

The Holocene history of the Guadiana estuary as told by diatoms and chrysophyte cysts

La historia holocena de lo estuario del Guadiana contada por diatomeas y quistes de crisofíceas

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Abstract: In order to tell the history of the Guadiana Estuary since the Last Glacial Maximum, a core collected therein, and spanning more than 13200 cal. years B.P., was studied regarding its diatom and chrysophyte cyst fossil records. Additionally, a diatom-based transfer function was used to reconstruct paleo-salinity and paleo-duration of tidal inundation to better understand the estuary's evolution in relation to sea-level rise and climate changes. This study identifies some important climatic events, such as the Allerød climatic optimum, the Younger Dryas and three dry and cold events at 10600, 9100 and 7600 cal. years B.P., most of which were not identified by other proxies. Moreover, it also revealed that, prior to 13200 cal. years B.P., there was a mudflat environment in the place where the core was collected, consistent with an estuary slightly confined in the narrow valley under marine/tidal influence. Afterwards, this environment evolved into a salt marsh. The strongest marine influence was inferred to the period between 10000 and 7000 cal. years B.P., embracing a phase of rapid sea-level rise, non compensated by sedimentation, that favored the development of a mudflat. From this period onwards, diatom assemblages seem to indicate an evolution to a more enclosed environment, probably similar to the actual configuration of the area.

Keywords: diatoms, chrysophyte cysts, Guadiana, sea-level rise, climatic events

1. INTRODUCTION

Estuaries are land-ocean transition zones which exhibit strong physico-chemical and biological gradients. One of the groups of organisms adapted to the environmental variability of the estuaries is the ubiquitous diatoms, unicellular algae with siliceous frustules. For this reason, diatoms are a valuable tool for paleoenvironmental reconstructions. However, this proxy has been scarcely applied on the Iberian Peninsula. Freitas *et al.* (2002) is one of the examples of works where diatoms have been used as indicators to support paleoenvironmental reconstructions from littoral lagoons along the West Portuguese coast. In addition to diatoms, some authors (e.g. Reavie *et al.*, 2002) also studied chrysophyte cysts (cysts of flagellate algae, predominantly planktonic, present in many freshwater systems), which allowed them to perform more accurate, multiproxy paleoenvironmental reconstructions.

Thus, the aim of the present study is to complement the works of Boski *et al.* (2002, 2008), Fletcher *et al.* (2007) and Delgado *et al.* (2012) regarding the evolution of the Guadiana estuary since the Last Glacial Maximum, using both diatoms and chrysophyte cysts as paleoenvironmental proxies for the first time.

2. STUDY AREA

The Guadiana River is the fourth largest river of the Iberian Peninsula. It rises in Spain and flows 800 km downstream to Vila Real de Santo António (Portugal) and Ayamonte (Spain). In its last 200 km it forms a natural border between Portugal and Spain. The Guadiana estuary is located in the south of the Iberian Peninsula and extends 70 km inland. According to Boski *et al.* (2008), the terminal part of the estuary corresponds to a river valley that was inundated during the Holocene transgression and is cut into Carboniferous shales and graywackes, and Cretaceous and Jurassic limestone. The depth of the valley reaches

some 85 m below present-day sea level, resulting in a rather unique accumulation of Quaternary sediments in terms of thickness. The regional climate is of the Mediterranean type.

3. METHODS

For the purpose of this study, 27 samples were collected along a core (CM6), recovered from a 63 m deep borehole. The borehole was drilled from a salt-marsh area on the left margin of the Guadiana River (Fig. 1). Samples were collected from the central part of the core at 3 m intervals or less (when identifiable changes in the mass proprieties of the sediment occurred). The age model of the studied profile was based on 12 ¹⁴C dating, mostly of organic material, extracted from the sediment samples (Delgado *et al.*, 2012).

For both diatoms and chrysophyte cysts studies, ca. 1 g of sediment of each sample was cleaned of organic matter and carbonates with H₂O₂ and HCl, respectively. Afterwards, the clean material was used to prepare permanent slides using Naphrax resin. The slides were observed under a Zeiss Axioskop light microscope at 1000 x magnification. Diatom-identification was based on Krammer & Lange-Bertalot (1986, 1988, 1991a, 1991b) and Witkowski *et al.* (2000). At least 300 valves were counted per sample. However, due to a frequent scarcity of diatoms in some analyzed samples, 100 valves were considered to be an adequate number to make samples statistically valid (Fatela & Taborda, 2002). Chrysophyte cysts found during the diatom counts and identification were also counted.

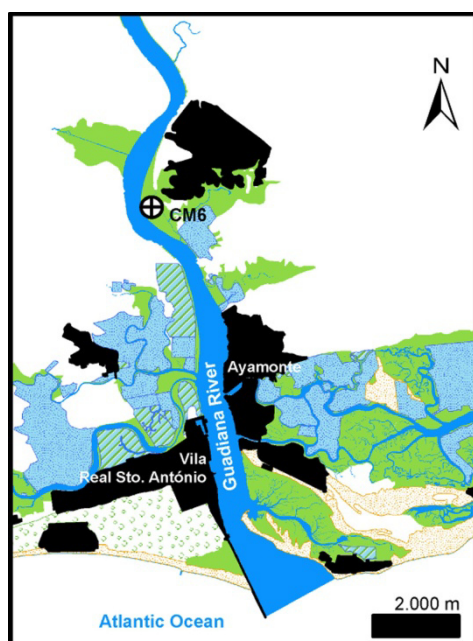


Fig. 1. Location of the CM6 borehole.

Paleoenvironmental interpretation was based on the diatom species (with relative abundances equal to or higher than 5 % in at least one sample) environmental preferences (salt, brackish or fresh water) and life-forms (benthic, micoplanktonic or planktonic). This information was obtained from Denys (1991/2) and Witkowski *et al.* (2000).

The number of diatom species (S), as well as the Shannon-Wiener (H') diversity index and the equitability (J'), were calculated, using the PRIMER program. Additionally, diatom valve and chrysophyte cyst concentrations were calculated, as well as the diatom valves dissolution index as defined by Ryves *et al.* (2001). This index varies between 0 (where all valves present dissolution signals or are broken) and 1 (all valves are pristine). Furthermore, based on the results obtained by Gomes *et al.* (2013), a diatom-based transfer function was developed to reconstruct paleosalinity and paleo-duration of tidal inundation, using the C2 program. A Q-mode cluster analysis was also performed using the CONISS method in the TILIA program. This analysis allowed samples to be grouped considering the similarities between their diatom association and thus creating zones along the core.

4. RESULTS AND DISCUSSION

Delgado *et al.* (2012) studied the CM6 core based on sedimentological, geochemical and paleontological (mainly foraminifera) data. A comparison of the results obtained by the above mentioned authors with the data presented in this study, point to a generally good agreement in what concerns the sequence of environmentally distinct zones. However, the five diatom horizons presented in Fig. 2, which are described below from the base to the top, revealed more details.

Horizon D-I (63.4-57.5 m depth; prior to 13200 cal. years B.P.) – Presents a high diatom diversity (S = 55 species and H' = 3.1) and the relative abundances of the species are well distributed between them (J' = 0.8). The dissolution index (0.4) shows that the species are moderately preserved in this zone. The diatom association that characterizes the zone is composed by the species *Cocconeis placentula*, *Epithemia adnata*, *Luticola mutica*, *Paralia sulcata*, *Opephora guenter-grassi*, *Pseudostaurosiraopsis geocollegarum*, *Tryblionella constricta* and *Delphineis surirella*, whose environmental preferences vary between salt, brackish and freshwater. Regarding their life-forms, they are mainly benthic diatoms. Moreover, the reconstructed salinity and duration of the tidal inundation are 33.2 ± 5.7 g/kg and 26.3 ± 14.9 %, respectively. This indicates that there was a mud-flat environment, compatible with a slightly confined estuary with a strong marine influence.

Horizon D-II (57.5-24.5 m depth; between 13200 and 8600 cal. years B.P.) – Compared to the previous zone, D-II presents higher concentrations of diatoms and chrysophyte cysts, lower H' and J' values, as well as a lower preservation of the diatom valves. The low values of J' are well expressed in the high abundances of *Tryblionella navicularis* (49 - 98%) throughout the zone. This species contributes to a clear brackish water signal and the dominance of benthic life-forms. The paleo-salinity and paleo-duration of the tidal inundation varied, respectively, between 36.2 ± 12.2 and 32.2 ± 6.8 g/kg and between -29.9 ± 27.1 and 17.5 ± 15.7 %. These data indicate that the environment evolved into a salt marsh. At 13000 cal. years B.P. it was possible to identify the Allerød climatic optimum by a decrease in chrysophyte cyst concentrations, as well as an increase in diatom concentrations and a decrease in *T. navicularis* abundance, which are all indicative of a more humid climate (implying higher fluvial discharges). This was also identified by Fletcher *et al.* (2007). At 12900, 10600 and 9100 cal. years B.P. there was an opposite signal, indicative of the Younger Dryas, and the cold/dry events 7 and 6 of Bond *et al.* (1997). Compared with the results of Delgado *et al.* (2012), it was possible to see that only the use of diatoms and chrysophyte cysts allowed the previous referred climatic events to be distinguished. Additionally, at 10000 cal. years B.P. there was an increase in the abundance of diatom species which prefer saltwater environments, indicating a higher marine influence due to rapid sea-level rise.

Horizon D-III (25.5-13.5 m depth; between 8600 and 6500 cal. years B.P.) – A higher marine influence, due to rapid sea-level rise, led to the development of a mudflat environment, which is indicated by an increase in diatom H' and J' (being similar to the values registered in the horizon I), diatom preservation, and by the dominance of diatom species such as *Cocconeis placentula*, *Epithemia adnata*, *Luticola mutica*, *Paralia sulcata*, *Opephora guenter-grassii*, *Pseudostaurosira geocollegarum*, *Tryblionella constricta* and *Delphineis surirella*. Additionally, the paleo-salinity and the paleo-duration of tidal inundation varied, respectively, between 24.6 ± 5 and 34.6 ± 5.8 g/kg and between 19.1 ± 15.3 and 44.2 ± 14.6 %. This interpretation is in agreement with Boski *et al.* (2002; 2008) and Delgado *et al.* (2012). The decrease in the concentration of chrysophyte cysts at 7600 cal. years B.P. is linked to Bond event 5. At 7000 cal. years B.P. the increase in chrysophyte cyst concentrations and fresh and brackish water diatoms (*L. mutica* and *P. geocollegarum*) points to a sea-level stabilization and to the development of a more restricted environment, in agreement with Delgado *et al.* (2012) and Boski *et al.* (2002).

Horizon D-IV (13.5-2.5 m depth; between 6500 and 800 cal. years B.P.) – At the base of the present zone, diatoms are scarce, which is compatible with the presence of a tidal channel (Delgado *et al.*, 2012). However, at the top the diatom H' is similar to that registered in horizon D-III. Additionally, there was a decrease in diatom and chrysophyte cyst concentrations also in relation to horizon D-III, which points to a higher marine influence. The presence of the species *Cymatosira belgica* and the values of the paleo-salinity (23.4 ± 5.5 to 24.6 ± 5.4 g/kg) and paleo-duration of tidal inundation (49.7 ± 14.5 a 52.5 ± 14.4 g/kg) point to a sandy flat environment, which developed as a result of the estuary's lateral progradation. This environmental evolution is also corroborated the foraminifera results in Delgado *et al.* (2012).

Horizon D-V (2.5-0 m depth; since 800 cal. years B.P. until present) – Diatom and chrysophyte cyst concentrations increase in relation to the previous horizon D-IV, but diatom H' decreases. Additionally the diatom preservation is weak, the most abundant species was *T. navicularis*. The paleo-salinity (32.9 ± 6.6 g/kg) and paleo-duration of the tidal inundation (7.3 ± 15.6 %) are responsible for a scenario similar to the one described for horizon D-II, suggesting the development of a salt marsh environment (similar to the actual configuration of the area), in agreement with Delgado *et al.* (2012). This evolution is a consequence of the development of a more restricted environment and resulted from the continued lateral progradation of the estuary, essentially under the action of local factors (Boski *et al.*, 2008).

5. CONCLUSIONS

The joint analysis of the diatoms and chrysophyte cysts allowed us to complement existing knowledge about the paleoenvironmental evolution of the Guadiana estuary. In the place where the CM6 borehole was drilled, prior to 13200 cal. years B.P. there was a mudflat environment. Afterwards the environment evolved into a salt marsh. At 13000 cal. years B.P. it was possible to pinpoint, for the first time in this record, the Allerød climatic optimum and distinguish it from the Younger Dryas (12900 cal. years B.P.). From 10000 to 7000 cal. years B.P., due to rapid sea-level rise, a mud flat developed in the study area. During this period it was also possible to identify cold/dry events at 10600, 9100 and 7600 cal. years B.P. From 7000 cal. BP onwards, diatom assemblages seem to indicate the evolution to a more restricted environment, probably similar to the current configuration of the area.

Furthermore, it was possible to demonstrate that diatoms and chrysophyte cysts are good environmental proxies, being more sensitive than foraminifera. For this reason they are valuable tools for paleoenvironmental reconstructions in estuarine zones, which

are influenced by both continental (e.g. precipitation) and marine variation (e.g. mean sea-level).

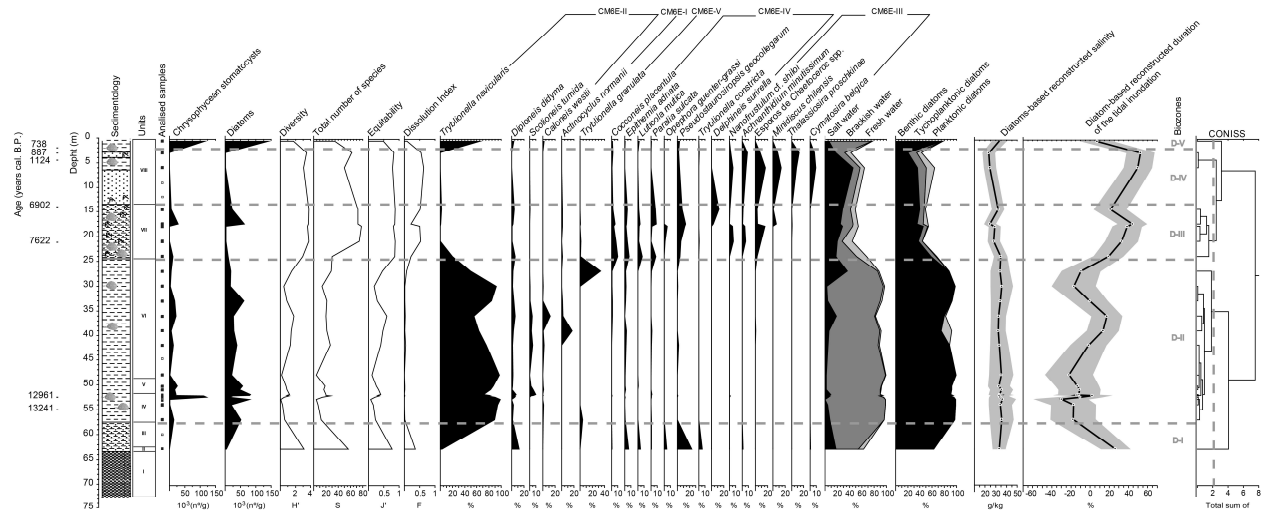


Fig. 2. Distribution of the diatom species with abundances equal or higher to 5 % along the CM6 core. From the left to the right: ages in cal. years B.P.; depth; sedimentology; units described by Delgado et al. (2012); analysed samples; chrysophyte cyst and diatom concentrations in the statistically valid samples; diversity, number of species; equitability; summary of the diatom environmental preferences and life-forms; paleosalinity and paleo-duration of the tidal inundation reconstructions; and diatom horizons defined on the basis of the cluster analysis.

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