternary sedimentary record (Llave et al., 2001; Hernández-Molina et al., 2002, 2006) and are separated by four relevant discontinuities: QBD (base of the Quaternary?) and MPR (mid-Pleistocene?). LPR erosive discontinuity could represent the onset of drift formation. TWT = two-way traveltime.

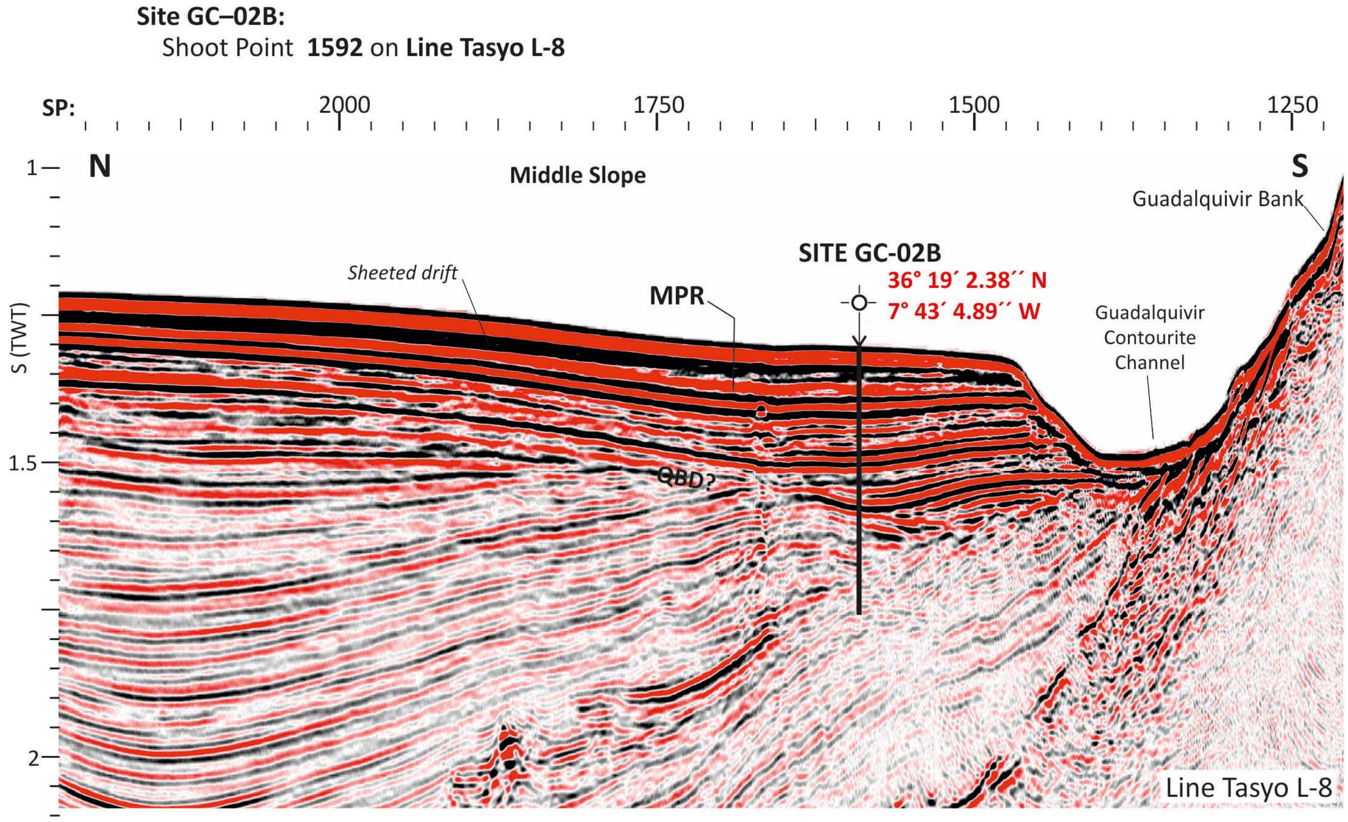


Figure AF10. Simplified bathymetric sketch with proposed Wite WI-01B on the contourite Depositional System on the western Portuguese middle slope.

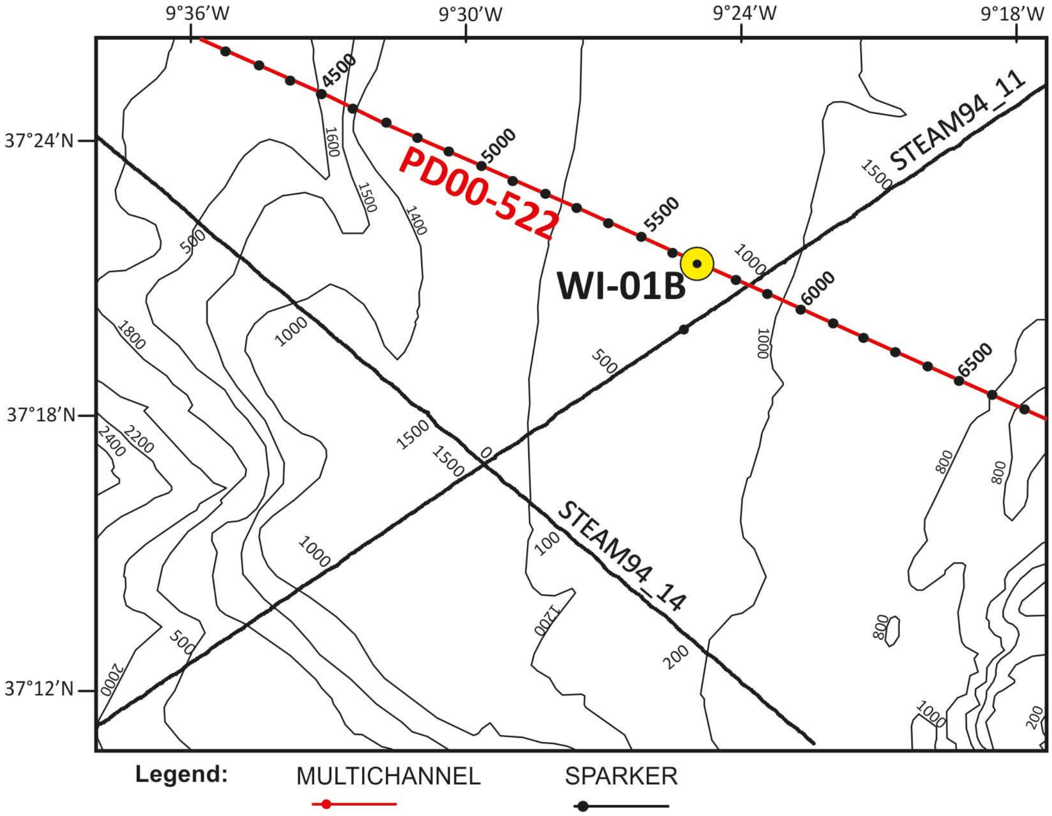


Figure AF11. Multichannel seismic (MCS) reflection profile (Line PD00-522) across the plastered drift on the middle slope showing the location of proposed Site WI-01B (MCS lines provided by TGS-NOPEC Oil Company). Four major low-resolution depositional sequences have been recognized in the Pliocene and Quaternary sedimentary record (Llave et al., 2001; Hernández-Molina et al., 2002, 2006) and are separated by four relevant discontinuities: M (late Messinian), QBD (base of the Quaternary?) and MPR (mid-Pleistocene?). LPR erosive discontinuity could represent the onset of drift formation. TWT = two-way traveltime.

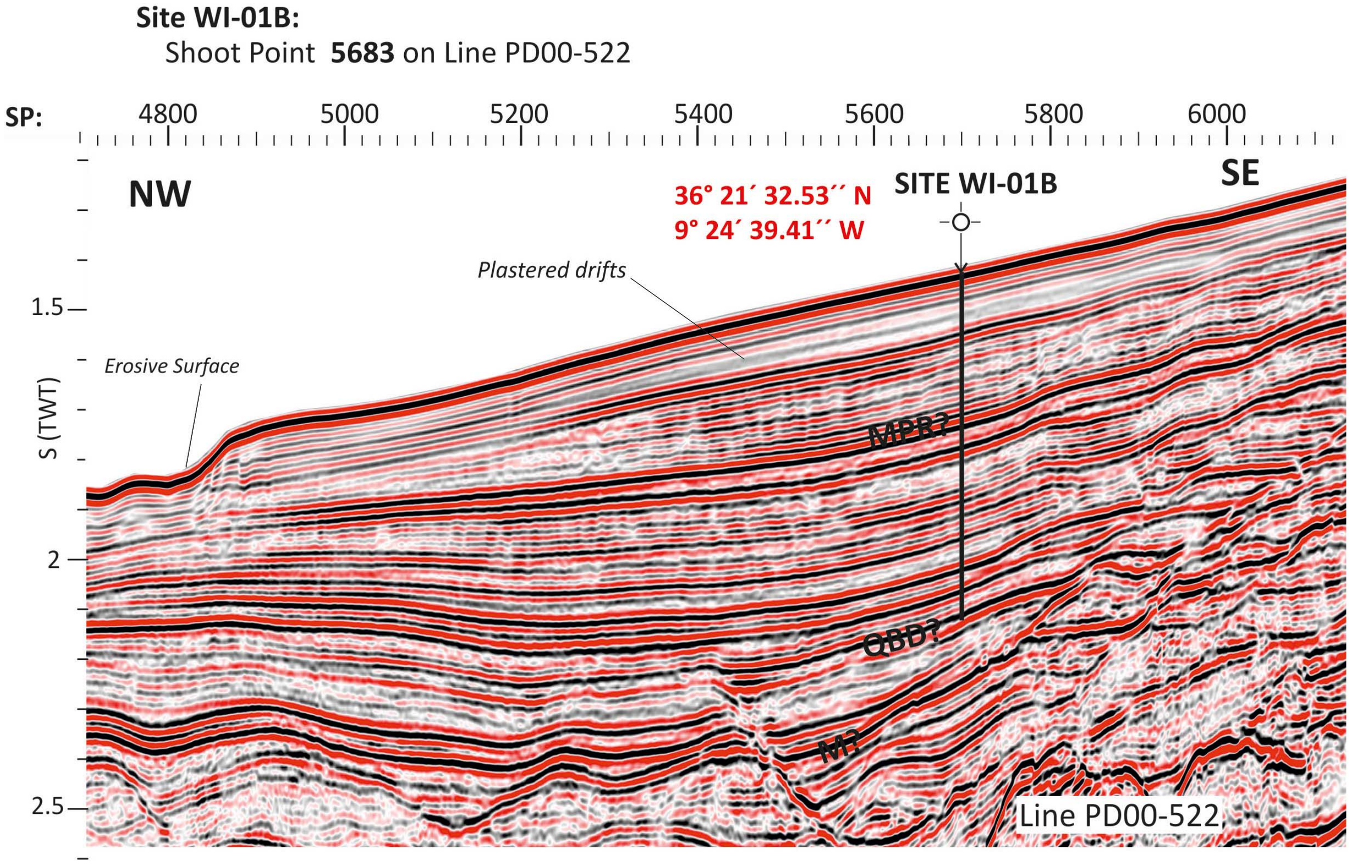


Figure AF12. Track lines for seismic Lines Steam-9407 and BS-09 indicating position of proposed Site SHACK-04A.

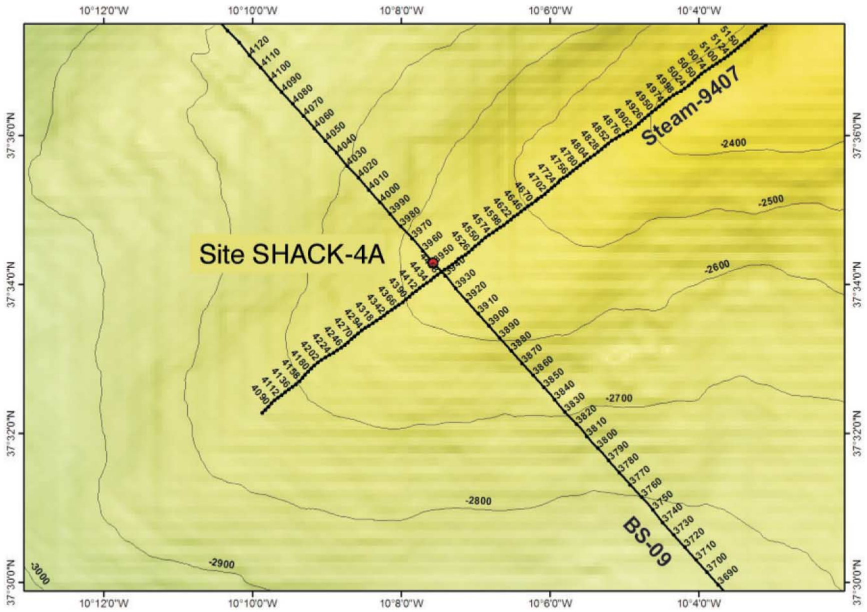


Figure AF13. Seismic Line BS09 indicating the position of proposed Site SHACK-04A at shotpoint 3950.

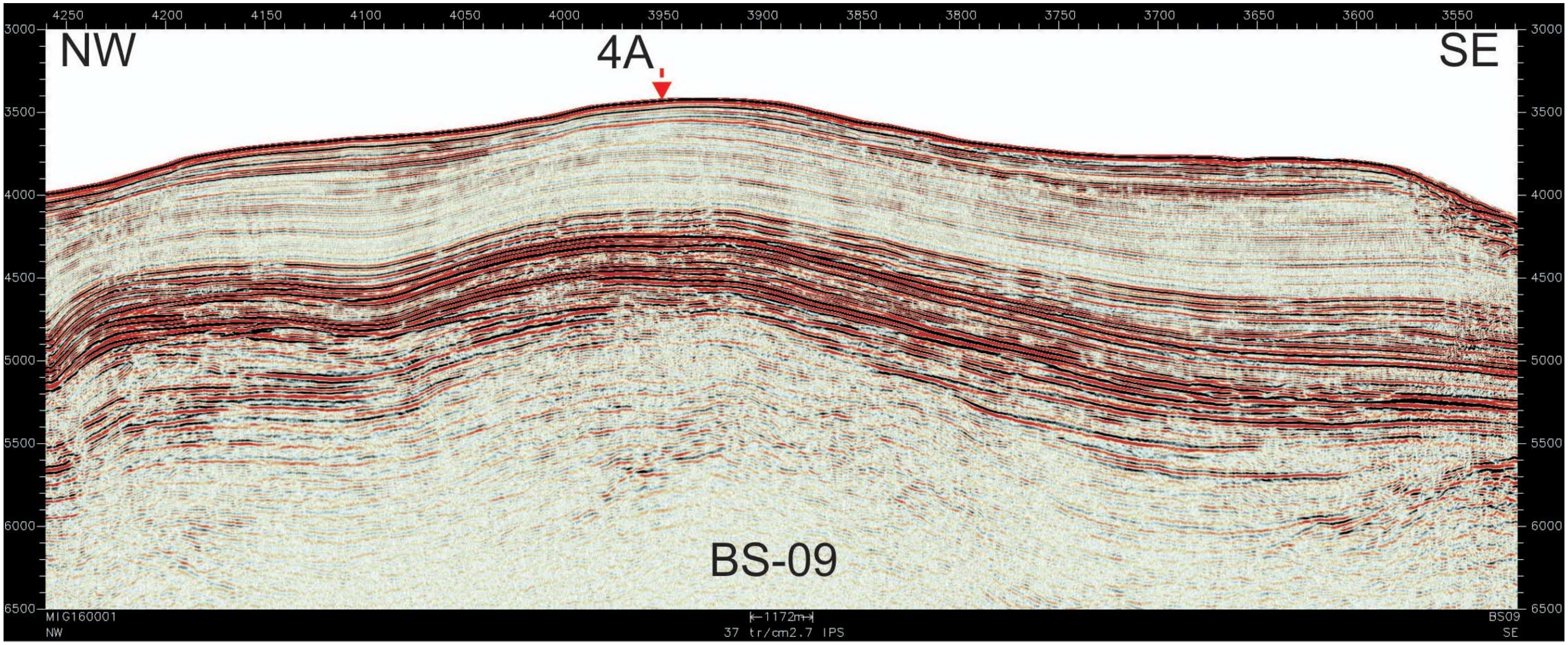


Figure AF14. Seismic Line Steam-9407 showing the position of proposed Site Shack-04A and depth of penetration (~150 mbsf).

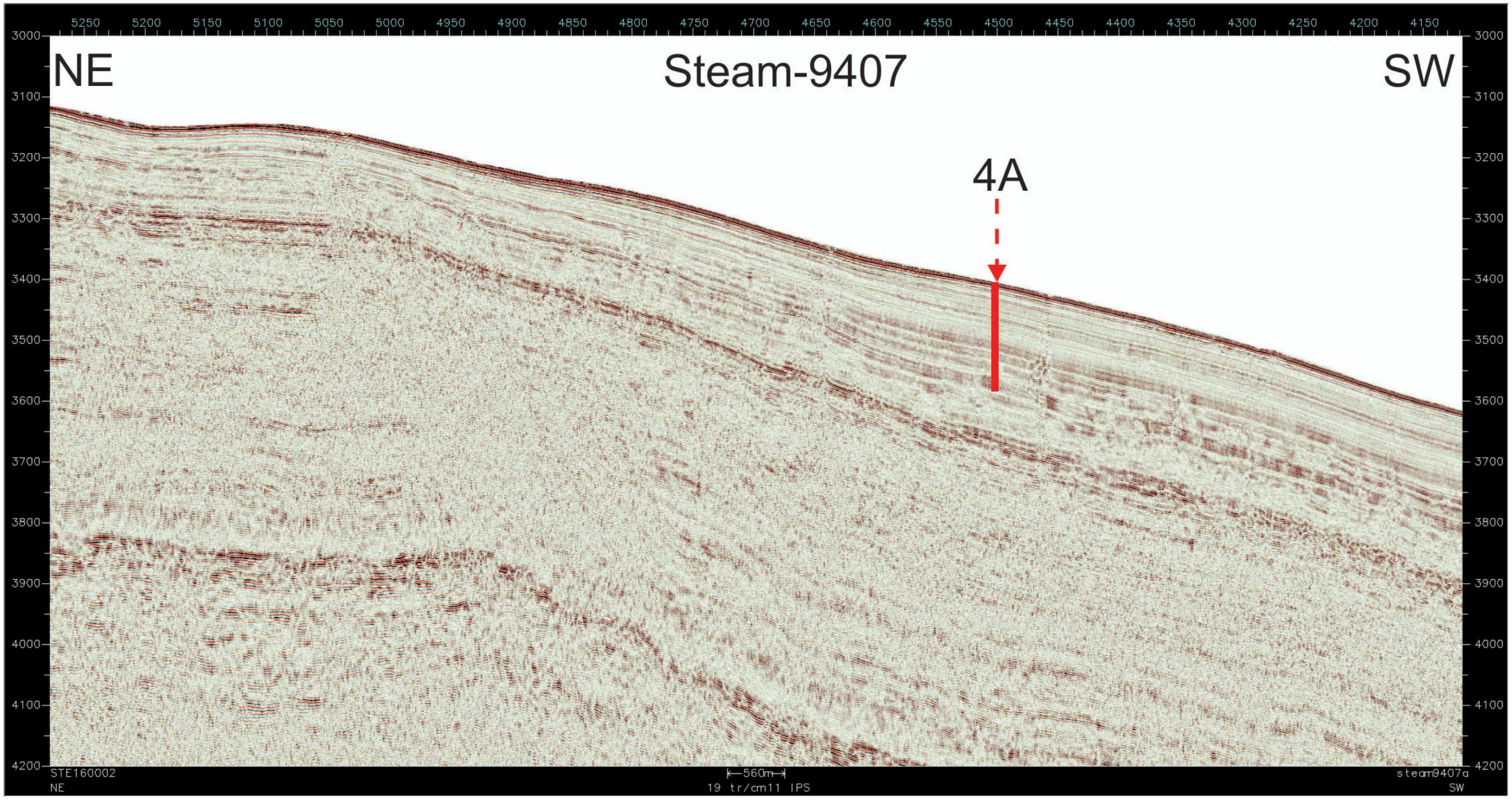


Figure AF15. Bathymetric sketch with proposed Sites GC-04B and GC-10A on the contourite Depositional System on the middle slope of the Gulf of Cádiz (close to the Strait of Gibraltar).

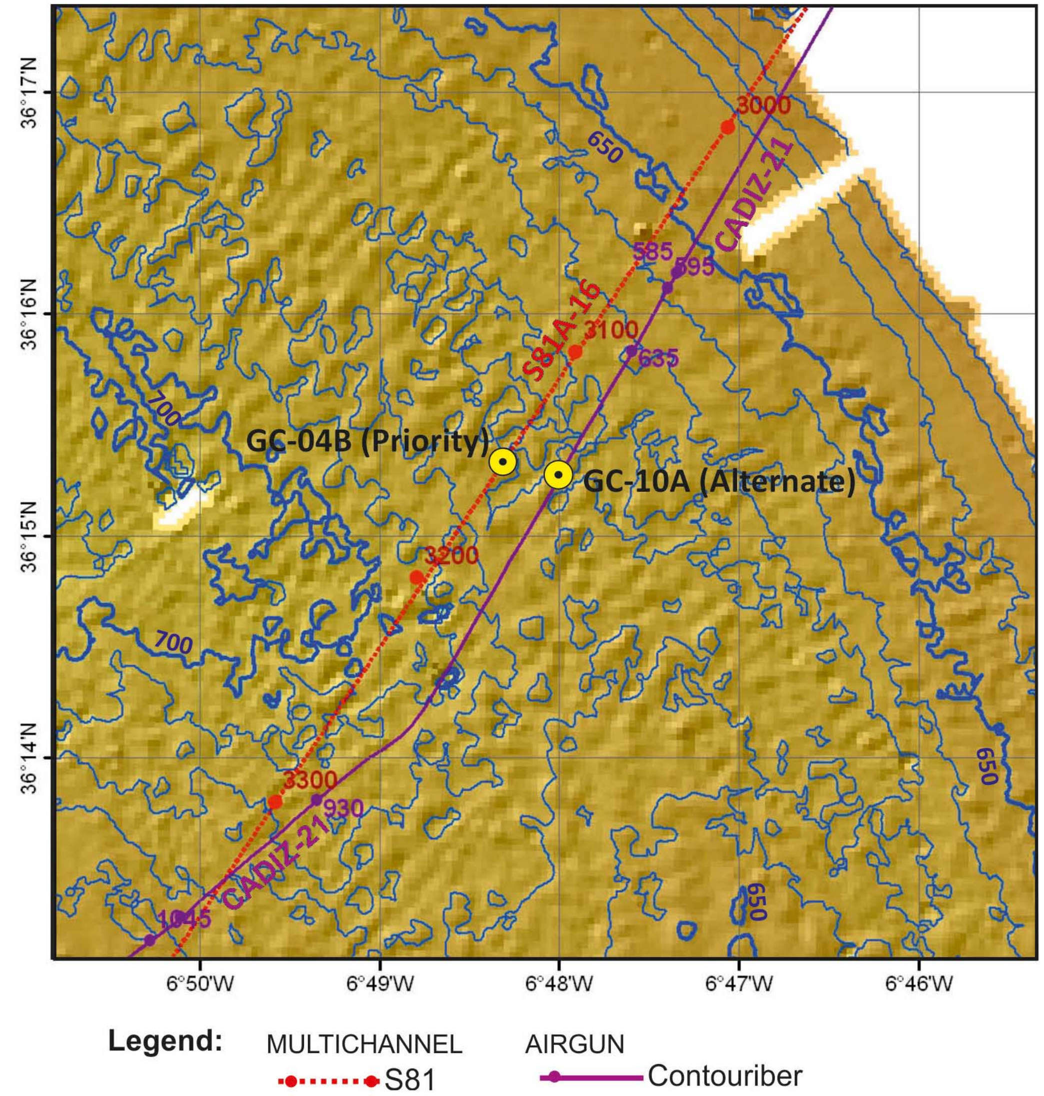
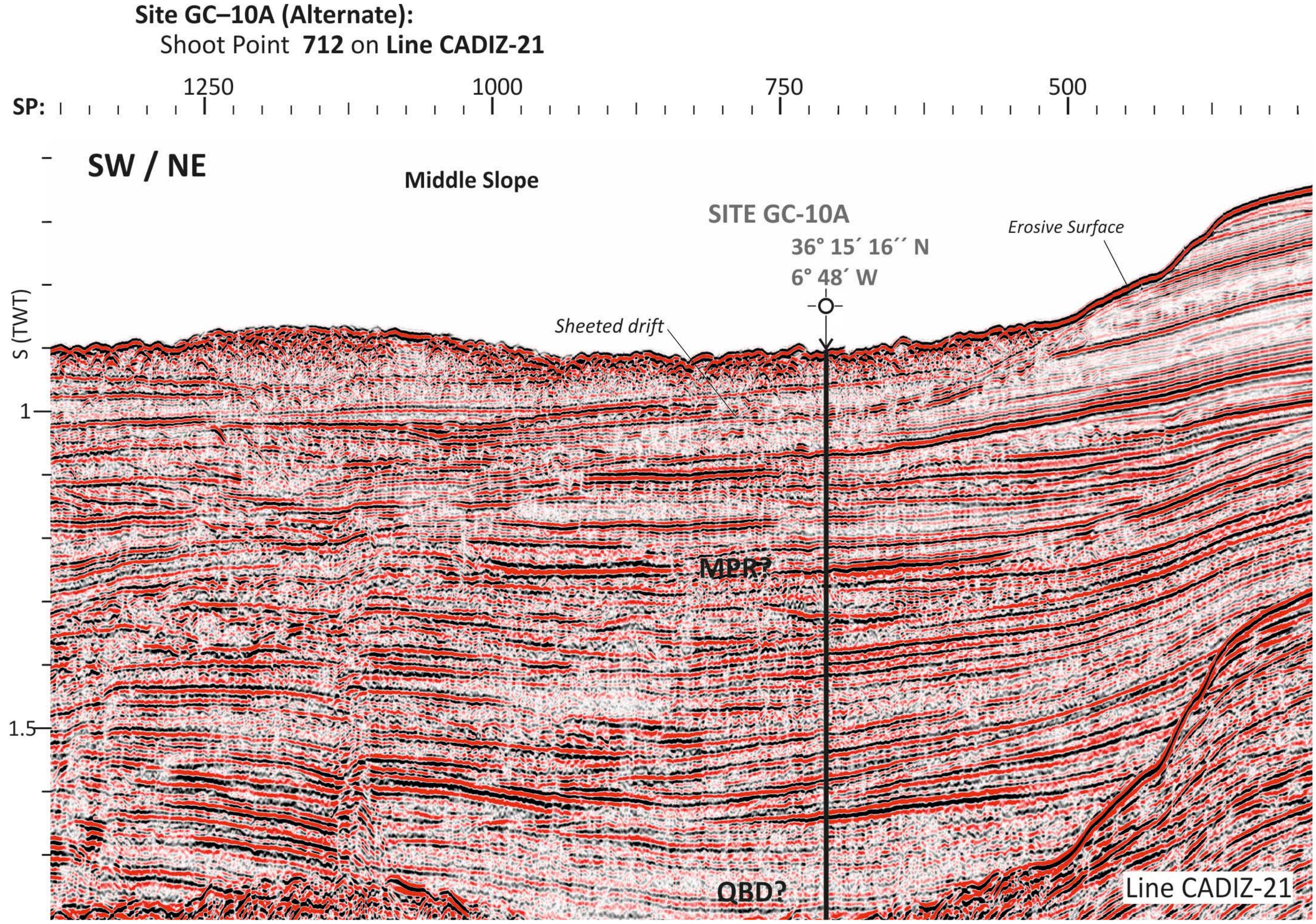


Figure AF16. Multichannel seismic (MCS) reflection profile (Line CADIZ-21) across the middle slope (CONTOURIBER Project) showing the location of alternate proposed Site GC-10A. Four major low-resolution depositional sequences have been recognized in the Pliocene and Quaternary sedimentary record (Llave et al., 2001; Hernández-Molina et al., 2002, 2006) and are separated by four relevant discontinuities: QBD (base of the Quaternary?) and MPR (mid-Pleistocene?). LPR erosive discontinuity could represent the onset of drift formation. TWT= two-way traveltime.



Expedition scientists and scientific participants

The current list of participants for Expedition 339 can be found at **iodp.tamu.edu/scienceops/precruise/medoutflow/participants.html.**