Marine Micropaleontology 117 (2015) 13–24

Contents lists available at ScienceDirect

Marine Micropaleontology

journal homepage: www.elsevier.com/locate/marmicro

Research paper

High-frequency surface water changes in the Tagus prodelta off Lisbon, eastern North Atlantic, during the last two millennia

Helga B. Bartels-Jónsdóttir [a,b,*], Antje H.L. Voelker [a,c,1], Fatima G. Abrantes [a,c,1], Emilia Salgueiro [a,c,1], Teresa Rodrigues [a,c,1], Karen Luise Knudsen [b]

[a] Laboratório Nacional de Engenharia e Geologia, Unidade de Geologia Marinha (UGM-LNEG), 2720-143 Amadora, Portugal
[b] Department of Geoscience, Aarhus University, DK-8000 Aarhus C, Denmark
[c] CIMAR Associated Laboratory, Rua dos Bragas, 289, 4050-123 Porto, Portugal

ARTICLE INFO

Article history:
Received 21 May 2013
Received in revised form 25 February 2015
Accepted 6 March 2015
Available online 11 March 2015

Keywords:
Tagus prodelta
Palaeoceanography
Last two millennia
Planktonic foraminifera
Stable isotopes

ABSTRACT

A high-resolution sedimentary sequence recovered from the Tagus prodelta has been studied with the objective to reconstruct multi-decadal to centennial-scale climate variability on the western Iberian Margin and to discuss the observations in a wider oceanographic and climatic context. Between ca. 100 BC and AD 400 the foraminiferal fauna and high abundance of *Globorotalia inflata* indicate advection of subtropical waters via the Azores Current and the winter-time warm Portugal Coastal Current. Between ca. AD 400 and 1350, encompassing the Medieval Climate Anomaly (MCA), enhanced upwelling is indicated by the planktonic foraminiferal fauna, in particular by the high abundance of upwelling indicator species *Globigerina bulloides*. Relatively light $\delta^{18}O$ values and high sea surface temperature (SST) (reconstructed from foraminiferal assemblages) point to upwelling of subtropical Eastern North Atlantic Central Water. Between ca. AD 1350 and 1750, i.e. most of the Little Ice Age, relatively heavy $\delta^{18}O$ values and low reconstructed SST, as well as high abundances of *Neogloboquadrina incompta*, indicate the advection of cold subpolar waters to the area and a southward deflection of the subpolar front in the North Atlantic, as well as changes in the mode of the North Atlantic Oscillation. In addition, the assemblage composition together with the other proxy data reveals less upwelling and stronger river input than during the MCA. Stronger Azores Current influence on the Iberian Margin and strong anthropogenic effect on the climate after AD 1750 is indicated by the foraminiferal fauna. The foraminiferal assemblage shows a significant change in surface water conditions at ca. AD 1900, including enhanced river runoff, a rapid increase in temperature and increased influence of the Azores Current. The Tagus record displays a high degree of similarity to other North Atlantic records, indicating that the site is influenced by atmospheric–oceanic processes operating throughout the North Atlantic, as well as by local changes.

1. Introduction

During the late Holocene, cooler and warmer intervals of the climate system have been referred to as the Dark Ages (DA) and Little Ice Age (LIA) versus the Roman Period (RP) and Medieval Climate Anomaly (MCA), respectively (e.g., Lamb, 1969; Mayewski et al., 2004). However, none of these periods are characterized by sustained cooler or warmer atmospheric or marine conditions (e.g., Cronin et al., 2003). High-resolution climate archives demonstrate marked anomalies of centennial, multi-decadal and even decadal to annual. The well-known Great Salinity Anomaly (GSA) and sea surface temperature (SST) decrease in the 1960s and early 1970s (Dickson et al., 1988) are anomalies in the recent past. In the North Atlantic, oceanographic anomalies are related to increased advection of Arctic Ocean water into the area (Dickson et al., 1988; Belkin et al., 1998), and they have also been linked to changes in the North Atlantic Oscillation (NAO) (e.g., Myers et al., 1989; Miettinen et al., 2010).

At present, climate variability in the North Atlantic realm is dominated by the NAO, which is the sea surface pressure difference between Iceland (Stykkishólmur) and the Azores (Lisbon), particularly during the winter season (Hurrell, 1995), and which is known to oscillate on seasonal to decadal timescales (Hurrell et al., 2003). The NAO affects the moisture and heat transport across the ocean and thereby also the hydrological cycles on the surrounding continents, as well as the thermohaline circulation (THC) in the North Atlantic. The two major climatic stages within the last 2000 years, the MCA and the LIA, have been linked to changes in the THC of the North Atlantic (Bianchi and McCave, 1999). In addition, Trouet et al. (2009) found evidence for a persistent positive NAO during the MCA and indication of a clear shift to weaker NAO conditions (predominantly negative) at the transition

* Corresponding author at: Department of Geoscience, Aarhus University, DK-8000 Aarhus C, Denmark.
E-mail address: helgabara@mac.com (H.B. Bartels-Jónsdóttir).
[1] Now at Divisão de Geologia e Georecursos Marinhos, Instituo Português do Mar e da Atmosfera, Lisbon, Portugal.

http://dx.doi.org/10.1016/j.marmicro.2015.03.001
0377-8398/

to the LIA on the basis of a tree-ring-based drought reconstruction from Morocco and a speleothem-based precipitation proxy from Scotland.

The study area, the Tagus prodelta (Portugal), is near the southern realm used for the definition of the NAO index. The regional climate is mainly determined by the atmospheric NAO and the eastern North Atlantic surface water circulation, particularly the Portuguese–Canary Eastern Boundary Current. High depositional rates in the Tagus prodelta allow reconstructing high-resolution palaeoclimatic records, and recent studies of the palaeoceanography and climate in the Portugal region have importantly contributed to a better understanding of atmospheric and oceanic processes operating in Iberia and the North Atlantic (Abrantes et al., 2005; Bartels-Jónsdóttir et al., 2006; Eiríksson et al., 2006; Gil et al., 2006; Lebreiro et al., 2006; Abrantes et al., 2009; Alt-Epping et al., 2009; Bartels-Jónsdóttir et al., 2009; Rodrigues et al., 2009; Vis and Kasse, 2009; Vis et al., 2010). Proxy records and instrumental data, covering the last ca. 100 years, also support our understanding of climate shifts in the past and the forcing mechanisms behind them (Abrantes et al., 2009).

In this study, we present a more complete, higher-resolution record of sea surface proxies than previously published for the last 2000 years on the western Iberian Margin, to constrain our understanding of the natural variability of the climate prior to the industrialization and anthropogenic greenhouse gas emissions and add to the understanding of human impact versus natural variability.

We present a high-resolution planktonic foraminiferal record, supplemented by stable isotope measurements, which give evidence for surface oceanographic changes (sea surface temperature and productivity) through the last ca. 2100 years in the Tagus prodelta. A regional transfer function (Salgueiro et al., 2008) for planktonic foraminiferal data is used to define patterns in water masses and changes in the SST throughout the studied period.

We aim to reconstruct changes in the surface of the ocean, at least at centennial time-scale, and to try to distinguish natural climate variability from anthropogenic forcing. The Tagus prodelta record is discussed in a local, as well as a regional oceanographic and climatic context, including possible larger-scale teleconnections.

2. Oceanographic setting

The geographical location of Portugal at the eastern margin of the Atlantic Ocean largely determines the oceanography and the climate along its coast. Off the Iberian Margin, the Eastern Boundary Current system of the North Atlantic subtropical gyre (Fig. 1A) marks the northern limit of the Canary Current coastal upwelling system. From May to September, coastal upwelling occurs off Portugal in response to the trade winds, associated with the southward flowing cool offshore Portugal Current and the inshore Portugal Coastal Current (Fig. 1B) (Fiúza, 1983). During autumn and winter, the Portugal Coastal Current is replaced by the warm Iberian Poleward Current (Fig. 1B) (Peliz et al., 2005).

The seasonality of the current flow off Portugal is linked to the seasonal migration of the semi-permanent subtropical high-pressure system, the Azores High. The pressure difference between the centre of the Azores High and Portugal increases during summer, leading to stronger north-northwesterly winds that are favourable to upwelling, e.g. the generation of widespread upwelling filaments (e.g. Sousa and Bricaud, 1992). The study area, the Tagus prodelta, is influenced mainly by the Cape Roca upwelling filament (Fig. 1C; Fiúza, 1983; Abrantes and Moita, 1999). Maximum standing stock of planktonic foraminifera occurs during upwelling and can, thus, be a measure of biological productivity (Thunnell and Sautter, 1992; Abrantes et al., 2002).

The Eastern North Atlantic Central Water (ENACW) flows approximately 100 m below the ocean surface layer along the Portuguese margin, and the source of upwelling water along the coast is either subtropical or subpolar ENACW, depending on the wind strength (Fiúza, 1983; Arhan et al., 1994). In our study region, the waters are typically of subtropical origin.

During the winter season and during a negative NAO phase, increased precipitation occurs in Portugal, and the discharge from the river Tagus rises (Trigo et al., 2002; Abrantes et al., 2005, 2009; Bartels-Jónsdóttir et al., 2009). Besides these known NAO winter effects (Trigo et al., 2002), it has been shown that the NAO also influences the summer climate in this area (Folland et al., 2009), with increasing rainfall during positive state of the SNAO (Summer North Atlantic Oscillation).

3. Material and methods

This paper presents a composite sedimentary sequence from marine cores at 90 and 96 m water depth, consisting of piston core D13902 (38°33.24′N, 9°20.13′W), gravity core PO287-26-3G (38°33.49′N, 9°21.84′W) and box core PO287-26-1B (38°33.49′N, 9°21.84′W) from the southern part of the Tagus prodelta (Fig. 1C). Only the lower part of the piston core was analysed, as the upper part was disturbed during coring. Data from the intervals 18–150 cm in core PO287-26-3G (305.5 cm long) and 240–400 cm in core D13902 (600 cm) are combined with the entire box-core (33 cm) (Fig. 2). The splicing of the core sections is based on between-core comparison of data such as foraminifera, isotopes and $U^{k'}_{37}$-SST (cf. Bartels-Jónsdóttir et al., 2006), resulting in a complete sedimentary record. For comparison, stable isotope ($\delta^{18}O$ *Globigerina bulloides*) records from cores PO287-6 (41.4°′N, 8.9°′W, 80 m water depth; Abrantes et al., 2011) and GeoB 8903 (38°37.5′N, 9°30.5′W, 102 m water depth; Alt-Epping et al., 2009), as well as $U^{k'}_{37}$-SST data from core GeoB 8903 (cf. Abrantes et al., 2009) (Fig. 1B, C), are also presented.

3.1. Age model

Sediment ages for the sequence were derived from ^{210}Pb dating (PO287-26-1B) and 18 accelerator mass spectrometry (AMS) ^{14}C age determinations (Bartels-Jónsdóttir et al., 2006). The radiocarbon dates were reservoir corrected by 400 years (cf. Abrantes et al., 2005) and converted to calendar ages with the INTCAL09 data set (Reimer et al., 2009).

The age model corresponds to that described by Bartels-Jónsdóttir et al. (2006), except that ages have now been calibrated with INTCAL09 (Table 1). The age model is different from that presented by Abrantes et al. (2005), which includes the upper part of core D13902 with a tsunami deposit and a hiatus (see below). Data from that part of the record are not included here but replaced by a record from core PO287-26-3G (Fig. 2).

Climatic reconstructions in this seismic active area have to take into account potential interruptions or sediment disturbances caused by tsunamogenic deposits (cf. Abrantes et al., 2008). The sediment sequence presented here does not show signs of tsunami-related deposits, but it cannot be excluded that the sedimentation may have been interrupted by a hiatus. An interval, with potential sediment disturbances caused by tsunamogenic deposits, formed during the AD 1755 earthquake, is marked with a dashed line in Fig. 2 and with a grey bar in Figs. 3–7. In addition, the core site was affected by a layer at around 15 cm (uncorrected depth; 25 cm corrected for compaction effect that occurred during subsampling) in PO287-26-1B, marked by a ^{210}Pb minimum that is also attributed to a tsunami (cf. Abrantes et al., 2008, 2009). This disturbed layer is excluded in the climate records. The sedimentation rate in the studied record varies from 0.07 to 0.57 cm/year, with the highest values in the upper/younger section.

3.2. Foraminiferal assemblage

Samples were washed with distilled water through a 63 µm-mesh size sieve, dried and dry-sieved through 150 and 2000 µm-mesh sieves. The analyses of planktonic foraminifera were carried out on