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# Guadalfeo and Adra submarine deltas evolution in response to sediment supply variations

**I. Mendes (1), F.J. Lobo (2), Ó. Ferreira (1), N. López-González (3), P. Bárcenas (4), L.M. Fernández-Salas (5)**

(1) CIMA, Universidade do Algarve, Campus de Gambelas, 8000-139 Faro, Portugal (imendes@ualg.pt)
(2) Instituto Andaluz de Ciencias de la Tierra (CSIC-Universidad de Granada), 18100 Armilla, Granada, Spain
(3) Instituto Español de Oceanografía, Centro Oceanográfico de Málaga, 29640 Fuengirola, Spain
(4) Dpto. Análisis Matemático, Facultad de Ciencias, 29080 Málaga, Spain
(5) Instituto Español de Oceanografía, Centro Oceanográfico de Cádiz, 11006 Cádiz, Spain

**Abstract:** The Guadalfeo and the Adra submarine deltas off the northern coast of the Alboran Sea have been built up under the direct influence of short and mountainous rivers. The area is subjected to strong climatic seasonality, with sporadic winter torrential floods and high summer aridity. In addition numerous anthropogenic activities have affected these systems, mostly during the last two centuries. In order to decode the influence of climatic variability and anthropogenic impacts on sediment supplies during the recent past, five sediment cores were collected from the Guadalfeo and Adra submarine deltas. Benthic foraminiferal and sedimentological analyses, combined with radiocarbon dating, were performed.

The impact of torrential floods alternating with periods of low rainfall or dry periods were recorded in the Adra and Guadalfeo prodeltas. Periods with low abundance of benthic foraminifera and high amounts of coarse-grained sediments, were interpreted as the result of enhanced sediment supply to the shelf triggered by major flood events. On the other hand, periods with high amounts of fine-grained sediments and high abundances of colonizers and opportunistic foraminiferal species indicate the establishment of new environments with distinct ecological constraints. These environments were driven by lower sediment supplies during low rainfall or dry periods. The most recent sedimentation seems to reflect the human interventions in the rivers basins, such as deviation of the main river courses and dams construction, which reduced the sediment input and promoted the deposition of shallow-water submarine deltas.

***Key words:*** *benthic foraminifera, climatic variability, human impact, deltaic environments, Alboran Sea*

## 1. INTRODUCTION

Benthic foraminifera, due to their wide distribution in all marine environments, and because of their rapid response to ecosystem changes, are the principal group of microfossils used to reconstruct depositional patterns and to assess paleoenvironmental changes. High-frequency paleoenvironmental changes may be recorded in subaqueous deltas during their different evolutionary phases. These environmental changes are usually associated to extreme climatic events such as catastrophic floods and interrupted periods of low fluvial discharges (e.g. Carlin & Dellapenna, 2014). Additionally, 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 are accumulated in shallow-marine settings (e.g. Carrión *et al*., 2003). River channel deviations can also lead to significant modifications of deltaic sedimentary environments, as they are able to alter the sediment supply reaching the coastal domain. In the end, the sediment accommodation in the deltaic systems is mainly controlled by changes in sediment supply reaching the coastal domain.

In order to understand the influence of climatic variability and anthropogenic impacts on the supply changes to the Adra and Guadalfeo submarine deltas, shifts of most abundant benthic foraminiferal species and species richness combined with sedimentological analyses and radiocarbon dating were performed in sediment cores collected from both submarine deltas.

## 2. STUDY AREA

The Guadalfeo and the Adra submarine deltas are located on the northern Alboran Sea shelf, western Mediterranean Sea (Fig. 1). The area is under the influence of a Mediterranean climate with sporadic winter torrential flows and increased summer aridity, especially marked in the Adra River basin (Liquete *et al*., 2005). The genesis of these deltaic systems is associated with the discharges of the short and mountainous Guadalfeo and Adra rivers, which drain the near-coastal Sierra Nevada Mountains. Major anthropogenic activities in the river systems took place during the last ca. 200

years, including the deviation of the main river courses. In the Guadalfeo River system, the deviation of the main river channel (2.5 km the west) to its present position occurred during the 1930's (Fig. 1a). More recently, the construction of Béznar (1977-1985) and Rules (1993-2003) dams have also contributed to limit the amount of sediments exported to the submarine delta. In the Adra system, the deviation of the main fluvial course to the east occurred in 1872 AD. The channel was silted up in 1910 AD as a result of a flood event and relocated to the west, at its present position (Fig. 1b). These artificial changes are reflected in the submarine morpho-stratigraphy of the delta that exhibit two main depocentres (lobes) (Fig. 1b).

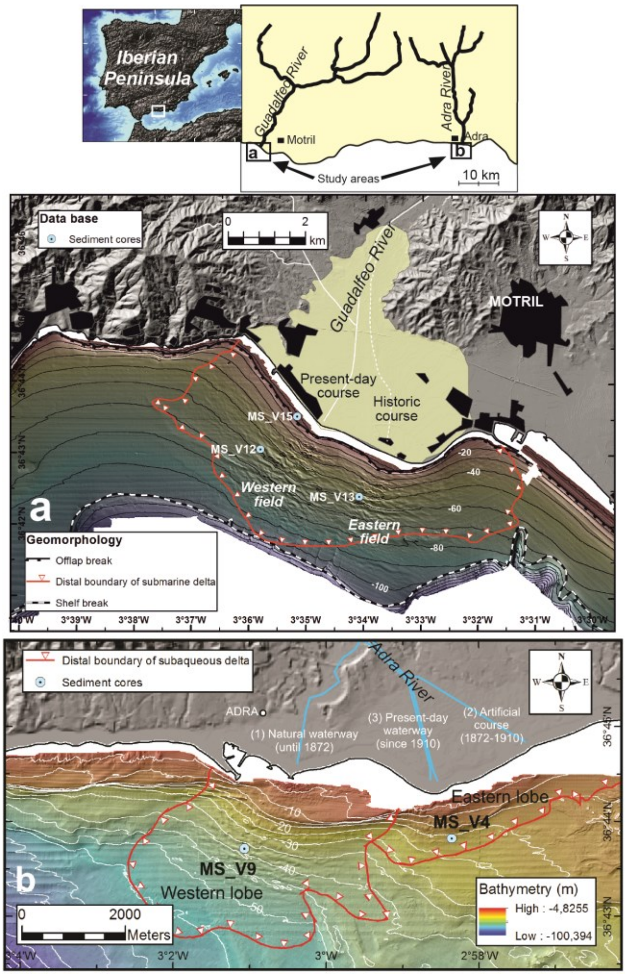

*Fig. 1. Location of the study areas in the southeast Iberian Peninsula, northern margin of the Alboran Sea, western Mediterranean Basin. (a) Submarine morphology off the Guadalfeo (a) and Adra (b) rivers, with indication of sediment cores location in both submarine deltas and the historic and present-day rivers courses.*

## 3. MATERIAL AND METHODS

Five sediment cores were collected from the Guadalfeo and Adra submarine deltas in November 2008, in the framework of the MOSAICO project. The cores were retrieved with a light-weighted vibrocorer. Off the Guadalfeo River, cores MS_V12 and MS_V15 were collected at 58.5 m and 11 m water depth, respectively, in front of the present-day river course. Core MS_V13 was collected at 57 m water depth, in front of the ancient river course (Fig. 1a). In the Adra prodelta core MS_V9 was collected in the western lobe, in front of the ancient river course, at 41.5 m water depth, and core MS_V4 was extracted from the eastern lobe, off the present river course, at 26.5 m water depth (Fig. 1b).

Five acceleration mass spectrometry (AMS) radiocarbon ($^{14}$C) dates were obtained (Table I). A mixture of plant debris was used. Grain size analyses were performed in 1-cm thick slices at 10 cm intervals or whenever macroscopic changes in the sediment facies were observed. Fine (silt and clay) and coarse (sand and gravel) fractions were wet separated using a 63 µm (4 phi) sieve. The grain size distribution of the fine fraction was analysed with the pipette method and the coarse fraction was subdivided by dry sieving using a sieve rack. Benthic foraminifera were analysed in 18 samples from core MS_V12, in 19 samples from core MS_V15 and in 13 samples from core MS_V13, from the Guadalfeo prodelta. In the Adra prodelta benthic foraminifera were analysed in 24 samples from core MS_V9 and in 17 samples from core MS_V4. The sand-sized fraction >63 µm was analysed under a binocular microscope. Whenever possible at least 300 well-preserved foraminiferal tests from each sample were attempted. The foraminiferal tests were sorted by species in Plummer cell slides, identified, and counted.

## 4. RESULTS

The results obtained for $^{14}$C dates in the five samples from de Guadalfeo and Adra prodeltas are showed in Table I.

Table I. AMS radiocarbon data obtained for the studied sediment cores.

| Core | Depth (cm) | Conventional radiocarbon age B.P. | Median probability Cal. Age A.D |
|---|---|---|---|
| MS_V12 | 142-143 | 190±30 | 1770 (180 Cal yr BP) |
| MS_V13 | 97-98 | 160±30 | 1774 (176 Cal yr BP) |
| MS_V9 | 50-51 | 210±30 | 1770 (180 Cal yr BP) |
| MS_V9 | 183-184 | 240±30 | 1663 (287 Cal yr BP) |
| MS_V4 | 152-153 | 170±30 | 1771 (179 Cal yr BP) |

Off the Guadalfeo River, grain size analyses showed higher percentages of the coarse fraction in core MS_V15 (14-98%) (Fig. 2a). In cores MS_V12 and MS_V13 the coarse fraction was composed primarily of sand (gravel <0.2%) and the fine fraction was silt dominated (clay <15%) (Fig. 2b, c). Generally, variations between coarse and fine fractions were observed throughout the cores, with the exception of the upper 60 cm of MS_V12 that showed relatively constant higher percentages of clayey silt. Both cores from the Adra prodelta are generally silt-dominated, with the exception of the last top 20-30 cm, which showed higher sand percentages (Fig. 2d, e).

The foraminiferal absolute abundances, expressed as total number of benthic foraminifera per gram, showed strong variations along the studied sediment cores. These values ranged from the total absence of benthic foraminifera at several core depths to maximum values of 889 specimens g$^{-1}$, recorded in the upper part of core

MS_V12 (Fig. 2b). The lowest values of abundance (0-7 specimens $g^{-1}$), were also recorded off present-day Guadalfeo river course, in core MS_V15 (Fig. 2a). Samples with less than 100 specimens identified were excluded from individual species distribution, such as several samples along the studied cores and the entire core MS_V15 (Fig. 2). Species richness also showed strong variations along the cores, with the exception of the upper 60 and 80 cm of cores MS_V12 and MS_V13, respectively, where relative constant values of species richness were observed. Regarding the strong variations, the higher value of species richness was observed in core MS_V4, with 73 species (Fig. 2e). Individual species distribution showed species with a relative abundance of >10% in at least one analyzed sample. Eleven species met this criterion and core MS_V9 showed the higher number of species (9). The relative abundance of individual species alternated between periods of complete absence to intervals of elevated abundance. For instance, *T. earlandi* reached the highest abundance (43%) near the base of core MS_V9 in the Adra prodelta (Fig. 2d) and showed abundances <10% in core MS_V12 off the Guadalfeo River. *Bolivina ordinaria* and *N. stella* were the only species that occurred in the four analyzed sediment cores, with abundances >10%. *Brizalina dilatata* only showed abundances >10% in cores from the Guadalfeo prodelta, while *R. arctica* and *E. scaber* were only observed with similar abundances in the Adra Prodelta (Fig. 2). On the other hand, *E. vitrea* and *S. loeblichi* were only recorded in core MS_V9, in the Adra prodelta (Fig. 1b).

## 4. DISCUSSION AND CONCLUSIONS

In the Guadalfeo prodelta, the datings obtained in the base of cores MS_V12 and MS_V13 indicate a similar age ca. 1770 AD, pointing for contemporaneous deposition in both depositional areas (Table I). However, higher sediment accumulation was observed in the western field, probably related with the river course deviation to its present position (Fig. 1a). In the Adra prodelta, core MS_V9 showed a more expanded sedimentary record that goes back in time to ca. 1663 AD. Core MS_V4 from the eastern lobe reaches back to ca. 1771 AD, a similar age than the obtained in core MS_V9 at 50 cm core depth (Table I). The lower sediment accumulation rate in the upper part of MS_V9 could be related with the first river channel deviation that occurred in 1872 AD (Cuéllar Villar, 2006) which led to a drastic reduction of the sedimentation in the western lobe.

In the Adra prodelta and the lower part of core MS_V12 in the Guadalfeo prodelta, intervals with low absolute abundances of benthic foraminifera and high amounts of coarse-grained sediments could be interpreted as periods of increased sediment supply to the shelf. These increases were promoted by torrential precipitation events that jointly with the steepness of the catchments favored the erosion of the catchment area. Indeed, torrential events, in this area, can produce even higher sediment discharges than the total amount for the rest of the year (Liquete *et al*., 2005). The low abundance or total absence of benthic foraminiferal assemblages is indicative of rapid deposition of a high quantity of sediment during short time spans, because the living faunas cannot catch up with the rapid burial, due to their reduced mobility (e.g. Hess *et al*., 2013). These torrential events could be related with periods of major floods that were documented on the southern Iberian Peninsula around 1770–1810 and 1860-1870 AD by Rodrigo *et al*. (2000). Additionally, the deforestation for the expansion of economic activities and mining exploration for lead (Cuéllar-Villar, 2006; Jabaloy-Sánchez *et al*., 2010) could also have contributed for the increased sediment supply to the shelf during these periods.

Sediment core intervals exhibiting increasing proportion of fine-grained sediments and higher abundances of foraminiferal species indicate the establishment of new environments with distinct ecological constraints. For instance, *T. earlandi* was described as an exceptionally robust species with an opportunistic life strategy, high resilience, and good survival potential under stress conditions (Alve and Goldstein, 2010). In the studied cores from the Adra prodelta, this species and *R. arctica* showed an abundance increase just after flood events of high sediment supply (Fig. 2, in dark blue). These relationships indicate that these species are good pioneer, able to rapidly colonize new habitats and dominate the new substrate as long as the competition is low. The competition seems to increase when species with an opportunistic behavior became more abundant. In particular, *B. ordinaria*, *B. elongata*, *E. scaber* and *A. beccarii/tepida* (Fig. 2, in orange) prosper in sediments rich in terrestrial organic matter, in areas influenced by river discharges, with fine sediments and more stable hydrodynamic conditions (e.g. Mendes *et al*., 2012). The abundance of these species that feed on bacteria or organic matter from terrestrial origin increased under more stable environmental conditions. This rise was promoted by a reduction of sediment input to the shelf under periods of low precipitation or dry climatic conditions. During the periods less influenced by river discharges, opportunistic species mostly feeding on fresh phytodetritus from spring bloom conditions also increased in abundance (Fig. 2, in light blue). These species are for example: *N. stella*, *B. dilatata*, *E. vitrea* (e.g. Mendes *et al*., 2012). The abundance increase of these opportunistic species during some periods indicates a stronger marine influence. The higher abundances of colonizer (*T. earlandi*) species associated with the increase of sand, in core MS_V13 from the Guadalfeo prodelta (Fig. 2c), also points to increased sediment supply to the shelf. This increase had, however, smaller impact than in the Adra prodelta, since benthic foraminiferal species despite buried can migrate to the sediment surface. In the upper part of core MS_V12 (Fig. 2b), the relative constant percentage of fine sediments, the highest values of absolute foraminiferal abundances and the high abundance of opportunistic species feeding on terrestrial organic matter and fresh phytodetritus, seems to indicate the stabilization of the sedimentation under the influence of the present-day river course, probably after dam construction. At core MS_V15, located at 11 m water depth, the absence of benthic faunas, the highest content of gravel in the lower part, the increased content of silt at two core depths and the high percentages of sand to the top, indicates a strong influence of coastal processes at shallow water and the impact river channel deviation and dams construction.

This study showed that the sedimentation on the Guadalfeo and Adra submarine deltas was mainly controlled by rainfall variability, coastal processes at shallow depths and anthropogenic interventions. At a regional scale, torrential events showed strong impact in the Adra submarine delta

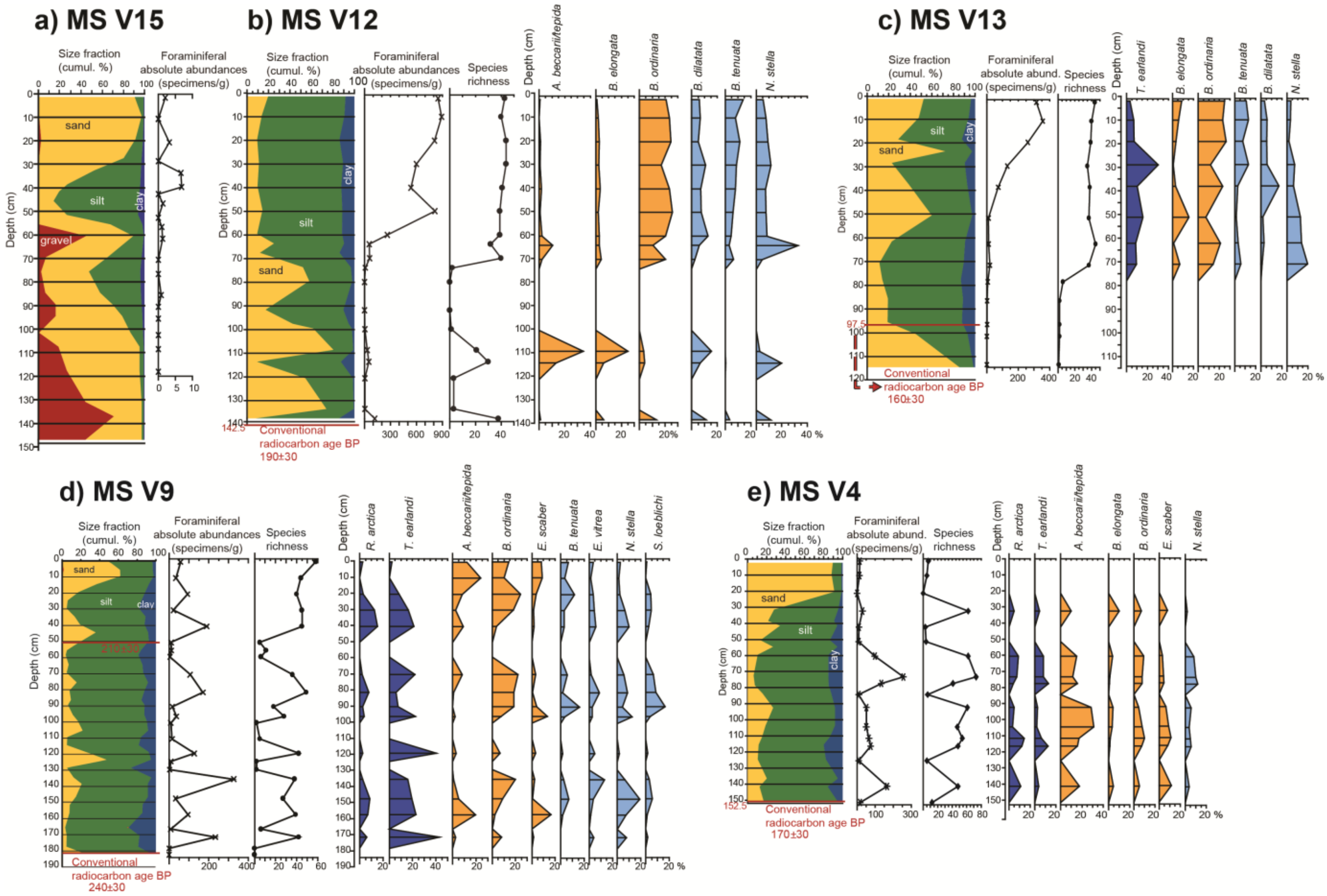

*Fig. 2. Variation with depth of grain size fractions, benthic foraminiferal absolute abundances, species richness and relative abundance of benthic foraminiferal species, with abundance >10%, for the analysed sediment cores MS V15, MS V12 and MS V13 in the Guadalfeo prodelta and cores MS V9 and MS V4 in the Adra prodelta. Radiocarbon dating obtained from plant debris indicated in red in the size fraction depth distribution.*

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