GUADIANA RIVER ESTUARY

Investigating the past, present and future

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2. Guadiana estuary– present state, past evolution and prospects for the future

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2.1. The Guadiana watershed

The Guadiana catchment extends over an area of 66 889 km^2, between the catchments of the Tagus and Guadalquivir rivers, of which 11 525 km^2 are in Portugal. Its upper part in Spain corresponds to what is called the Western La Mancha province (Figure 2.1) (see Box 2.1).

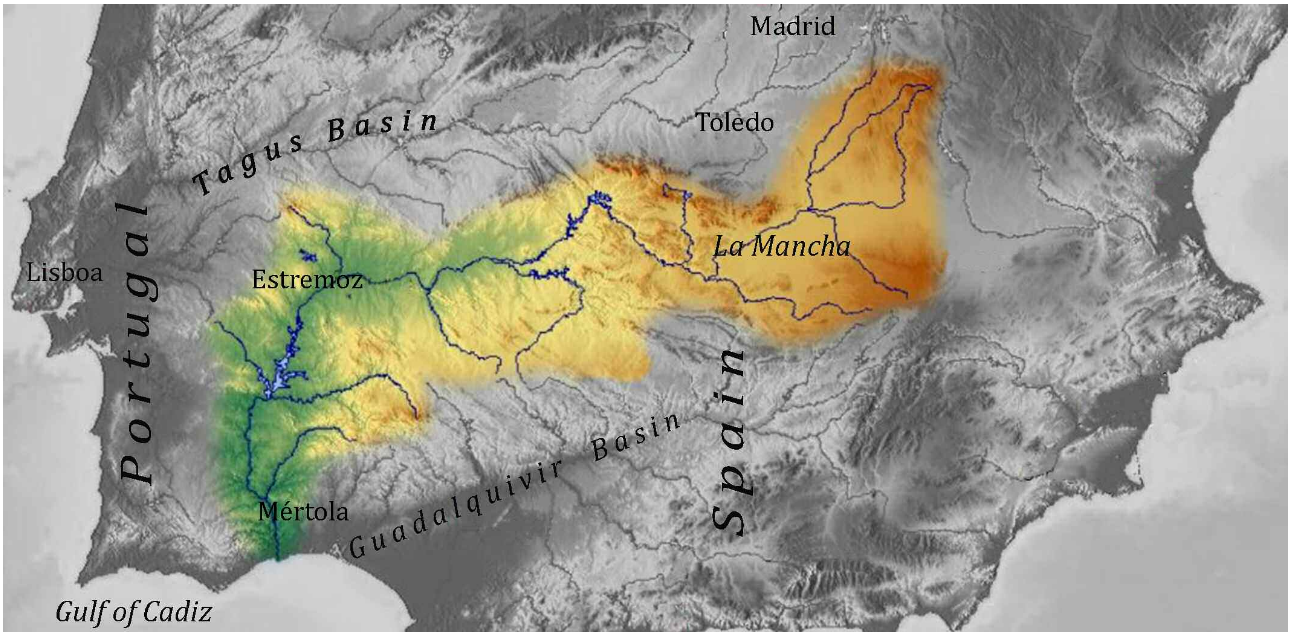

Figure 2.1.
The Drainage Basin of Guadiana River

Box 2.1 Do you know that

La Mancha province is an arid highland of Central Spain, south of Madrid, bordered on the North by Alcarria and to the South by the Sierra Morrena mountains. The lack of correspondence of the term La Mancha to any special signification in Spanish, besides "stain" or "spot", points the etymology to Moorish term al-mansha i.e. wild dry land. Indeed, the scarce precipitation and large thermal oscillations have always severely limited agriculture, which historically could not take the full advantage of predominantly very fertile soils. Due to intensive irrigation these limitations were overcome in the 20th century. Windmills have probably become the most identifiable symbol of the La Mancha region, after Miguel Cervantes immortalized the fight of Don Quixote against them.

To the North the watershed is limited by alignments, of the Sierra de Altomira (http://www.castillalamancha.es/sites/default/files/documentos/paginas/archivos/altomira_liczepa_fich.pdf) with heights between 700 and 1,000 meters and the Mancha de Toledo, with profusion of endorheic lagoons between 600 and 800 meters above sea level. The origin of the Guadiana was historically placed in the area of Campo de Montiel under the name Rio Pinilla. The drainage in this area is mostly underground through the dissolution voids within the karstified calcaraeous rock substratum (Figure 2.2 and annex V) and therefore has no permanent character. So, the actual river source is either placed in the Lagoons of Ruidera (natural park), fed by the waters from the springs that drain the aquifer of Campo de Montiel (http://cvc.cervantes.es/literatura/cervantistas/coloquios/cl_IX/cl_IX_19.pdf) or in the Wetlands of Daimiel (natural park), which are fed by the rivers Ciguela and Záncara.

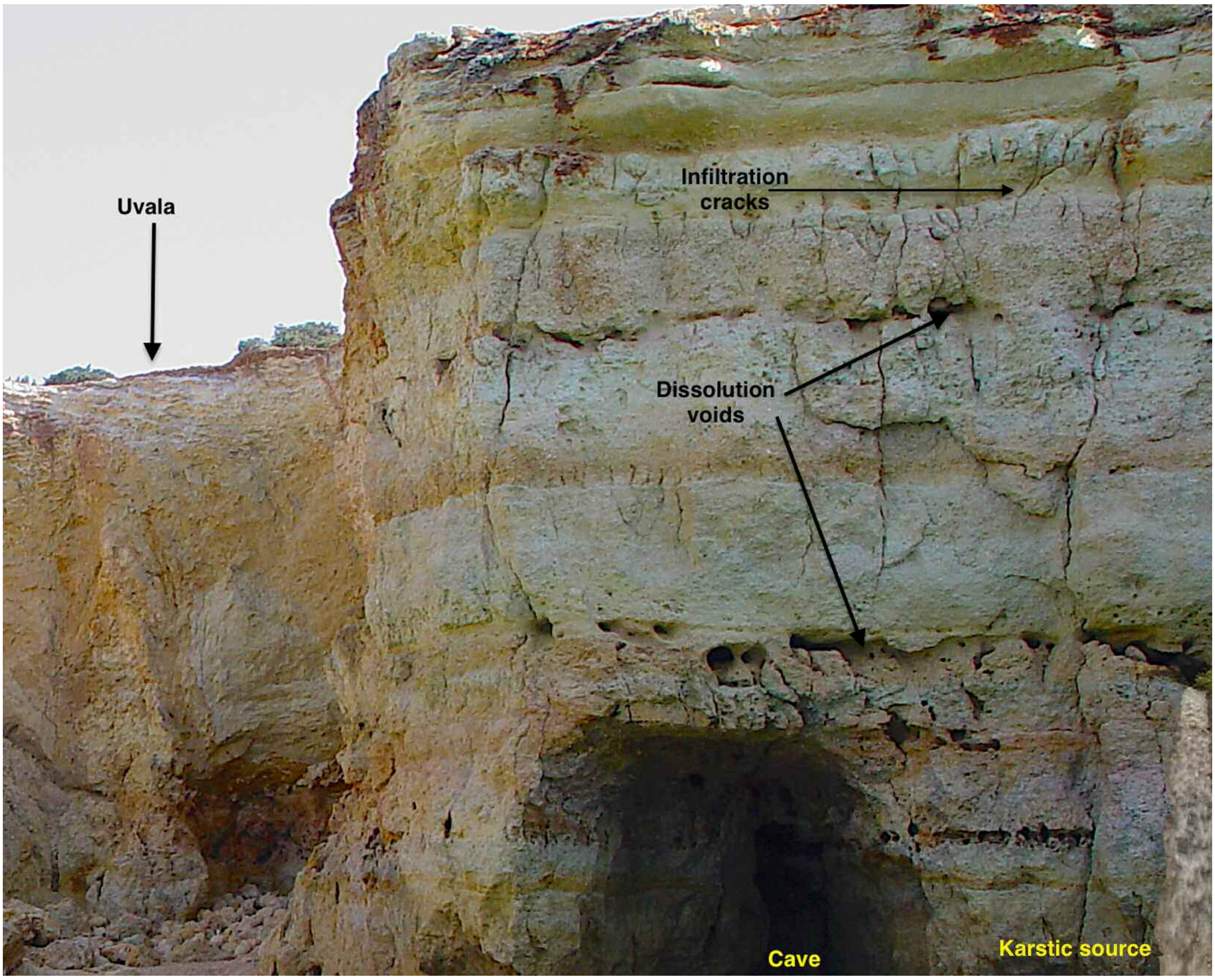

Figure 2.2.
An example of karstic dissolution features and underground drainage developed in calcareous rocks. On the left hand side the scarp cuts the collapsed cave termed uvala (photo by T. Boski, 2007).

Whatever its exact origins, the river runs through the southern Iberian plain in a direction east to west and after 578 km, it begins to turn to the south near the town of Badajoz, approaching the frontier with Portugal. From the mouth of the Caia River to the confluence with the Cuncos River, the Guadiana River marks 40 km of the international boundary between Portugal and Spain. It flows in Portuguese territory for 142 km and once more becomes the natural border for the last 60 km of its course between its confluence with the Chança River and the estuary mouth in the Gulf of Cadiz.

The climate of the Guadiana watershed is characterized by hot and dry summers and cold wet winters. The annual thermal oscillations between +50°C and -10°C in the inland part of the watershed create conditions for potential evaporation of 800 mm/yr – 1000 mm/yr, what is substantially higher than the precipitation, whose typical values vary between 450 mm/yr and 700 mm/yr. Consequently there is very strong demand for water in the whole basin, resulting in the construction of 62 permanently monitored dams (25 in Portugal and 37 in Spain) and countless other water retention structures across smaller tributaries (http://snirh.pt/index.php?idMain=1&idItem=1.3&sbaciaid=23). More than 75% of water demand is for irrigation. Damming of rivers in SW Iberian Peninsula was initiated probably by Romans for the purpose of rural and urban supply. It continued to support the rural economy for two millennia and in the 19th Century was applied for the purpose of mineral processing in the Iberian Pyrite Belt (see also Morais & Domingues, chapter 6 in this book).

Notwithstanding its importance for supporting the socioeconomic systems in Portugal and in Spain, artificial water retention by man did not substantially affect the flow of water and sediments to the ocean until the end of the 19th century. Over the 20th century water storage capacity in the drainage basin grew almost exponentially from nil to ca. 15000 hm^3 in 2002 when the Alqueva dam enclosed the largest artificial lake in Europe, with a total retention capacity of 4200 hm^3 (see also Morais & Domingues, chapter 6 in this book). The last figure is in fact very close to the annual discharge of the Guadiana measured at the hydrographic station at Pulo de Lobo.
(see Box 2.2).

From the above cited figures we may conclude that in the conditions of average discharge (4200 $hm^3/year^{-1}$) it will be necessary to wait more than 3 years in order to fill the river dams of the Guadiana that are operational at present. Despite the maintenance of so called "ecological discharge" assuring the delivery of 20 – 40 m^3/s^{-1} of water to the estuary, river dams have very drastically altered the transfer of water to the coastal ocean, and at the same time the transfer of sediments and nutrients essential to maintain the coastal zone of Gulf of Cadiz in equilibrium (see also Garel, chapter 1 in this book).

Box 2.2 Do you know that

Pulo do Lobo rapids and waterfall (Portuguese meaning wolf's leap) are situated in a narrow gorge of Guadiana, with a total height difference of 30 m, 17 km N from Mértola. The river gorge is a spectacular erosional feature cut into the folded and fractured Variscan schists and quartzites. This magnificent natural site is situated within the Lower Guadiana Natural Park (http://www.icnf.pt/portal/ap/r-nat/rnscmvrsa). The narrowness and the depth the river bed provide perfect conditions for the measurement of river discharge to which contributes 91% of the watershed. The highest discharge of ca. 8000 m3/sec was recorded in 1947, while the annual average is ca. 80 m^3/s^{-1}.

Figure Box 2.2.
O Pulo do Lobo.

2.2. The Guadiana estuary

In physical terms the Guadiana estuary extends from its mouth between the localities of Ayamonte and Vila Real de Santo António (Figure 2.3) and Mértola 60 km to the North where tidal changes in water level may still be observed. In chemical terms, i.e. of the chlorine ion limit 0.1‰ Cl^-, the estuary extends only 8 - 20 km inland or to the localities of Castro Marim and Alamo. Thus the chemical definition embraces either lower or both lower and middle estuary depending on very variable river discharge and mixing with marine water.

Figure 2.3.
Map showing some localities of the lower estuary. Source image: Google maps. This reproduction is according the the google terms and conditions (fair use).

2.2.1. Geology

At the Algarve-Andalusia regional scale the primary geological domains are:

a) The Variscan (Old) Massif rocks, represented by the Baixo Alentejo Flysch group and by the Southwest Domain;
b) The Meso-Cenozoic Algarve sedimentary belt;
c) The Guadalquivir river basin sediments;
d) Pleistocene and Holocene fluvial and estuarine deposits.

Usually, these four geological domains are separated according to their respective ages and lithologies. The first group (a) corresponds to Palaeozoic formations (see annex I: Geological Time Table), being composed mostly of schist and greywacke, although in the Southwest Domain there are also quartzite rocks. The Meso-Cenozoic belt (b) extends along the Algarve coast, presenting varied carbonated lithologies that range from dolomites to marls or even sandstone. In turn, the Guadalquivir river basin sediments (c) belong to the Cenozoic (see annex I: Geological Time Table) and are composed of sediments with variable grain sizes. The youngest, (d) Pleistocene and Holocene sediments (see annex I: Geological Time Table), mostly silts, sands and gravels were deposited during the last glacial cycle in the incised river palaeovalleys and along the littoral zone in general. Of special interest are the valley infills because they form the true geological archives of environmental changes, which occurred regionally and globally over the last fourteen millennia. The Guadiana sedimentary archive will be discussed in section 2.4 of this Chapter.

2.2.2. Geomorphology

Continental domain

In the Continental domain surrounding the Guadiana estuary it is possible to observe numerous geomorphological features, some identifiable on both margins but others on only one. Older rocks belonging to the Variscan Serra Algarvia are more representative on the Portuguese side. On the Spanish side, younger Mesozoic and Cenozoic sedimentary rocks are predominant; these are characterized by absence of large elevations, and gentle slopes without a strong incision of the drainage network. An intermediate unit called the Barrocal that only exists in the Portuguese territory separates the Variscan mountains from the littoral domain.

Littoral domain

In the Littoral domain contiguous to the Guadiana estuary, the relief morphology is more homogenous than in the continental domain, with flat areas as well as some small elevations. Sandy beaches are dominant, although dunes are also present. The inner part of the estuary, is formed by salt marshes and intertidal mud flats which are separated from the highly energetic land – ocean interface by elongated and continuous bodies of coastal sand like: particularly dune ridges, sand spits, barrier-islands, tidal deltas and terraces and also submerged deltas.

Salt-marshes and mud flats

The structure of salt marshes is characterized by the presence of creeks, pools and small embankments. The creeks are the principal routes by which the tidal waters enter and leave the marsh as the tide rises and falls. They are important for the different habitats that they create, and for the exchange of materials as well as organisms between the marsh and the rest of the estuary. Salt-marshes are areas sheltered from wave action and where water flows are moderated so that organic material, muds and other sediments can settle out. The sediments include tiny fragments of shells, sands (mostly derived from the sea) and finer silts and clays (creating muddy sediments, mostly derived from the rivers).

The presence of salt water is the main factor which distinguishes salt marshes from the other types of wetland that one finds in the more interior zones of an estuary and that are more influenced by fresh water. In reality there is not a clear delimitation between the two regimes, but rather a gradual transition. The ecological importance of salt marshes arises from the diversity of habitats that they support. Owing to the specific characteristics of salt marshes the diversity of plant species to be found is relatively low. This reflects the hostile conditions for plant life generally– few species and groups are adapted to live in these demanding environments. These plants show some similarity in their form, being generally small plants, fleshy and hairless, with small, glaucous leaves with shiny surfaces. The diversity of the plants increases as one goes up a salt marsh. In the upper marshes the specialists, which are called 'halophytes', become mixed with others, the non-halophytes, and a more varied topography generally creates a wider range of niches encouraging the co-existence of a greater diversity of plants. Salt marshes undergo continuous changes, with some areas undergoing growth, and others degradation and retreat even on an inter-annual scale.

Sand spits and littoral ridges

When the sediments carried by the Guadiana River reach the coastline, they are integrated into the littoral longshore and cross-shore transport due to the action of waves and tides, giving rise to large sandy coastal units, like sand spits and littoral ridges (see box 2.3). Littoral ridges are sand accumulations, developed along the coastline, that remain connected to land throughout their whole length. Sand spits are similar to littoral ridges, being also sand accumulations, but are not always connected to land. Sand spits are connected to land at one extremity and continue as a tongue of sand through the sea. In the Guadiana estuary, sand spits are only developed on the Spanish margin, and they partially block the mouth of the estuary (see Box 2.3.).

Dune ridges

Wind action over beach sand is responsible for sand being transported and then deposited where obstructed by the presence of objects. The resulting accumulations of sand can grow and give rise to sand dunes. These dunes continue to rise with the sand transported by wind and become stabilized by vegetation that helps dunes to be further developed. Whilst the dunes grow and become even more vegetated, new dunes arise at their front, creating a series of dune ridges oriented according to the primary wind direction. In the Guadiana estuary, dune ridges are particularly developed on the Portuguese margin. Monte Gordo pines has been planted on these dune ridges.

> **Box 2.3.**
>
> Since its construction in 1974, the groin of Vila Real de Santo António interrupted the longshore drift of sandy sediments. On one hand this intervention prevented the shoaling of navigation channel but the another drastically decreased the transfer of sand to the Spanish side of the estuary and provoked local beach erosion.

Barrier-islands

Sandy formations that are completely separated from land are designated as barrier-islands, because they form elongated sand bodies in front of the mainland and are separated from it by aquatic surfaces and intertidal zones. Nowadays, there are no barrier islands at the Portuguese margin, although it is very probable that, in the recent geological past they may have actually existed. In the Spanish margin it is still possible to identify barrier-islands, although they are already deeply altered by human action.

Tidal shoals and terraces

Close to the main river channel and to the inlets that separate barrier-islands, there are a series of sand accumulations termed flood and ebb tide deltas (see also Garel, chapter 1 in this book). Protected from intense wave action, flat and low lying plains composed of fine sediments, normally mud and clay, called tidal terraces have developed. There are two types of tidal terraces. The first type has very little or even no vegetation at all and is located in the lower areas. The second type develops in the higher lying terraces and presents a well-developed vegetation cover. This latter type makes the transition to the salt marsh areas, being sometimes designated as lower salt marsh.

2.3. Socio-economic characterization

During the last decades, the Guadiana River basin has undergone a significant demographic change due to rural depopulation and parallel (compensating) development of tourism activities in the coastal zone. The latter is most significantly seen in the summer with the arrival of countless numbers of tourists which leads to a considerable increase in the seasonal population of the estuary.

The resident population of the Guadiana estuary, especially in the cities of Vila Real de Santo António, Castro Marim, Ayamonte and Isla Cristina, has always been connected to the exploration of the land and the sea, but also taking advantage of the privileged location as a centre of commerce between the two nations.

Commerce

The navigability of the Guadiana River, together with its location on the border between Portugal and Spain, has driven the development of the Ayamonte and Vila Real de Santo António ports. These ports have then contributed to the development of commerce and the growth of the local economy.

Agriculture

A considerable part of the Guadiana estuary is used for agriculture, practised either on the dryer slopes or on the land reclaimed from the estuary. Irrigated agriculture has been developed in the lower and marshy areas, while on the dryer soils and on the slopes there are traditional dry land tree crops such as carobs, olive trees and almond trees, or even cereals such as wheat, barley or oats.

Salt production

Salt production, described in Chapter 5, is one of the oldest activities in the Guadiana estuary area, being an a fast growing component of the local economy. There are both traditional and industrial, or semi-industrial, salt explorations in the Guadiana estuary.

Aquaculture

The development of fish farms in the Guadiana estuary has been undertaken mostly by conversion of older salt pans into fish tanks. There are fish farms on both margins of the estuary, where fish species are produced either in an intensive or semi-intensive regime. Although they create richness and employment for the estuarine populations, these farms have a strong impact on the environmental quality of the estuarine waters.

Cattle rearing

Cattle rearing is an economic activity currently in decline in the Guadiana estuary region. However, it is still possible to find bovine or caprine cattle grazing on the degraded salt marshes or the slopes where extensive agriculture is practiced. This activity often complements the primary farming system based on crop cultivation.

Tourism

Nowadays, economic activities related to tourism, recreation and leisure are the most important in terms of revenue for the Guadiana estuary. Besides sun and sea tourism, clearly dominant in Isla Canela, Isla Cristina, Vila Real de Santo António and Monte Gordo, there are new developments more related to cultural tourist activities, mainly in Ayamonte and Castro Marim, but also nature-based tourism in the areas with high natural heritage value on both sides of the estuary. That kind of activities, based on unspoiled natural values of waters and of the estuarine and river valley margins should be developed and promoted

Hunting

Hunting is practised only in restricted areas around the estuary, as in the protected areas it is forbidden. Hunters seek mostly hares, rabbits, partridges and turtle-doves. As the estuarine area has important communities of aquatic birds, hunting around such areas creates a considerable impact for the estuarine avifauna.

Fishing

Fishing is legal in the main river channel only if practiced with lines and fish-hooks. It is forbidden in the salt marshes and tidal creeks. Nevertheless, illegal shrimp and bivalve fishing occurs in almost the whole estuary. This illegal fishing is an important source of revenue for fishermen that live in the Guadiana estuary region.

Open sea fishing is done by many fishermen, mostly from Isla Cristina and in lower numbers by fishermen from Ayamonte and Vila Real de Santo António. Although these fishermen do not fish in the estuary, they land their catches here and as a result there is an important local industry of fish processing and marketing.

Nature Conservation

The high natural heritage value of the Guadiana estuary is clearly demonstrated by the extensive salt-marsh areas, salt steppes, salt pans (both traditional and industrial), lagoons, tidal creeks, barrier island, and many other locations and habitats of great ecological value (http://www.cima.ualg.pt/MEGASIG/). All these habitats support plant and animal communities that not only increase the estuary's natural value, but also make it unique and irreplaceable. Because of such variety and richness, it was soon realized that it would be necessary to safeguard some areas from urban sprawl and industrial growth. The Sapal de Castro Marim and Vila Real de Santo António Nature Reserve was thus created in 1975 (http://www.icnf.pt/portal/ap/r-nat/rnscmvrsa). This was the first nature reserve to be created in Portugal. Some years later, in 1989, the Marismas de Isla Cristina Natural Landscape was created on the Spanish side of the estuary. These two protected areas have been key for maintaining the ecological diversity of the Guadiana estuary. Today, with the ongoing development of tourist facilities and consequent urban growth, the importance of these protected areas has become even greater.

Recently, the creation of the European network of areas with high nature conservation value, the NATURA 2000 network (http://ec.europa.eu/environment/nature/natura2000/index_en.htm), has reinforced and increased the areas dedicated to nature conservation in the estuary. Due to the important bird communities that use the estuary, two Special Protection Areas (SPA) have been created, one on each margin of the estuary (Castro Marim Saltmarshes SPA and Isla Cristina SPA). Besides these areas dedicated to birds, three Special Areas of Conservation (SAC) were created to protect specific habitats (Lower Guadiana SAC, Isla Cristina Saltmarshes SAC and Isla de S. Bruno SAC).

Pollution

The Guadiana estuary still shows a high environmental quality, without persistent pollution problems (see also Bebianno et al., chapter 7 in this book). During the MEGASIG Project, the organic fraction of sediments collected along the tidal creeks and estuarine channels was analysed in order to detect possible pollution sources. The lipid fraction of the organic matter was subjected to specific studies and the analyses done led to the identification of some types of molecules that indicate the presence of industrial plastic. Nevertheless, generally speaking, no concentrations or evidences typical of persistent pollution resulting from human activities were found.

2.4. Past and future environmental changes in the Guadiana estuary

2.4.1 Reconstruction of the last 14 thousand years in the Guadiana estuary

Due to the tectonic fracturing and impervious character of rocks, the Guadiana valley was deeply incised into the shale and greywacke substratum of the Old Massif. Over the Quaternary period (the last 2.4 million years- see annex I- Geological Time Table) and in particular during the last 700 thousand years when the Northern Hemisphere experienced glacial periods, the mean sea level lowered to 120 – 140 meters below that presently observed. These periods, termed marine lowstands corresponded to the expansion of North American and Scandinavian ice caps locking thousands of cubic kilometres of water. They were witnessed all over the world, a strong incision of the river beds and export of the sediment to the sea, whose limits here were some 30 kms to the south of the present coastline. In the following period of climate warming, the retreat of melting ice caps occurred and the ensuing sea level rise led to a progressive inundation of the continental shelf. Marine waters have penetrated deeply into the valley of Guadiana creating a new space that accommodated new sediments, which contain the record of accompanying environmental changes. Assembling of geophysical, geotechnical and geological data enabled to create the digital reconstruction of terminal tract of deeply incised Guadiana paleovalley, which corresponds to the present estuary. The 3D diagram based on tens of thousands interpolated depth points is depicted in Figure 2. 4

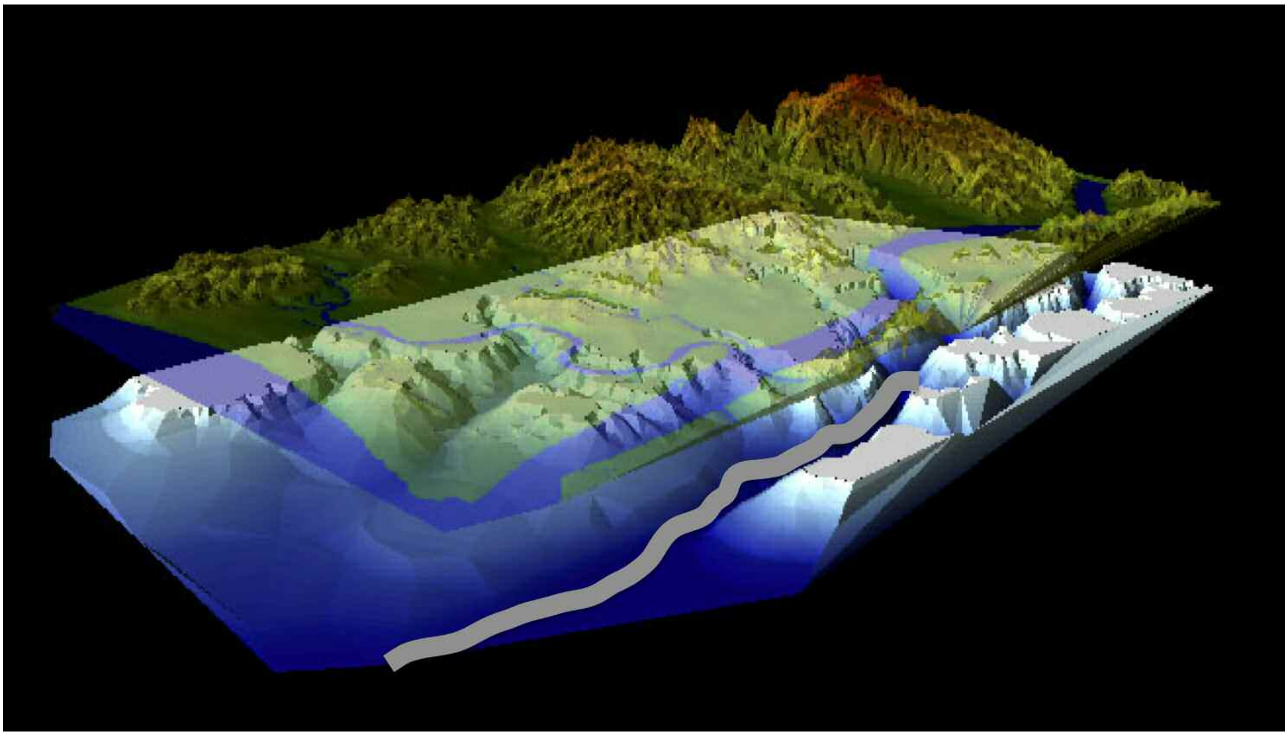

Figure 2.4.

Digitally reconstructed land surface of Guadiana palaeovalley some 18 000 years ago. The upper image layer shows present topography and the river course. The projection is vertically exaggerated 50 times.

To study the complex history of sedimentation and obtain the information on the past environmental conditions, the CIMA team carried out several mechanical drilling campaigns, which produced six continuously cored boreholes (Fig. 2.5). The mechanic drillings were further complemented by tens of shallower hand drilled boreholes. The deepest of the boreholes (CM6 in Figure 2.5), drilled on the Spanish side of the river, ca. 2 kms north from the International bridge reached a depth of 62.5 m and is the longest sediment profile of that type in Europe.

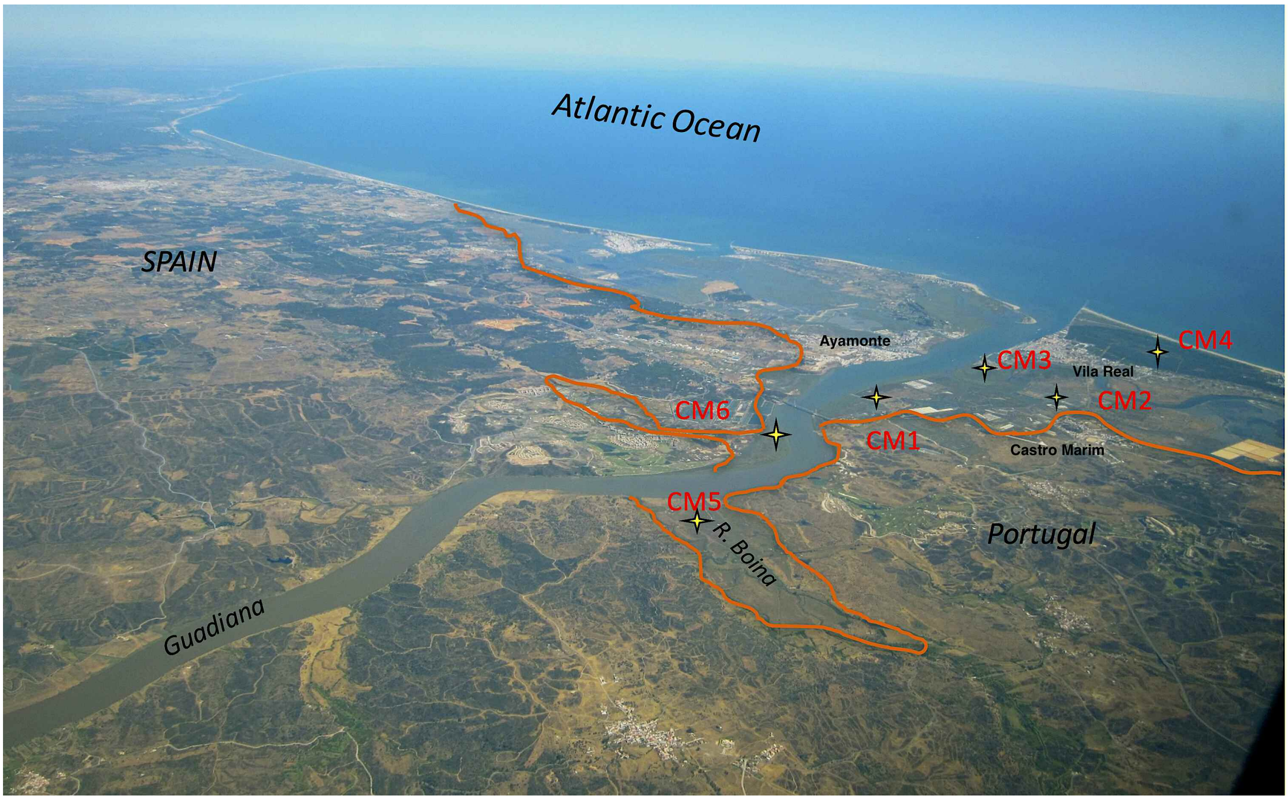

Figure 2.5.
Oblique view of Guadiana River estuary showing the localization of boreholes which permitted the reconstruction of regional sea level changes during the past thirteen millennia. Orange line indicate the limits of maximum sea transgression ca. 7500 yrs before the present (photo by T.Boski, 2013).

The initially observed fast (8 – 10 mm/yr) sea level rise (see the first segment of the curve in Fig. 2.6) laid sediments whose pollen inventory indicated the predominant forest flora of pines and oaks. Marine waters stopped rising ca. 12.5 thousand years ago during the cold period of Younger Dryas when the flora became more shrubby, including junipers, artemisia and ephedra. This colder and dryer climatic period terminated some thousand years afterwards, at the beginning of Holocene period (see annex I- Geological Time Table), with the sea level resuming its rise at a rate of 7-8 mm/year. That accelerated marine transgression culminated (see Figure 2.6) with a major jump of 4-5 meters during just two – three centuries. It transformed the whole estuarine area, some 7.5 thousand years ago, into a vast embayment completely open to the Atlantic Ocean.

The climate was mild at that time and the regional landscape was covered by oaks, olive and pine trees in decreasing order of abundance, as dominant arboreal species. Since then, the marine advance progressed at 1.2 mm/rate until the 20th century. The first signals of human presence in the SW Iberian Peninsula were detected indirectly through pollen analysis around 5 millennia ago, when a conspicuous deforestation is detected in parallel to the expansion of shrubs. The anthropic activities were also detected since 4500 years ago (beginning of the Copper Age), by a higher content of chemical elements like Pb, Co, Ni, and Mn, and to a lesser extent to Zn, Cu, and Ni, which were introduced by early mining activities at the beginning of the Copper Age. Mining activities became particularly intensive between

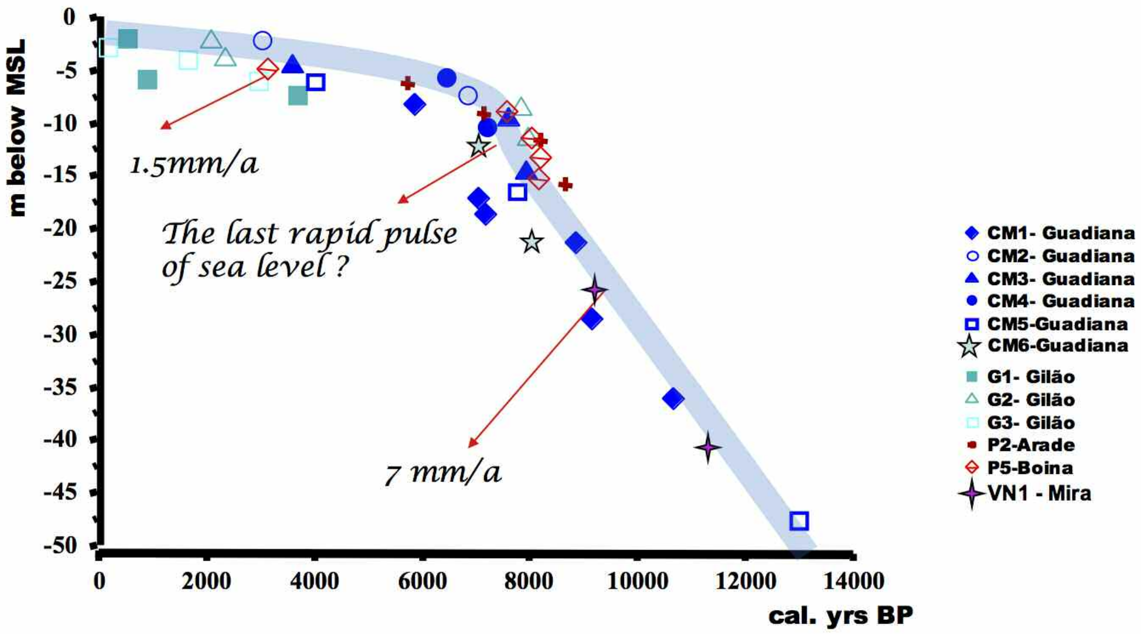

Figure 2.6.
Sea level curve of Southern Portugal based on borehole data mostly from Guadiana estuary and complemented by information from Gilão, Arade, Boina and Mira Estuaries. The time scale is expressed in calibrated years before present.

the late Bronze Age and the Roman period (3000-1500 yrs before present), when higher than previous levels of metal pollution were detected. Roman times saw the Lower Guadiana estuary as a vast swampy salt marsh area, drained by several channels used for navigation. In general, the intensification of human occupation during Moorish domination and medieval epochs led to the higher sediment input from land where wood cutting and agricultural practices lead to an increased soil erosion. During Roman times, Castro Marim was an important commercial harbor and maintained this function until 1774. The progressive shoaling of the channels aggravated by the impact of 1755 Lisbon tsunami imposed the necessity to move the port closer to the main inlet. The new facility became a part of the infrastructure of Vila Real de Santo António, an example of modern urban planning ordered by Marques de Pombal. It provided shelter to the fishing fleet exploring the fertile waters of Guadiana shelf and in the second half of 19th century to the transport of minerals mined in the Iberian Pyrite Belt (San Domingos Mine being the most prominent) and exported to the United Kingdom. Shoaling by continuous deposition of sands, transported by the western coastal drift current and pushed into the estuary by tides, continued to be a severe problem for navigation in 20th century. It led to the construction of a jetty by Portuguese authorities in 1974, which contributed to the accretion of more than 200 hectares of the new land on the Western side, during the next 10 years.

2.5. The future evolution of the Guadiana estuary

Two main factors that define the morphology of an estuary or delta are changes of the sea level and changes in supply of sediments. Assuming that the present rate of sea-level rise estimated at 3 mm/yr will continue or more probably will accelerate during the 21st Century and beyond, the reduction of fluvial sediment supply due to the regulation of river discharge represents a major challenge for the management of estuarine ecosystems. In contrast to the Holocene period of sediment input accommodated into the new unrestricted space created by sea level rise, coastal systems including saltmarshes will retreat because reduced river flow and reduced terrestrial sediment input. Both phenomena are caused by river damming, which is particularly intensive in the Guadiana watershed. Saltmarshes thriving on both sides of the main estuarine channel under the Nature Reserve protection, rely on a continuous fine grain sediment delivery from fluvial sources, and it is exactly for that reason that river discharge is critical for sustaining the saltmarsh ecosystems. The present estimations of minimum environmental flow do not take into consideration the fluvial discharge required to maintain saltmarshes under the pressure of the rising ocean waters. The CIMA team accepted the challenge of filling this gap in knowledge and carried out decadal time scale modelling of estuarine response to the sea level rise foreseen in the IPCC (http://www.ipcc.ch) scenarios for the end of 21st century. From this exercise, it appears that for the upper limit scenarios (probably the most realistic), the expansion of intertidal zone limits at the Spanish and Portuguese margins is visible on the banks of most of secondary tidal channels. Under the worst sea level rise scenario, the low and mid marsh will be forced to migrate into a new higher setting. However its establishment will be successful if the biogeochemical conditions for halophytic plant development are appropriate and there is no man made spatial constraints like roads, building or any hard artificial land cover. Submerging of saltmarshes due to sea level rise and sediment starvation may be avoided by implementing a multi-dimensional and integrated approach that consists of: (1) Determination of minimum ecological flow based on a full spectrum of natural flows, in terms of temporal and spatial variability; (2) possible removal of the unnecessary coastal structures to allow the natural sedimentation process to take place within the system; (3) bypassing the dams to enhance the fine fluvial sediment needed to sustain the marshes to be delivered to the estuarine system; and (4) a possible transplanting of the dominant marsh species or development of a back-barrier perimarine wetland.

Acknowledgements

The research presented in this paper has been supported by the project
EVEDUS funded by the Portuguese Science and Technology Foundation, MEGASIG and SPICOSA projects funded by the European Union under Interreg IIB and 6 Framework Programs. Carlos Loureiro, D. Ruwan Sampath and Carlos Sousa provided invaluable help in creating the digital terrain models.

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