Title: Drilling the "Shackleton sites" on the Portuguese Margin as a Quaternary Marine Reference Section

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Abstract

Few marine sediment cores have played such a pivotal role in paleoclimate research as those recovered from the Portuguese margin (hereafter referred to as the "Shackleton sites"). These cores preserve a high-fidelity record of millennial–scale climate variability for the last several glacial cycles and can be readily correlated to Greenland ice cores. We propose a drilling expedition to extend these remarkable sediment analogs to the polar ice cores into the Quaternary.

1. Introduction

This white paper concerns drilling the so-called "Shackleton sites" on the Portuguese Margin. Although this contribution promotes drilling of a specific expedition, many of the goals and issues of this program are relevant to the more general discussion of the future of paleoceanographic research by IODP. The "Shackleton sites" on the Iberian Margin include Calypso and kasten cores recovered during several cruises aboard the *Marion Dufresne* (MD95, MD99 MD01, and MD03; Fig. 1). The continuity, high sedimentation rates, and fidelity of the sediments on the Portuguese Margin have provided a detailed record of millennial-scale climate variability that can be confidently correlated to Greenland ice cores (Fig. 2). The Iberian Margin piston cores serve as marine reference sections for the last glacial cycle. Here we propose to extend this record through the Quaternary by drilling with the JOIDES *Resolution (JR)*.

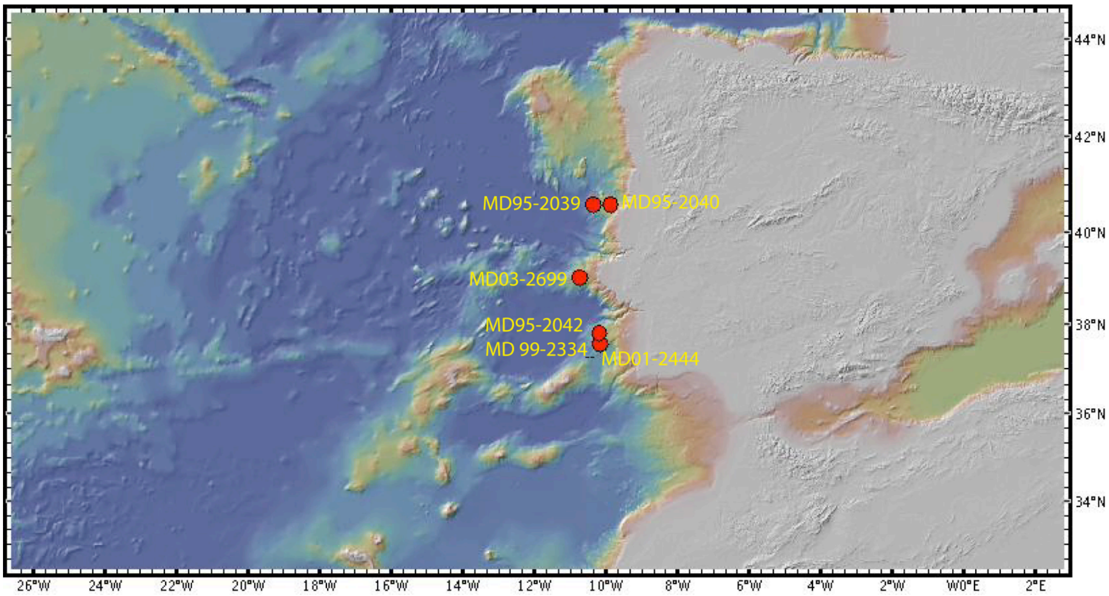

Fig. 1. Location of selected piston cores on the Portuguese Margin that have yielded high-resolution records..

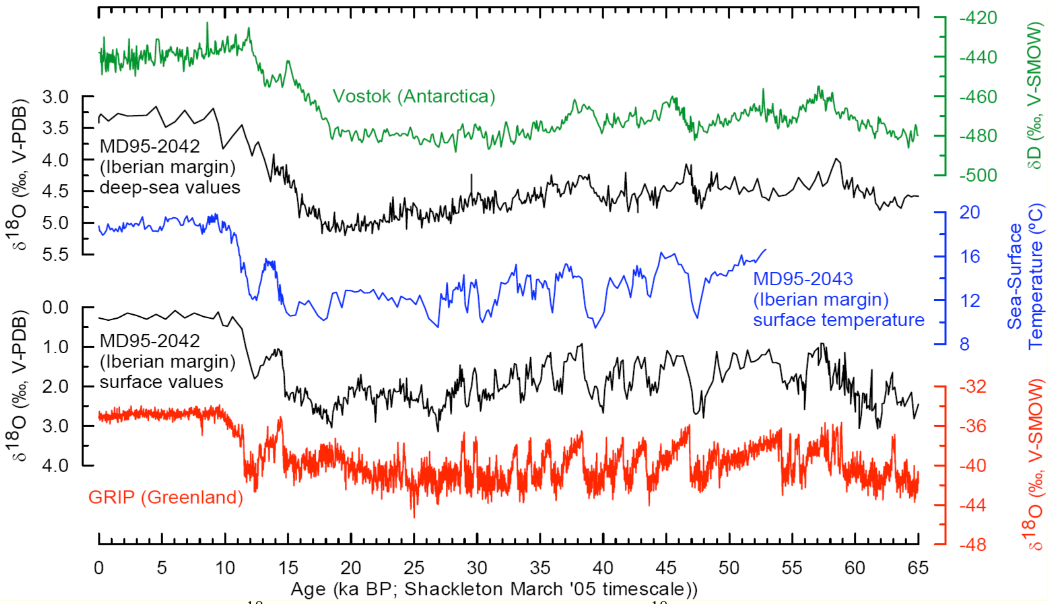

Fig. 2. Correlation of $\delta^{18}O$ record of GRIP ice core (red) to $\delta^{18}O$ of *Globigerina bulloides* (lower black record) in Core MD95-2042. Resulting correlation of Vostok δD (green) and benthic $\delta^{18}O$ of MD95-2042 (upper black record). Also shown is SST derived from alkenones (Uk37) in MD95-2043.

2. Previous Work

A large number of proxy records already exist from the Iberian Margin for the last four climate cycles and study of these cores have resulted in many important contributions including:

1.) timescale development including calibration of the Greenland time scale (e.g., SFCP04 ice-core chronology; Shackleton et al., 2004).
2.) inter-hemispheric phasing (lead/lag) of the climate system during the last glaciation (Shackleton et al., 2000) and deglaciation (Skinner et al., 2005, 2006)
3.) millennial-scale variability over the past four climate cycles (Cayre et al., 1999; de Abreu et al., 2003, 2005; Martrat et al., 2007; Moreno et al., 2002; Pailler and Bard, 2002; Schonfeld et al., 2003; Skinner et al., 2003)
4.) study of past interglacials (5e, 7, 9, 11) (Shackleton et al., 2002, 2003; deAbreu et al., 2005; Desprat et al., 2006, 2009; Eynaud et al., 2000)
5.) marine-terrestrial linkages by studying pollen that is transported to the deep-sea environment off Portugal (Shackleton et al., 2002, 2003; Desprat et al., 2006; Sanchez Goni et al., 1999, 2002; Roucoux et al., 2001, 2006; Tzedakis et al., 2004, 2009).

The oldest Calypso piston core extends to Marine Isotope Stage 15 (MD03-2699). Drilling by the JOIDES Resolution is needed to extend these records into the Quaternary at several locations along the Iberian Margin that are known from seismic profiles to possess high sedimentation rates and be free from down-slope transport.

3. Objectives

3.1 Marine Sediment Analogs to the Polar Ice Cores

The polar ice cores have provided superb records of climate change and have become the benchmarks of Pleistocene climate variability. <u>An important challenge for IODP is to identify complementary marine sections with sufficiently high sedimentation rates and climate signals that are suitable for comparison with the ice core records.</u> Only by integrating marine and ice core stratigraphies can we address mechanisms of the coupled ocean-atmosphere system, including the causes of Dansgaard-Oeschger variability, glacial-interglacial cycles and atmospheric CO_2 variation. The oldest ice recovered in Greenland and Antarctica is 124 ka and 900 ka, respectively, and these records are unlikely to be extended beyond 200 ka (Greenland) and 1.5 Ma (Antarctica). <u>IODP is in uniquely suited to recover marine sediment analogs to the polar ice cores and extend these records beyond the oldest ice in Greenland and Antarctica</u>. Because ice cores are compressed at depth, some marine sections may have greater resolution than the ice cores for older glacial-interglacial periods.

3.2 Interaction of Orbital and Millennial Bands

An important focus of paleoclimate research over the past 15 years has been to understand the origin of millennial-scale climate oscillations that are expressed in records of Greenland and Antarctic ice cores. With few exceptions, deep-sea sedimentary records generally lack the resolution needed to delineate such variability; however, exceptions do exist such as sediments from the Portuguese Margin (Fig. 2). Millennial-scale climate variability has been well documented for the last glacial cycle in the North Atlantic, but relatively little is known about such variability during older glacial periods of the Pleistocene. Drilling on the Portuguese Margin will yield long, continuous time series of millennial-scale variation to study: 1. How millennial and orbital bands of climate variability interact? For example what role do millennial-scale events play in triggering glacial terminations (Wolff et al., 2009)? and 2.) How did millennial-scale variability "evolve" as glacial and orbital boundary conditions changed during the Pleistocene? Did millennial-scale climate variability change in frequency or amplitude across the mid-Pleistocene transition (~920 and 640 ka) when the average climate state evolved toward generally colder conditions with larger ice sheets, and the spectral character of climate variability shifted from dominantly 41 to 100 kyrs? For mostly practical reasons, the study of climate on long and short timescales has been largely decoupled, yet it is probably the interactions between millennial and orbital bands that hold the key to solving some of the outstanding problems in paleoclimatology. <u>Documenting these interactions requires long, continuous sediment records with high accumulation rates and the *JR* is currently the only platform available for delivering such records.</u>

3.3 Overcoming The Problem with Age Models on Millennial Timescales

Determining the correlation and phase relationships of millennial-scale variability in the ocean-climate system is difficult because absolute dating is too imprecise to resolve the exact timing of events on these time scales (Andrews et al., 1999). Correlation is often based on "wiggle matching" of climate records that pre-supposes synchronicity for which there is no independent evidence (Wunsch, 2006). <u>An alternative approach is to determine the relative phasing of changes in proxy variables that monitor different components of the ocean-climate system in the same core</u>. Shackleton et al. (2000, 2004) successfully applied this approach to Portuguese Margin Core MD95-2042 by correlating the planktic $\delta^{18}O$ to Greenland and then determining the phase relationships between Greenland and Antarctica by comparing the timing of planktic and benthic $\delta^{18}O$ changes. This same approach of comparing surface and deep proxies from the same core can be extended to older glacial periods to study interhemispheric phase relationships. Few places exist in the ocean where this approach is feasible.

3.4 Marine-Terrestrial Linkages

Marine archives recovered adjacent to the continents have the potential to link continental and marine climate records. <u>The Portuguese Margin has emerged as a critical area for 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) to the deep-sea environment</u> (Tzedakis et al., 2004, 2009). The western Iberian margin not only provides a rare opportunity to link terrestrial and marine records, but also offers the possibility of tying them to polar ice-cores. This approach can be extended throughout the Quaternary with appropriate recovery of long sediment cores from the Portuguese Margin by ocean drilling.

3.5 Sampling and analysis

The ice core drilling community has enjoyed well-earned success as measured by the quality of the records produced and the number of papers published in respected journals. Because ice cores are few in number, the ice core community has been forced to carefully coordinate and focus their research efforts on a few key records. Ice core samples from the same depth are typically divided among multiple investigators and results are often replicated among laboratories. Alley (2003) suggested that paleoceanographers should consider following the ice core community's lead and organize a research effort to "generate a few internationally coordinated, multiply replicated, multiparameter, high time resolution-type sections of oceanic change." We support such an approach and propose that Portuguese Margin drilling could serve as an example of a new strategy for sampling and analyzing IODP cores.

High-resolution sampling is required to capture millennial-scale climate variability even in regions of high sedimentation rates such as the Portuguese Margin. Adequate core material is needed to accommodate the anticipated high demand for samples as well as preserving material for future. Effort needs to be invested in recovering multiple copies of marine reference sections to obtain adequate material by drilling more than the usual number of holes at each site. Even under good drilling conditions, three holes are often needed to obtain a complete spliced stratigraphic section. We suggest drilling 5 holes at each site to provide primary and secondary splices. A multi-proxy approach requires close coordination among research groups including shipboard and non-shipboard scientists. By establishing requirements of each potential research group early in the planning process, the drilling strategy can be tailored to meet all sampling needs.

4. Community Support

There is wide interest and support within the paleoceanographic community in seeing the Shackleton sites drilled. At a recent IODP-ICDP workshop on "Acquiring High to Ultra-high Resolution Geological Records of Past Climate Change by Scientific Drilling"(29th Sept-1st Oct 2008, GFZ, Potsdam), the Shackleton sites were identified as a key target for future IODP drilling to obtain marine sediment analogs to the polar ice cores. The European Science Foundation has funded a workshop on drilling the Iberian Margin as part of the Magellan Workshop Series to be held in November 2009 in Lisbon, Portugal.

5. Planning

We believe a stand-alone proposal is warranted to drill the Shackleton sites to ensure the sections are continuously cored and properly recovered with multiple holes at several locations. An extensive array of high quality seismic data exists for the Iberian Margin and will facilitate identifying suitable drilling locations. A full drilling proposal will be submitted for April 1, 2010 following the Magellan workshop.

IODP Proposal #644 (GUCADRILL: Environmental Significance of the Mediterranean Outflow Water and its Global Implications) includes one of the Shackleton sites (WI-02A) at the location of piston core MD95-2042. The main objective of this drilling proposal is to study the history of Mediterranean Outflow Water (MOW) on North Atlantic circulation, and we are concerned about the priority of WI-02A in the drill plan. We plan to submit an Ancillary Program Letter (APL) for October 1 to request 3 days of drill time to triple APC Site WI-02A to a depth of 150 m at each hole. This time is based on the IODP Coring Time Estimator Program and includes trip in, pull to mud line between holes, and trip to completion upon last hole but no logging. Triple APC to 200 m would require 4.2 days.

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