Quaterly Science Reviews 129 (2015) 37–56

Contents lists available at ScienceDirect

Quaternary Science Reviews

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

Major storm periods and climate forcing in the Western Mediterranean during the Late Holocene

Jean-Philippe Degeai [a, *], Benoît Devillers [a], Laurent Dezileau [b], Hamza Oueslati [a], Guénaëlle Bony [a]

[a] CNRS UMR5140 ASM, Université Montpellier III, MCC, 34970 Lattes, France
[b] Université de Montpellier, Géosciences UMR5243, 34095 Montpellier, France

A R T I C L E   I N F O

Article history:
Received 5 June 2015
Received in revised form
4 September 2015
Accepted 1 October 2015
Available online xxx

Keywords:
Storminess activity
Lagoonal sequence
Climate forcing
Solar activity
Late Holocene
Western Mediterranean

A B S T R A C T

Big storm events represent a major risk for populations and infrastructures settled on coastal lowlands. In the Western Mediterranean, where human societies colonized and occupied the coastal areas since the Ancient times, the variability of storm activity for the past three millennia was investigated with a multi-proxy sedimentological and geochemical study from a lagoonal sequence. Mappings of the geochemistry and magnetic susceptibility of detrital sources in the watershed of the lagoon and from the coastal barriers were undertaken in order to track the terrestrial or coastal/marine origin of sediments deposited into the lagoon. The multi-proxy analysis shows that coarser material, low magnetic susceptibility, and high strontium content characterize the sedimentological signature of the paleostorm levels identified in the lagoonal sequence. A comparison with North Atlantic and Western Mediterranean paleoclimate proxies shows that the phases of high storm activity occurred during cold periods, suggesting a climatically-controlled mechanism for the occurrence of these storm periods. Besides, an in-phase storm activity pattern is found between the Western Mediterranean and Northern Europe. Spectral analyses performed on the Sr content revealed a new 270-year solar-driven pattern of storm cyclicity. For the last 3000 years, this 270-year cycle defines a succession of ten major storm periods (SP) with a mean duration of 96 ± 54 yr. Periods of higher storm activity are recorded from >680 to 560 cal yr BC (SP10, end of the Iron Age Cold Period), from 140 to 820 cal yr AD (SP7 to SP5) with a climax of storminess between 400 and 800 cal yr AD (Dark Ages Cold Period), and from 1230 to >1800 cal yr AD (SP3 to SP1, Little Ice Age). Periods of low storm activity occurred from 560 cal yr BC to 140 cal yr AD (SP9 and SP8, Roman Warm Period) and from 820 to 1230 cal yr AD (SP4, Medieval Warm Period).

1. Introduction

Cyclonic activity represents a major natural hazard to populations inhabiting coastal areas, and especially in highly populated regions, as demonstrated by the catastrophic super-typhoon Haiyan in Philippines (Lagmay et al., 2015). Such dramatic events highlight the debate on the possible influence of climate change and global warming on the increasing intensity and frequency of cyclones (Gaertner et al., 2009; Mann et al., 2009; Knutson et al., 2010; Mendelsohn et al., 2012; Nissen et al., 2014). Some regions in the world are particularly vulnerable to this cyclonic risk, like in the Gulf of Mexico or in Southeastern Asia with respectively hurricane and typhoon events. In the Mediterranean, where coastlines have generally been densely inhabited since the Ancient times, the most powerful cyclogenesis corresponds to explosive cyclones (Kouroutzoglou et al., 2014, 2015), tropical-like storms (Fita et al., 2007), or, more rarely, to hurricane-like events, the so-called medicanes (Emanuel, 2005; Flaounas et al., 2015). Numerical models used to predict the occurrence and recurrence of these storm episodes are based upon past records. Instrumental datasets on the last decades or historic documentations on the last centuries allow the study of the annual to multi-decadal storminess frequency (e.g. Bartholy et al., 2009), but to assess the centennial to millennial cycles, it is necessary to use information from sedimentary sequences which have recorded the paleostorm events. This field of research, the palaeotempestology, was successfully applied to evidence the millennial frequency of cyclones during the mid-to late-Holocene in the western North Atlantic (Donnelly and

* Corresponding author.
E-mail address: jean-philippe.degeai@cnrs.fr (J.-P. Degeai).

http://dx.doi.org/10.1016/j.quascirev.2015.10.009
0277-3791/

Woodruff, 2007), Northwest Florida (Liu and Fearn, 2000; Lane et al., 2011; Das et al., 2013), the Northeastern United States (Parris et al., 2010), the Central Pacific (Toomey et al., 2013), Southern Japan (Woodruff et al., 2009), Western Australia (Nott, 2011), Northeastern New Zealand (Page et al., 2010), Northern Europe (Sorrel et al., 2009, 2012), or the Northwestern Mediterranean (Dezileau et al., 2011; Sabatier et al., 2012).

The new storminess proxies established in these works were tentatively correlated with ice-rafted debris (IRD) indices and records of sea-surface temperature (SST) or solar irradiance in order to study the relationship with climate dynamics (Donnelly and Woodruff, 2007; Sabatier et al., 2012; Sorrel et al., 2012; Van Vliet-Lanoë et al., 2014). For example, in the Northwestern Mediterranean, the millennial cyclic evolution of the stormy episodes was tentatively proposed to be explained by the variability of the North Atlantic Oscillation (NAO) during Holocene Cold Events (HCE), although relationships and models are complex and still not totally satisfactory (Sabatier et al., 2012). Indeed, the periods of high storminess activity in the North Atlantic and western Europe during the last millennium have been reported either to positive or negative NAO phases (Trouet et al., 2012), while the NAO indices reconstructed for the last millennia show some discrepancies according to the paleoclimate proxies used in the reconstructions (Trouet et al., 2009; Olsen et al., 2012; Ortega et al., 2015). Besides, less information is available on the frequency of storm events on a shorter centennial timescale (Muscheler, 2012; Sorrel et al., 2012).

During a storm event, a sedimentary layer consisting of detrital material reworked from the coastal area or the inner shelf, the so-called tempestite, can be deposited in the terrestrial topographic depressions along the shoreline (Budillon et al., 2005; Sabatier et al., 2008; Horton et al., 2009; Hawkes and Horton, 2012). Consequently, the coastal lakes and wetlands such as lagoons or maritime marshes at the back of coastal barriers provide a relevant geomorphic setting to track the paleostorm activity (Sabatier et al., 2008, 2010a; Woodruff et al., 2009; Dezileau et al., 2011; Lane et al., 2011; Otvos, 2011). Different methods have been used to detect these tempestites in a sedimentary sequence: biological indicators such as foraminifera (Collins et al., 1999; Hippensteel and Martin, 1999; Hawkes and Horton, 2012; Pilarczyk et al., 2014), diatom (Parsons, 1998; Page et al., 2010), molluscs (Jelgersma et al., 1995; Sabatier et al., 2008, 2012), or pollen (Liu et al., 2008); sedimentological characteristics such as grain-size (Liu and Fearn, 2000; Sabatier et al., 2008, 2012; Horton et al., 2009; Parris et al., 2010; Dezileau et al., 2011; Toomey et al., 2013), mineralogy (Sabatier et al., 2010a, 2012), or microtextural features of quartz grains (Costa et al., 2012); and elemental or isotopic geochemistry (Lambert et al., 2008; Woodruff et al., 2009; Page et al., 2010; Sabatier et al., 2010a, 2012; Dezileau et al., 2011; Das et al., 2013).

This paper focuses on the study of paleostorms from high-resolution geochemical and sedimentogical analyses of a lagoonal sequence in the Northwestern Mediterranean. The main objectives are: (1) find a combination of proxies detecting the palaeostorm events in the sedimentary sequence; (2) analyse the time of recurrence of these events during the last millennia at different timescales (centennial to millennial); (3) compare our results with other regional and global climate proxies in order to understand the causes of the variability of storm periods.

2. Geological setting

The study area is located in the Languedoc region, along the continental shelf of the Gulf of Lions in the Northwestern Mediterranean (Fig. 1A). The many lagoons in this coastal plain give an excellent opportunity to find sedimentary sequences recording the palaeostorm events. The Languedoc plain is surrounded by the Mesozoic tabular karstic plateau of the Larzac to the northwest and the Hercynian crystalline to metamorphic basement of the Cevennes to the northeast (Fig. 1B). A phase of subsidence occurred in the Languedoc plain during the Oligo-Miocene period when the rifting that led to the opening and oceanization of the western Mediterranean affected the passive margin of the Gulf of Lions (Barruol and Granet, 2002; Dèzes et al., 2004; Bache et al., 2010).

During the Quaternary sea-level falls, valleys incised the inner continental shelf and the coastal lowlands (Tesson et al., 2005; Larue, 2008; Raynal et al., 2009; Labaune et al., 2010). The last post-glacial sea-level rise on the continental shelf began ca. 18 kyr ago (Lambeck and Bard, 2000; Rabineau et al., 2006). From the mid-Holocene, the decelerating eustatic sea-level rise along the shoreline of the Gulf of Lions induced the construction of sandy coastal barriers at the back of which formed lagoons (Barusseau et al., 1996; Certain et al., 2005; Tesson et al., 2005; Raynal et al., 2009; Court-Picon et al., 2010). Amongst these ones, the lagoon of the Bagnas is located in the southern termination of the Thau lagoon, between the cities of Agde and Marseillan (Fig. 1C). This is a 2 km-long on 1.5 km-width semi-elliptical brackish and shallow (less than 1 m-depth) body of water almost completely filled with sediments, transforming from a lagoon into a maritime marsh. The watershed basin (ca. 10 km^2) extends mainly to the northwest of the Bagnas pond and is drained by the 4-km long Bragues River flowing in a NNW-SSE direction. The maximal elevation on the watershed peaks at 114 m at the summit of the scoria cone of the Mont Saint-Loup in the southern corner of the catchment area. The elevation does not exceed 40 m in the most part of the watershed basin. This is covered essentially with Pleistocene alluvial terraces (Fig. 1D), which are composed of quartz and basalt gravels and pebbles mixed in a brownish to reddish silty clayey matrix. Volcanic terrains outcrop on the northern flank of the Mont Saint-Loup with a basaltic lavaflow fossilizing phreatomagmatic deposits superimposed by scoriaceous material.

The Bagnas pond is partly surrounded with marshy deposits progressively filling the basin. To the Southeast, beaches and dunes in the littoral zone form a sandy coastal barrier with a maximal width of 500 m (Fig. 1D). The geomorphic analysis of the subsurface coastal topography and field surveys reveal the presence of washover fans associated with storm events at the back of the littoral sandbar southeast to the Bagnas pond. All these coastal landforms belong to the Holocene highstand sea-level transgressive system tracts which started to extend in this area between 6500 and 4500 cal yr BP (Labaune et al., 2008).

3. Material and methods

3.1. Sampling

A 9 m long core (B1, Fig. 2) was taken on a levee in the Bagnas pond using a drilling machine equipped with a hydraulic piston and a 1 m-long cylindrical corer with a 80 mm-diameter cutting shoe. Supplementary cores were taken in the floodplain of the Hérault River with a percussion corer to document the sedimentological properties of the alluvial deposits from the Hérault River (Fig. 1C). Additionally, 62 samples of sediments were collected from the watershed of the Bagnas lagoon and from the coastal beach and dune barriers in order to study the composition of the detrital material transported then deposited in the Bagnas depression. This study is focused on sedimentological and geochemical analyses owing to the low abundance of micro-fauna in some parts of the B1 sequence, preventing to obtain consistent high-resolution continuous records on the whole sequence with micro-palaeontological proxies.