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A 1-Ma record of sea surface temperature and extreme cooling events in the North Atlantic: A perspective from the Iberian Margin

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A B S T R A C T

The Iberian Margin is a sensitive area to track high and low latitude processes, and is a key location to understand major past climatic and oceanographic changes. Here we present new biomarker data from IODP Site U1385 ("Shackleton site") (1017–336 ka) that, when combined with existing data from Cores MD01-2443/4 (last 335 ka), allows us to assess the evolution of sea surface temperature (SST) and meltwater influx over the last 1 Ma at the Iberian Margin. Interglacial periods throughout the last 1 Ma show SST close to 20 °C, even during the so-called "luke-warm" interglacials that are marked by relatively low atmospheric CO_2 concentrations. During glacial periods, extremely cold stadial events are recognized at the Iberian Margin, and are very likely related to meltwater discharges from the European and British-Irish ice sheets into the NE Atlantic, which were transported southwards by the Portugal Current. We subdivided the record into four intervals on the basis of the timing and the magnitude of these extremely cold stadials: 1) from 1017 to ~900 ka, only minor sporadic freshwater input occurred during deglaciations; 2) from 900 to 675 ka extreme cold events occur as terminal stadial events at the beginning of the deglaciations, which results in abrupt deglacial SST shifts; 3) from 675 to 450 ka only a few, very short-lived events are recorded and seldom is there freshwater input at the Iberian Margin; 4) during the last 450 ka the extreme cold events occurred under full glacial conditions, with particularly severe events during MIS 6 and 8. We propose these mid –glacial events are associated with a strong discharges of European ice sheet (EIS). The fact that these extreme cold events do not coincide with deglaciations questions the role of European ice sheet discharges in triggering deglaciations.

1. Introduction

Over the last million years, the earth's climate system underwent repeated long term climatic shifts between glacial and interglacial conditions. The timing, duration and amplitude of major glacial-interglacial cycles have been modulated by changes in the Earth's orbit around the sun. In particular, the Early Pleistocene symmetrical, low-amplitude and high-frequency (41 ky obliquity) climate cycles were gradually replaced by the Middle Pleistocene asymmetrical, high-amplitude and low-frequency (100 ky eccentricity) climate cycles (Clark et al., 2006; Lisiecki and Raymo, 2005). The transitional period during which the 41 ky cycles changed to 100 ky is known as the Mid Pleistocene Transition (MPT) or Early Middle Pleistocene Transition (EMPT) (Head and Gibbard, 2015). Although the MPT timing is still under debate, Clark et al. (2006) defined the MPT as the interval encompassing 1250 to 700 ka. However, some authors suggested that the 41 ky climate variability persisted (Pisias and Moore, 1981) until nearly 700–600 ka ago (Berger et al., 1994; Maslin and Brierley, 2015; Ruddiman et al., 1989), when the strong quasi-100 ky climate cycles began (Mudelsee and Schulz, 1997). The end of the MPT is also

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characterized by an increase in the flux of northern sourced bottom waters during interglacial periods and is associated with a northward penetration of relatively warm and saline surface waters into the Norwegian-Greenland Seas, which enhanced deep convection and promoted deeper penetration of North Atlantic deep water (NADW) (Lear et al., 2016; Poirier and Billups, 2014).

Glacial periods over the last 1 Ma, have been punctuated by episodes characterized by drops in SST, increases in fresh water input (% $C_{37:4}$) (Martrat et al., 2007; Rodrigues et al., 2011) and the southward expansion of the polar planktonic foraminifera *Neogloboquadrina pachyderma* (formerly known as *N. pachyderma* sinistral) (de Abreu et al., 2003; Voelker and de Abreu, 2013). These events were linked to iceberg discharges from the Northern Hemisphere ice sheets and their associated meltwater input into the North Atlantic region. Records of ice-rafted debris (IRD) and freshwater input indicate the presence of iceberg discharges at different latitudes of the North Atlantic; north of 55 °N (Alonso-Garcia et al., 2011b; Hernández-Almeida et al., 2012; McClymont et al., 2008; Wright and Flower, 2002), between 50 and 40 °N (Hodell et al., 2008; Naafs et al., 2011), and also south of 40 °N on the Iberian Margin for the last 580 ka (de Abreu et al., 2005; de Abreu et al., 2003; Martrat et al., 2007; Rodrigues et al., 2011; Voelker and de Abreu, 2013). Intensification of cold conditions in the (sub)polar areas and increased iceberg calving favored the migration of the subpolar front, which is marked by a steep temperature gradient that separates the relatively warm temperatures of the subtropical gyre to the south/east and the cold waters of the subpolar gyre to the north/west (Barker et al., 2015). Changes in the position of the subpolar front as a response to ice-rafting and abrupt climate events have been identified based on planktonic foraminifer assemblages (Alonso-Garcia et al., 2011a; de Abreu et al., 2005; de Abreu et al., 2003; Eynaud et al., 2009; Salgueiro et al., 2010, 2014; Voelker and de Abreu, 2013; Wright and Flower, 2002). However, these works did not include mid-latitude records beyond 420 ka, hampering the inference of the position of the subpolar front south of 55 °N during the oldest glacial-interglacial cycles of the last 1 Ma. The few continuous and high resolution paleoceanographic records from the mid-latitudes are located in the central Atlantic (Naafs et al., 2010) and the western mid-latitudes (Poirier and Billups, 2014). Long alkenone-SST records have been produced from the SW Iberian Margin during the last decade (Martrat et al., 2007; Rodrigues et al., 2011), although none of these records attain more than 580 ka (i.e. MIS 15) involving sedimentation rates between 11.5 cm/ky and 1.9 cm/ky in the older part of the MD03-2699 record (Rodrigues et al., 2011). There is only one study from the Bay of Biscay in which iceberg and freshwater discharges have been identified in low resolution for the last 1.2 Ma (Toucanne et al., 2009). Therefore, the impact of the MPT changes in the eastern North Atlantic mid-latitude climate and oceanography, and, in particular, on the SW Iberian Margin is poorly documented and understood.

The Iberian Margin preserves a pristine record of glacial-interglacial climate change because it is sensitive to migrations of the subpolar Front and sea-ice expansion in the North Atlantic (Fig. 1). Paleoceanographic records from the SW Iberian Margin are not only influenced by low-latitude climate processes, but also by high latitude climate variability, such as the migration of the subpolar front associated with sea ice advances/retreats (Eynaud et al., 2009; Naughton et al., 2009; Voelker and de Abreu, 2013) and, hence, the sediments from this region faithfully reflect high latitude climate change (Shackleton et al., 2000). Here we present an alkenone-based SST record combined with the alkenone proxy %

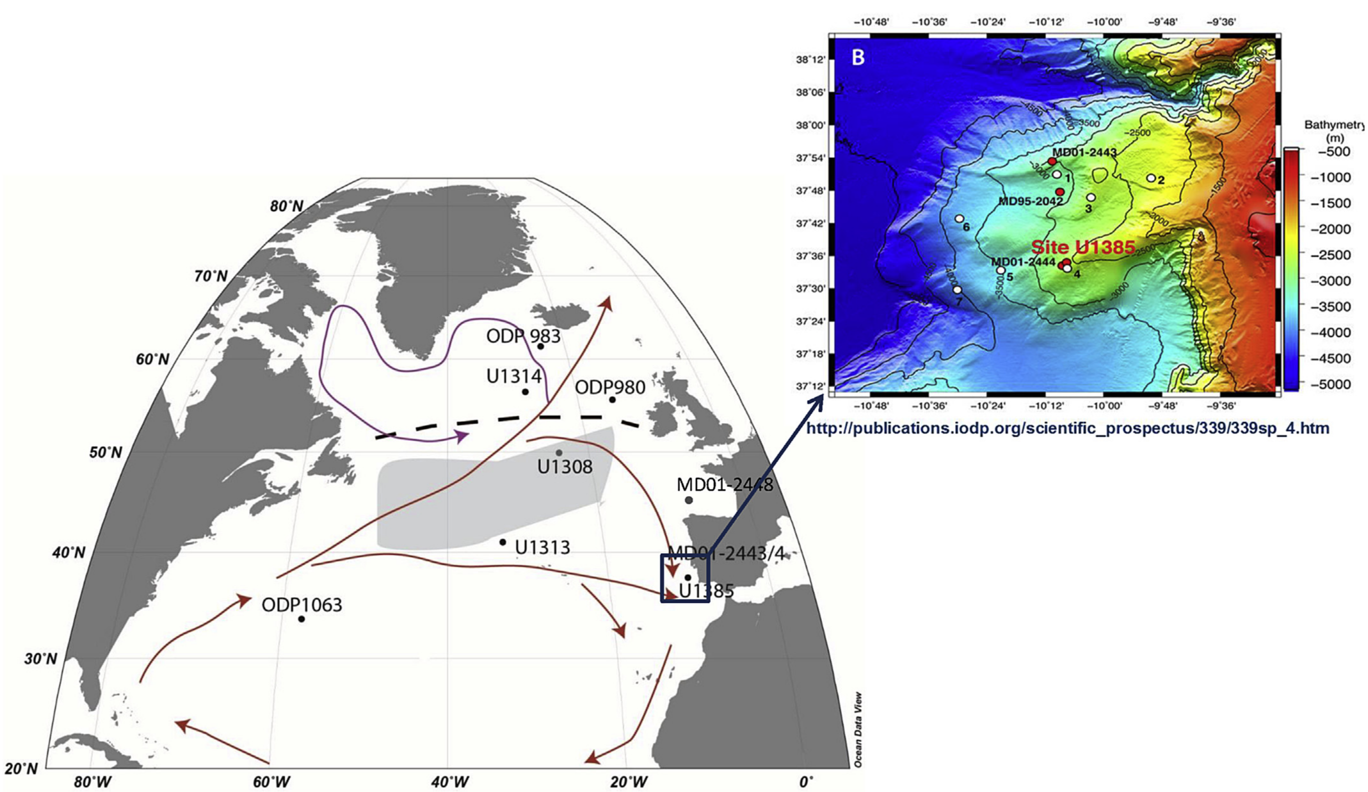

Fig. 1. Location of sites U1385 and MD01-2444/3 and other available North Atlantic records discussed in the text. North Atlantic surface circulation shown in red, and the subpolar gyre in purple. The IRD belt (for the last glacial period) is represented by the grey zone. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)