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Anomalous SST warming during MIS 13 in the Gulf of Lions (northwestern Mediterranean Sea)

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ABSTRACT

During the PROMESS campaign (summer 2004) a borehole (PRGL1) was drilled in the upper slope of the Gulf of Lions covering the last 530 kyr. Here, we present new biomarker data from 440–528 kyr in order to reconstruct past climate variability, sea surface temperature (SST) (alkenone-based) and oxygenation of the bottom waters (based on *n*-hexacosanol and *n*-nonacosane ratio) during Marine Isotope Stages (MIS) 12 and 13. Contrary to southern paleorecords, MIS 13 showed the warmest SST values of the past 530 kyr in the Gulf of Lions, which is in agreement with recent findings in northern continental paleorecords. Our data suggest that the ice volume in northern latitudes and its effect on Inter-Tropical Convergence Zone (ITCZ) position during winter caused the anomalous warming in the northwestern Mediterranean during MIS 13. Moreover, the northward incursion of the ITCZ could have modified the stadial reinforcement of north-westerly winds documented from MIS 11 to the present.

1. Introduction

The MIS 13 has been the subject of recent studies due to the disagreement between southern and northern paleorecord reconstructions. Compared with the later interglacials, benthic $\delta^{18}O$ values of MIS 13 (478–533 kyr) (Lisiecki and Raymo, 2005) showed the heaviest values, which are usually interpreted as a signal of larger global ice volume. This view is in agreement with the Epica Dome C δD (EDC δD) records, where MIS 13 yielded the coolest interglacial temperatures of the 800 kyr (about 4 °C cooler than the Holocene; Jouzel et al., 2007). However, several continental records of the Northern Hemisphere contradict the idea of a cooler interglacial having a larger ice volume. For example, analysis of sediment cores from: (1) the Loess deposits in China (Vandenberghe, 2000; Sun et al., 2006; Guo et al., 2009), lower and middle Danube River (Fitzsimmons et al., 2012) and Serbia (Marković et al., 2009); (2) Greenland coast (de Vernal and Hillaire-Marcel, 2008) and (3) lakes of the Tibetan plateau (Chen et al., 1999) and Siberia (Prokopenko et al., 2002) suggest that the conditions during MIS 13 were relatively warm and coupled with relatively low global ice volume.

The intensity of the north-westerly winds in the Gulf of Lions has been suggested to be influenced by the extension of the ice-sheets in the Northern Hemisphere (Kuhlemann et al., 2008; Cortina et al., 2011, 2013). The presence of large ice-sheets during Last Glacial Maximum (LGM) resulted in the southward displacement of the position of the polar front (Pflaumann et al., 2003) causing the invasion of Arctic air masses into the northwestern Mediterranean with a consequent decrease of sea surface temperatures (SST) in the Gulf of Lions (Kuhlemann et al., 2008). Therefore, the study of SST variations in the Gulf of Lions could be a good indicator of the northern ice-sheet variability. Here, we present new biomarker data from MIS 12 to MIS 13 of the core PRGL1 situated in the Gulf of Lions with the main goal to investigate the northern ice-sheet extension during MIS 13 and to provide new insights into the paleoclimatic conditions during this interglacial stage.

2. Study area

As part of the European Project PROMESS 1 (profiles across Mediterranean Sedimentary Systems), borehole PRGL1 (300 m

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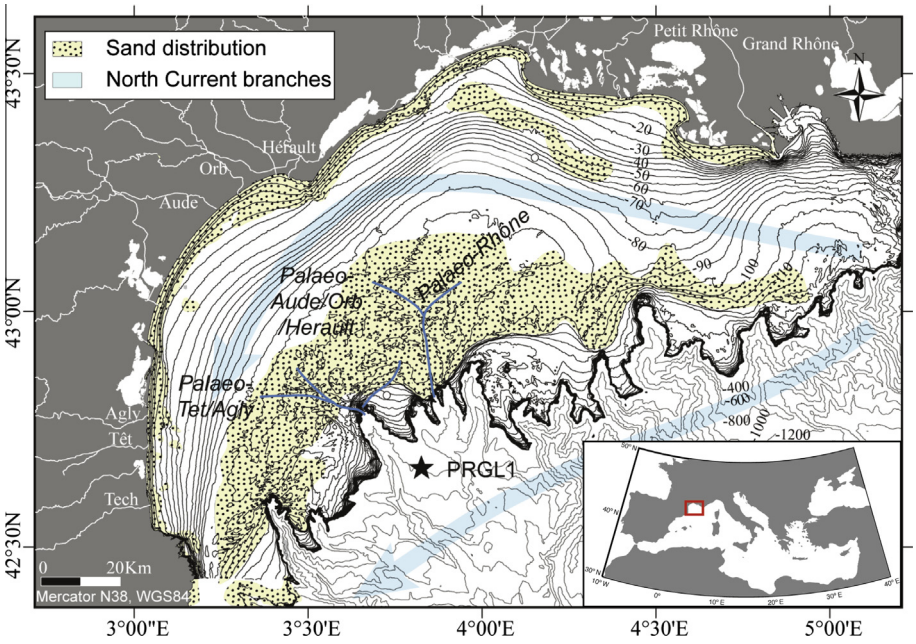

Fig. 1. Map of the Gulf of Lions taken from Jouet et al. (2006). The present-day morphology and the sand distribution on the continental shelf (Aloïsi, 1986) illustrating the last glacial sea-level rise. Blue arrows depict the two North Current branches. Core site PRGL1 is indicated by a black star. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

length) was drilled in the upper slope of the Gulf of Lions (42.690° N, 3.838° E) (Fig. 1) on the interfluve of the Boucart and Herault canyons at a water depth of 298 m. The study site is very suitable for the preservation of continuous sedimentary records because: (1) there is a good balance between the sedimentation rates and the accommodation space; (2) it is not strongly influenced by the Rhône deltaic system and (3) it is distant from the Catalonian Margin, where strong erosive processes have been documented (Rabineau et al., 2005).

The general oceanographic circulation in the Gulf of Lions is governed by a cyclonic along-slope Northern Current (NC), which is divided in two branches: the principal branch flowing through the continental slope, and a secondary branch that penetrates the continental shelf (Millot, 1990) (Fig. 1). Due to seasonal stratification and changing wind regimes, the current oscillates in magnitude and direction over the year, doubling its intensity during winter compared to summer (Béthoux, 1984).

The study area is under the influence of the cool north-westerly winds (the Mistral and Tramontana), blowing through the Pyrenees, the Massif Central and the Alps. On a large scale, the north-westerly winds induce upwelling that spreads out over two-thirds of the gulf, and downwelling over one-third (Millot, 1982). Consequently, north-westerly winds are responsible for downwelling and upwelling processes simultaneously. The upwelling processes bring colder and nutrient-rich intermediate and deep waters to the mixed layer. It is during these productive events, mainly during winter–spring transition, when the highest annual coccolithophore production occurs (Rigual-Hernández et al., 2013). Coccolithophores are one of the main producers of C_{37}–C_{39} long-chain ketones with two to four double bonds, known as alkenones (e.g., Volkman et al., 1980). The relative content of unsaturated ketones depends on the growth temperature of the microalgae (Brassell et al., 1986) and thus the alkenone ratio in sediments can be used for reconstructing past SSTs. Therefore, the SST estimates inferred from this indicator in the Gulf of Lions can be used to reconstruct the SSTs during the periods of maximum production and export of coccolithophores, i.e. the annual upwelling events during the winter–spring transition.

3. Methods

A total of 197 samples (1 cm thick slices) for biomarker analysis were taken from borehole PRGL1 between 231.44 mbsf (440 kyr) to 300.58 mbsf (528 kyr), covering MIS 12 to MIS 13. In order to avoid significant differences in the age resolution due to differences in the sedimentation rates during glacial and interglacial periods (Sierro et al., 2009), samples were taken every 20 cm during glacials and 1 cm during interglacials. The estimated alkenone-based SST reconstructions for MIS 12 and MIS 13 are plotted in Fig. 2b (red line). Moreover, the four climate cycles following MIS 12 (from 29–440 kyr) (Cortina et al., 2015) are also shown in Fig. 2b (orange line) (data available online: http://doi.pangaea.de/10.1594/PANGAEA.854682) in order to compare MIS 13 with other interglacials. Furthermore, data for the terrestrial derived bottom oxygenation index (898 samples) are also provided for the first time covering the last five climate cycles (23–528 kyr) (Fig. 2c).

3.1. Age model

From 19 to 157.10 mbsf, we used the age model published by Sierro et al. (2009). For the second interval (from 157.10 to 300.58 mbsf) we used the age model published by Frigola et al. (2012). In both cases the age model was mainly based on comparison of the *Globigerina bulloides* $\delta^{18}O$ record with the LR04 benthic stack (Lisiecki and Raymo, 2005) with the exception of the upper part where the isotope record was tuned to Greenland ice cores. Including all sources of error, the uncertainty in the LR04 age model has been estimated to be 4 kyr from 1000 kyr to present (Lisiecki and Raymo, 2005).

The calculated sedimentation rates resulted in an average sampling resolution of 1150 yr during interglacials and 160 yr during glacial stages. The base of PRGL1 was deduced to correspond to MIS 13 taking into consideration the sedimentary units identified and the extinction of the coccolithophore *Pseudoemiliania lacunosa* at about 275 m (Frigola et al., 2012).