Estuarine, Coastal and Shelf Science 167 (2015) 300–312

Contents lists available at ScienceDirect

Estuarine, Coastal and Shelf Science

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

Multi-proxy evidence of rainfall variability recorded in subaqueous deltaic deposits off the Adra River, southeast Iberian Peninsula

I. Mendes [a,*], F.J. Lobo [b], L.M. Fernández-Salas [c], N. López-González [d], P. Bárcenas [e], J. Schönfeld [f], Ó. Ferreira [a]

[a] CIMA, Universidade do Algarve, Campus de Gambelas, 8005-139 Faro, Portugal
[b] Instituto Andaluz de Ciencias de la Tierra (CSIC-Universidad de Granada), 18100 Armilla, Granada, Spain
[c] Instituto Español de Oceanografía, Centro Oceanográfico de Cádiz, 11006 Cádiz, Spain
[d] Instituto Español de Oceanografía, Centro Oceanográfico de Málaga, 29640 Fuengirola, Spain
[e] Dpto. Análisis Matemático, Facultad de Ciencias, 29080 Málaga, Spain
[f] GEOMAR Helmholtz-Zentrum für Ozeanforschung Kiel, Germany

ARTICLE INFO

Article history:
Received 6 October 2014
Received in revised form
1 June 2015
Accepted 5 August 2015
Available online 8 August 2015

Keywords:
Climatic variability
Benthic foraminifera
Geochemistry
Deltaic environments
Human impact
Northern Alboran Sea

ABSTRACT

The Adra River deltaic system, southeast Iberian Peninsula, shows a steep topography and is subjected to strong climatic seasonality. This system has been affected by alternating wet and dry periods, and it has also undergone numerous anthropogenic activities such as deforestation, mining activities, river channel deviations and dam construction, particularly during the last two centuries. Two sediment cores were retrieved off the Adra River, from the western (MS_V9) and eastern (MS_V4) lobes of the subaqueous deltaic deposit. A multi-proxy study was carried out, including grain size, benthic foraminiferal assemblages, magnetic susceptibility and geochemical element analyses, in order to understand the sedimentary expression of recent climatic cycles and anthropogenic interventions in the river basin.

Periods of increased deposition of coarse-grained sediments, low absolute abundance of benthic foraminifera and high elemental ratios indicative of terrigenous contributions, were interpreted as periods of increased sediment supply to the shelf. Four flooding events were recorded in core MS_V9 and three events on core MS_V4, of which two were observed in both cores. They were related to periods with major floods that were documented on the southern Iberian Peninsula around 1770–1810 and 1860–1870 AD. On the other hand, sediment core intervals exhibiting increasing proportion of fine-grained sediments and higher abundances of foraminiferal species assigned as successful colonizers (*Textularia earlandi*) and opportunistic species that feed on bacteria or terrestrial organic matter (*Bolivina ordinaria*, *Bulimina elongata*, *Eggerelloides scaber* and *Ammonia beccarii* or *tepida*), indicate the establishment of new environments with new ecological constraints. They were related to significant decreases of terrigenous sediment input during low rainfall or dry periods. The increase of opportunistic species feeding on fresh phytodetritus (*Nonionella iridea*, *Nonionella stella*, *Nonionella* sp., *Brizalina dilatata*, *Epistominella vitrea* and *Bolivinellina pseudopuntata*), under more stable environmental conditions, also point to a stronger marine influence on the prodeltaic environments during these periods. The human interventions on the river basin after 1872 AD, with the deviation of the main river channel to the east, led to a drastic reduction of the sediment exported to the western delta lobe. This study showed that the sedimentation on the Adra subaqueous deltaic deposit was mainly controlled by rainfall variability from 1663 to 1872 AD, and afterwards by anthropogenic interventions.

1. Introduction

High-frequency paleoenvironmental changes may be recorded in subaqueous deltas during their different evolutionary phases, and therefore these systems can be used as very high-resolution environmental archives. These environmental changes are usually

* Corresponding author.
E-mail address: imendes@ualg.pt (I. Mendes).

http://dx.doi.org/10.1016/j.ecss.2015.08.005
0272-7714/

associated to extreme climatic events such as catastrophic floods interrupting periods of predominantly marine deposition due to low fluvial discharges (e.g. Carlin and Dellapenna, 2014). In the last centuries, the most significant event was the Little Ice Age (LIA) (e.g. Lebreiro et al., 2006; Andrews et al., 2009). Superimposed to climate changes, anthropogenic activities in the river basins (e.g. deforestation, forest firing and mining activities) may also lead to extensive erosion and export of large sediment volumes that tend to be accumulated in shallow-marine settings, obliterating the climatic signals to a large extent (Carrión et al., 2003; Jabaloy-Sánchez et al., 2010).

River channel deviations can also lead to significant modifications of deltaic sedimentary environments, as they are able to considerably alter the sediment supply reaching the coastal domain, promoting significant coastline changes and the modification of major depocentres (Mateo and Siringan, 2007; Jabaloy-Sánchez et al., 2014). These deviations can be caused either by autocyclical processes such as channel avulsion and subsequent delta-lobe switching, by tectonic processes or by anthropogenic interventions, generally aimed at regulating the coastal environment. As a consequence, the deltaic evolution may be defined by multiple stages driven by the above-defined channel shifts (Fanget et al., 2013). In the end, the accommodation of deltaic systems to natural or human-induced changes is mainly effected by changes in sediment supply that ultimately reach the coastal domain (e.g. Mateo and Siringan, 2007).

Benthic foraminifera, due to their wide distribution in all marine environments, and because of their rapid response to ecosystem changes (e.g. Murray, 2006), are the principal group of microfossils used to unravel depositional patterns and to assess paleoenvironmental changes in deltaic environments (e.g. Martins et al., 2006; Bartels-Jónsdóttir et al., 2009; Mendes et al., 2010, 2012b; Di Bella et al., 2014). Additionally, geochemical element ratios and changes in magnetic susceptibility obtained from sediment cores, are useful proxies that can provide meaningful information for paleoclimate studies (e.g. Rothwell and Rack, 2006).

Deltaic systems of the south-eastern Iberian Peninsula are excellent examples to record multiple climatic cycles during the recent past. In particular the Adra River catchment is characterized by a Mediterranean subdesertic climate with a pronounced seasonal variability, a low precipitation of less than 300 mm yr^{-1}, which mostly occur as torrential rains (Liquete et al., 2005). Rainfall fluctuations with alternance of wet and dry periods occurred during the last few centuries (Rodrigo et al., 2000). In addition, the sparsely vegetated areas with high erosion indexes, in combination with the occurrence of flash floods by torrential rains, may transport large amounts of sediments to the sea and trigger the formation of deltas (Liquete et al., 2005; Bárcenas et al., 2015). All these processes are promoted by the high altitudes reached by river catchments due to the proximity of the Betic Mountains, and by the different interventions made by humans, accentuated during the last centuries for economical purposes (e.g., agriculture, mining, flood mitigation, coastal management) (Carrión et al., 2003; Jabaloy-Sánchez et al., 2010). The present multi-proxy analysis of two sediment cores collected from the subaqueous deltaic deposit off the Adra River, northern Alboran Sea, unravelled the influence of climatic events involving rainfall variability and possible interferences of anthropic activities in the shallow-marine record during the past few centuries. Sedimentological and micropaleontological, i.e., benthic foraminiferal analyses provided essential paleoenvironmental information, radiocarbon dating helped to constrain the events in a temporal framework, and semi quantitative X-ray fluorescence (XRF) and magnetic susceptibility measurements were used to detect fluctuations of terrigenous supplies.

2. The study area: the Adra River deltaic system

2.1. River basin

The Adra River drainage basin drains the central sector of Sierra Nevada Mountains, and is laterally bounded by Sierras of Gádor to the east and Contraviesa to the west (Fig. 1a). The basin is located in the Internal Zone of the Betic Cordillera, with outcrops of Palaeozoic to Triassic metamorphic rocks. The northern upper part is covered by schists and quartzites of the Nevado-Filábrides Unit, whereas the lower part is covered by carbonates, schists, phyllites and quartzites of the Alpujárrides Unit. Both units are separated by the Alpujarras Corridor, an E–W depression filled by Neogene and Quaternary terrigenous sediments (Carvajal and Sanz de Galdeano, 2008) (Fig. 1a).

The Adra River basin is the fifth largest at the northern margin of the Alboran Sea, with 750.7 km^2 and a basin maximum elevation of 2682 m (Liquete et al., 2005). The river basin shows relatively high erosional indexes at a regional scale, as it is poorly protected by vegetation (Liquete et al., 2005). The Adra River shows the highest water discharges of the south-eastern Mediterranean coast of Iberia, with a mean value of 1 $m^3\ s^{-1}$. The average sediment load is estimated at 4.8 kg s^{-1}, and the mean sediment yield is exceptionally high, with more than 200 t $km^{-2}\ yr^{-1}$ (Liquete et al., 2005).

For the last five centuries, the rainfall variability revealed from historical precipitation records and instrumental data, showed that the climatic regime of the southern Iberian Peninsula was characterized by alternating dry and wet periods (Rodrigo et al., 1999, 2000). Several periods of exceptionally intense rainfall have been documented: (1) 1590–1650 AD during the main phase of the LIA; (2) a single peak around 1700 AD; (3) several wet years around 1800 AD; (4) a significant peak around 1860 AD; (5) several peaks between 1900 and 1950 AD; and (6) a peak around 1960 AD (Esteban-Parra et al., 1998; Rodrigo et al., 1999, 2000). Dry periods prevailed during the 1500–1590 AD and 1650–1750 AD intervals. Recent exceptionally dry years were recorded in 1825, 1875, 1920 and 1950 AD. A general decreasing trend in precipitation is recognised after 1960 AD (Rodrigo et al., 1999). Flooding frequency has been related to periods of increased rainfall (Brázdil et al., 1999).

Deforestation in the vicinity of the Adra River drainage basin was triggered by the outburst of several economic activities during the end of the 18th century and the first half of the 19th century, such as sugar factories, the onset of lead mining in 1822 AD and foundries (Cuéllar-Villar, 2006). Repeated flooding events increased in the basin from 1850 AD onwards, causing overflows, the infill of distributary channels, the formation of wetlands and, consequently, the development of infectious diseases (Cuéllar-Villar, 2006). In order to mitigate flooding effects, the main river channel was deviated to acquire a NW–SE trend, the works were executed between 1862 and 1872 AD (Cuéllar-Villar, 2006). During a major flood in 1910 AD, the new artificial diversion changed the main river channel to its present position (Fig. 1b).

2.2. The submarine environment

Wave conditions show two main approaching directions off the Adra River, westwards and east-northeastwards. Westward-directed waves are slightly more frequent, although east-northeastward-directed waves are more energetic (Jabaloy-Sánchez et al., 2010). Depth averaged current velocities above the Adra River subaqueous deposits change the direction according to wind dominance. Current velocities are higher than 0.1 m s^{-1}, reaching more than 0.2 m s^{-1} in shallow water, although currents are slightly more intense under easterlies dominance (Bárcenas et al., 2011).