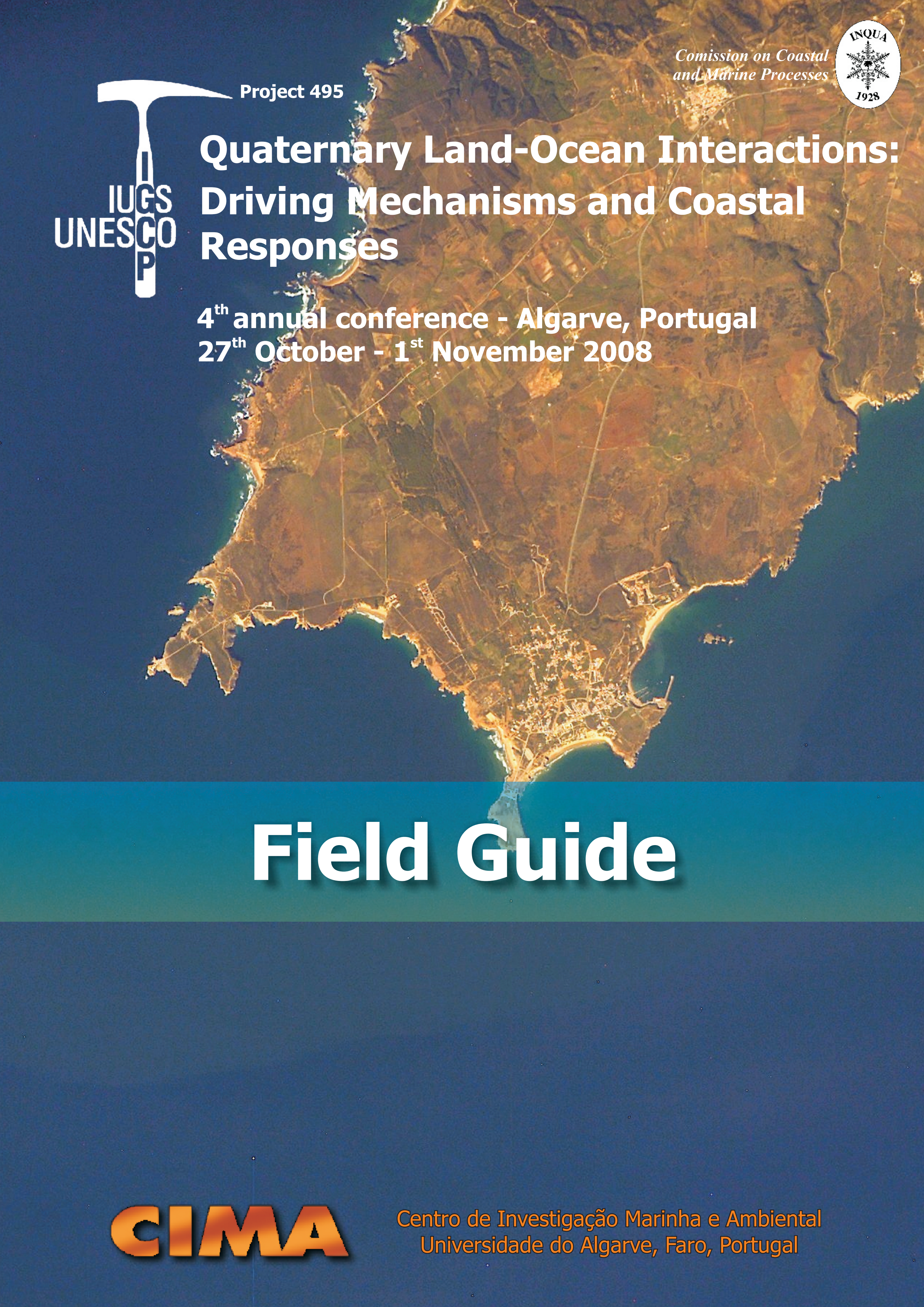

Comission on Coastal and Marine Processes

INQUA 1928

Project 495

IUGS UNESCO IGCP

Quaternary Land-Ocean Interactions: Driving Mechanisms and Coastal Responses

4th annual conference - Algarve, Portugal
27th October - 1st November 2008

Field Guide

CIMA
Centro de Investigação Marinha e Ambiental
Universidade do Algarve, Faro, Portugal

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Project # 495

INQUA Commission on Marine and Coastal Processes

Quaternary Land-Ocean Interactions: Driving Mechanisms and Coastal Responses

IGCP 495 Fieldtrip

Algarve and Alentejo, Portugal
30th October – 1st November 2008

FIELD GUIDE

Edited by :
Tomasz Boski and Sarita C. da Encarnação

CIMA – Centre for Marine and Environmental Research
Universidade do Algarve

Remissive Index

Day 0 – 28 October

Day 1 – 30 October

Day 2 - 31 October

Day 3 – 1 November

STOP III - *Guadiana Estuary*

1. **Geographical coordinates:**

37º 10' 19'' N; 7º 23' 50'' W

2. **Regional geological setting**:

Algarve presents very conspicuous geological zoning, which is present also in the area of Guadiana Estuary (Fig.1).

The Hercynian Serra in the North which belongs to the Hesperic Massif is essentially composed of shales and greywackes. The central zone is occupied by Triassic, Jurassic and Cretaceous formations, composed essentially of red sandstones and conglomerates, dolerites and limestones. The southward littoral fringe is dominated by clastic limestones and siliciclastic sediments respectively dated from Miocene and Plio-Pleistocene. The Algarve Basin started to form in the Late Triassic during the early phase of North Atlantic opening, under E-W to ENE-WSW distensional regime. The present morphology of the continental shelf has been shaped since the Neogene. The shelf evolution since the Tortonian, involved switching from carbonate reef to terrigenous sedimentation, in semi-graben structures, leading to the accumulation of tens of meters of sands and silts which were seen in Cacela.

3. **Local geology and hydrography**:

The Guadiana River flows 810 km from its headwaters in Spain to its mouth in Portugal, with 150 km of the main river and many longer tributaries in Portugal, and 110 km of the main channel forming the border between the two countries.

The drainage basin area is 66,889 km², of which just 17% (11,525 km²) is inside Portuguese borders while 83% (55,364 km²) is in Spain. The mean yearly rainfall in the basin area varies from 400 to 600 mm, but a clear seasonality is typical, with summer months usually very dry and hot. Consequently, the river flow varies seasonally, from 200–600 m^3s^{-1} during winter to

0.1–20 m^3s^{-1} in summer. In addition, significant fluctuations of river inflow are observed from year to year, varying from 20×10^8 m^3 in a dry year to 800×10^8 m^3 in a wet year.

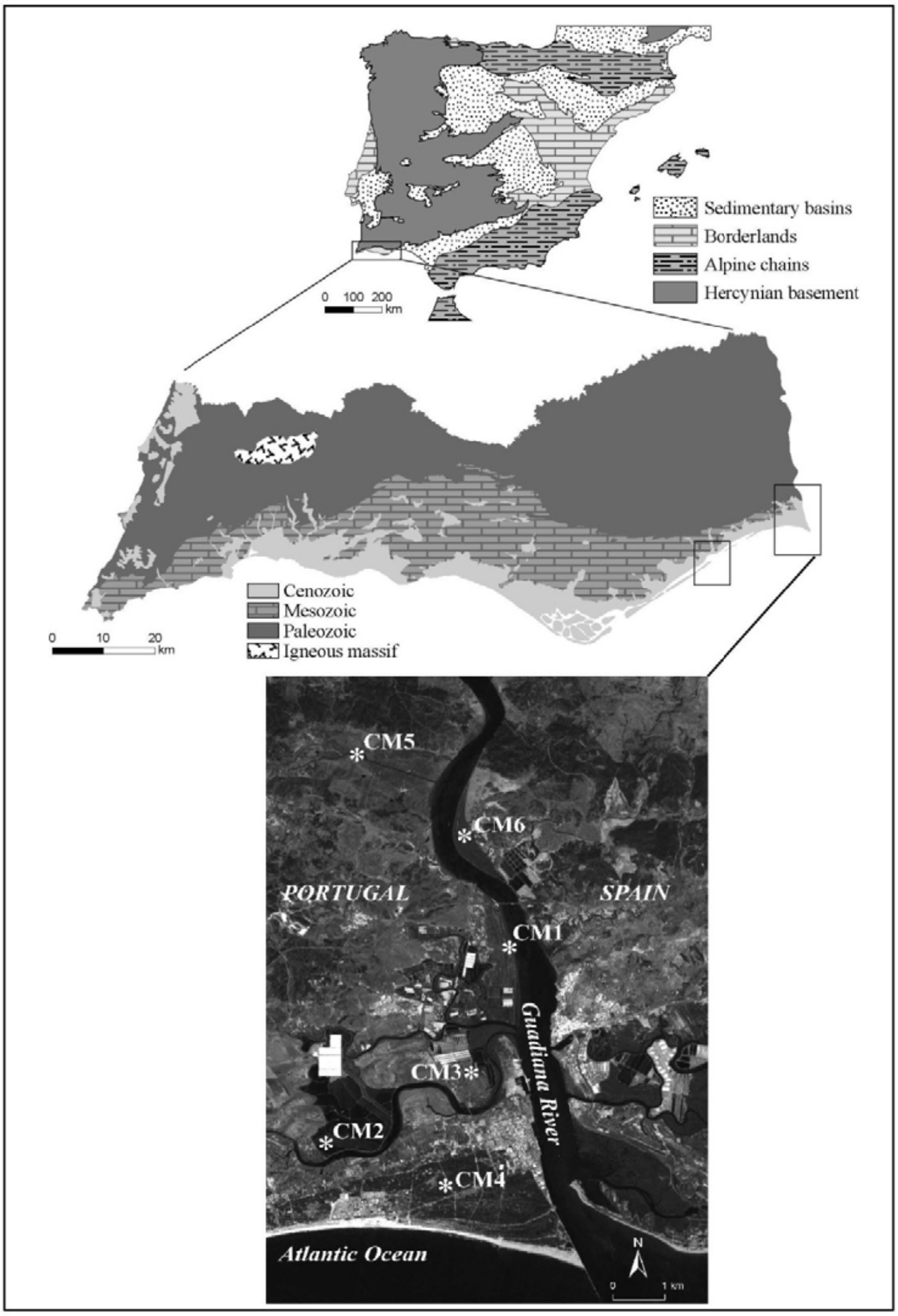


Figure 1. Geological setting of Guadiana Estuary with the localization of major boreholes marked by *.

The estuary has a maximum width of 550 m and a depth varying between 5 m and 17 m, is permanently open, and flows continuously, apart from annual and seasonal variations. The tidal regime of the estuary is meso-tidal, with average amplitude of 2 m. Mean residence time is 70 days, but in the lower estuary and during the rainy season, residence time may be of 10 days. The Guadiana estuary can be considered as partially stratified. However, when the flow in the river is low, the estuary becomes vertically homogeneous, whereas during periods of high flow in winter and spring, stratification can occur.

The low permeability and tectonic fracturing of the Paleozoic basement shales and greywackes defined the morphology of river paleovalley. In fact it is quite unique in South Iberia by being so narrow and deep: 600 m wide and over 80 m deep below mean sea level ca 7 km inland from the mouth. On the western Portuguese margin of the estuary the incision is less deep and the Hercynian basement is covered by the Jurassic carbonate rocks. The morphology of the paleovalley which was progressively drowned and sediment infilled following the last deglaciation, is shown in the Fig. 2.

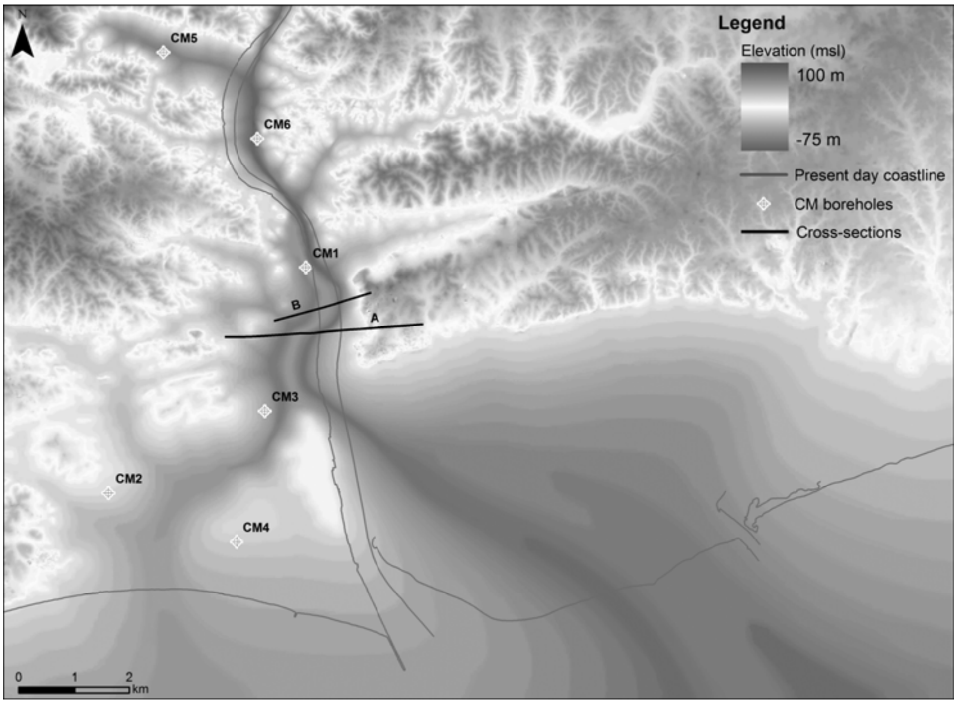
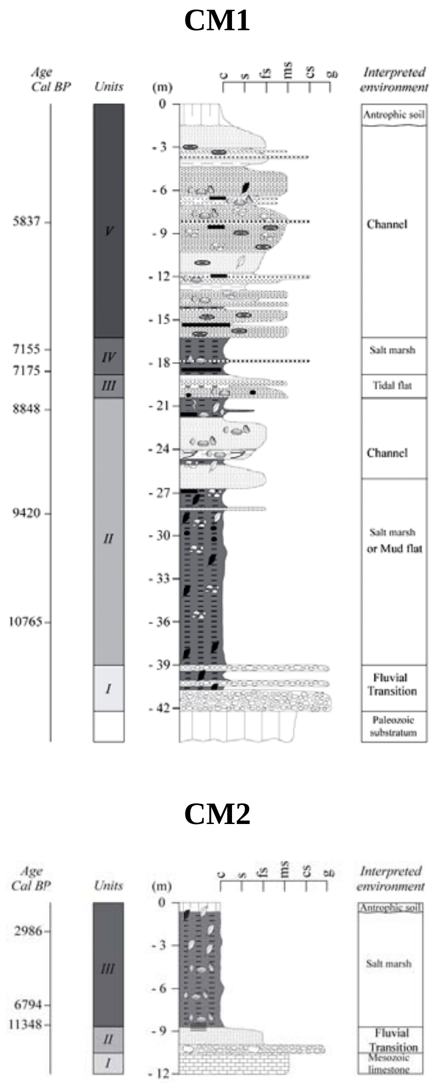


Figure 2. Pre-inundation morphology of the area of Guadiana River Estuary.

The pre-transgression surface was reconstructed by triangulation using the data from tens of destructive, percussion boreholes, the seismic profiling and 6 cored boreholes whose location is shown in Fig. 1 and 2 and the respective lithological profiles are resumed in Fig. 3 and 4. The generalized cross section through the valley infill is shown in the Fig. 7.



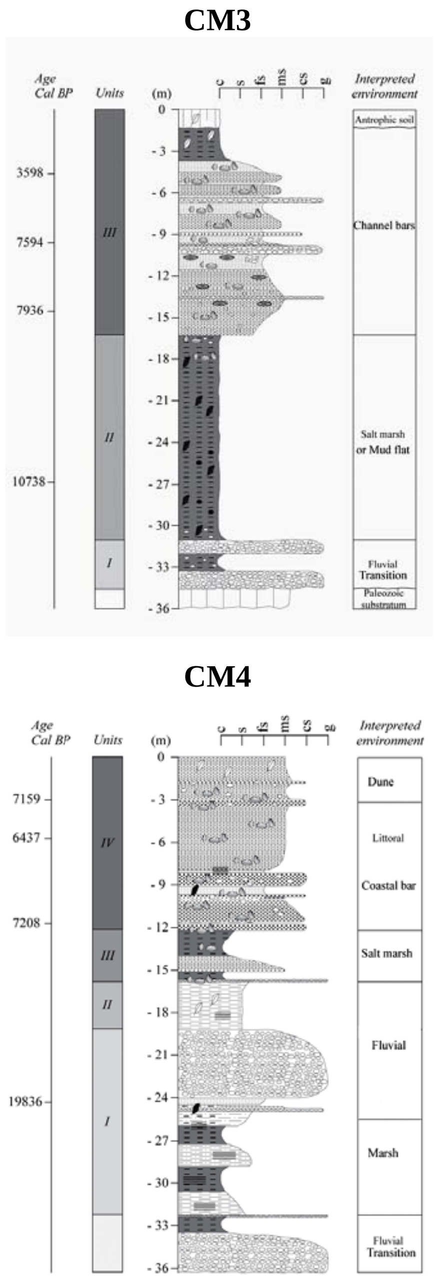


Figure 3. Lithological profiles in boreholes CM1 to CM4.

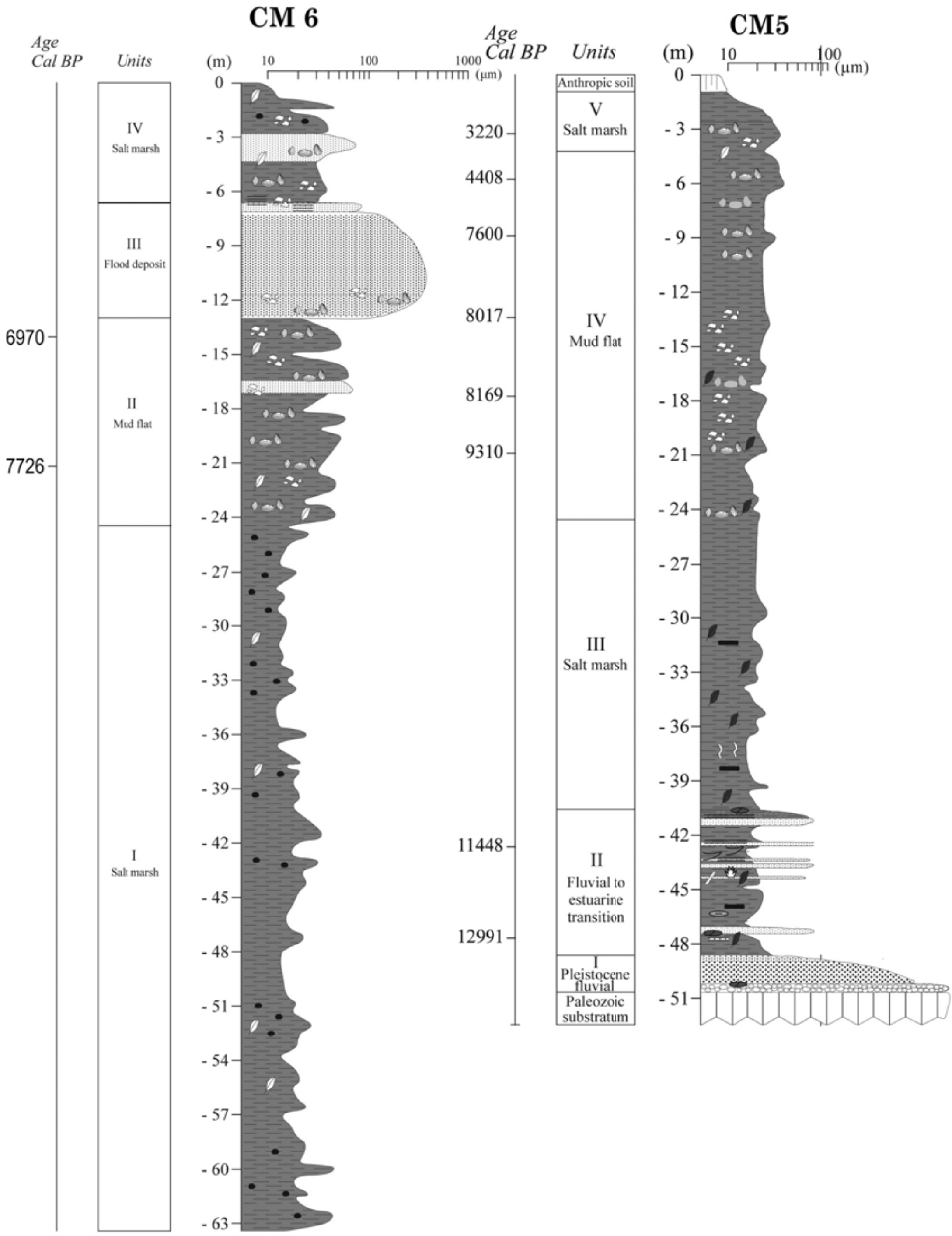


Figure 4. Lithological profiles in boreholes CM6 and CM5.

Notwithstanding the observed lithological differences, the Holocene sedimentary infill observed in boreholes CM1 and CM3 recorded two distinct sedimentary facies with a boundary in the approx. 7000 yr. Cal BP, respectively. In CM1 the boundary is set at 16,2 m depth. It separates a sequence of rhythmic fining up series interpreted as point bar facies, from the lower mostly clayey, bioturbated facies. In the latter, dissipated vegetal fragments, mud balls, and frequent flaser structures points to upper intertidal flat environment, under continuous influence of tidal currents. Reddish clayey layers observed in this unit indicate occasional supply of materials rich in ferruginous pigments, eroded from Plio-Plesitocene formations cropping out along Algarve-Andaluzia coasts. Likewise, due to the fast sea level rise in the corresponding period, the fine sediment load could be effectively trapped and fixed by the salt marsh vegetation which itself could maintain a constant position in relation to the tidal flooding. The reported discrete centimetre-scale peaty levels indicate the recurrence of brackish/fresh water conditions which most probably occurred in semi-confined ponds. Numerous traces of rootlets indicate that these patches of peat are *in situ*.

In borehole CM2, the principal, clayey unit is interpreted as an upper marsh, composed almost exclusively of clay deposited in a confined lagoon environment sheltered by the sand spit to the south, occupied at present by Monte Gordo dune field. The lack of any observable discontinuity within this unit indicates that these conditions prevailed throughout the entire period of deposition i.e. since ca 7900 yr. Cal BP. The 30 hand auger drillholes (Santos & Boski, 2000) which were done over the surface of about 1km^2 around CM2, have showed that this unit is laterally homogenous, composed entirely of clayey–silty sediments enclosing levels of well preserved valves of *Cerastoderma edule*, *Ruditapes decussatus* and other species which were mentioned above.

Sediments drilled between 31.2 m and 16.5 m in borehole CM3, belong to a remarkably homogeneous facies of clays, very rich in vegetal remains with some bioclastic deposits from channel lags. These facies are typical for confined marshes developed within the reaches of the central estuarine basin where agglutinated foraminifera species dependent on fine sediment, account for almost 100% of the entire assemblage. The two ^{14}C dates so far obtained

(9470 yr. BP at 26.9 m and 7080 yr. BP at 14.52 m) point once more to conditions of rising sea level at an accelerated pace of 0,6–1 m per century. Lithofacies from 16.4 to 1.5 m depth are mostly fine sand with frequent channel lags, indicating a shift to the environment of increasing tidal energy. The observed replacement of the upper marsh foraminifera by lower intertidal level species, as it happened in our case around 8500 yr. cal BP. must have occurred when the sea level rise became faster than marsh accretion. Combining these figures with the dating of the submerged rocky shore ridges on Algarve shelf suggests that shelf sands became an important component of the estuarine infill between 7500 yr cal BP. According to Zazo *et al*. (1994) in that period the first phase (H1) of barrier progradation along the Gulf of Cadiz coasts began, which enabled the enclosing of Ria Formosa.

Of the 4 cores considered, the sedimentary column of the CM4 borehole is certainly the most complex. Two basal gravel units enclose the salt marsh sediments overlain by swamp/creek laminated and hardened deposit which experienced prolonged subaerial exposure inferred from presence of carbonate nodules and oxidized levels. Further to the west in the Gulf of Cadiz, in the Estuaries of Tinto-Odiel and Guadalete Rivers the similar sequences were attributed to the highstands during the isotope stage (IS) V, ca 128 ka (Zazo, 1999) or to the IS III highstand (Dabrio *et al*., 2000), ca. 25-30 ka. The first evidence of marine sedimentation in predominantly sandy the shell rich, gravel layer at 15.2 m. The existing datings 7208 yr. cal BP at -15.2 m, 6437 yr. cal BP at -9.75m and 7159 yr. cal BP at –7m point to (with all necessary reserves imposed by the highly dynamic environment) rapid accretion of a coastal bar or one high energy event which led to reworking of material. The uppermost 3 m of sands are barren of any fauna at macro- and microscopic scale and contain abundant floral remains, thus their deposition occurred in a subaerial environment of the coastal dune system.

The sedimentary profile of Beliche Rivulet – Borehole CM5:

The chronologically resolved sedimentary record in borehole CM5 begins with a silty layer, containing wood fragments dated 12991 yr cal. BP, at 47.67 m depth; no foraminifera have been observed at this level. However, intertidal foraminifera do occur in above the 47.67 m level before the second dated level, at 42.70 m, with an age of 11448 yr. cal BP. Therefore to that, which in chronostratygraphical terms corresponds to the Younger Dryas (YD) a transitional fluvial/marine origin may be attributed. Given the lack of any observable discontinuity in lithology, it may be assumed that this transition occurs within the Guadiana Estuary without any major interruption in sedimentation. Indeed, at a similar depth of 45 m in the Ria de Vigo, Galicia, Spain, seismic reflection profiles, also show a clear discontinuity which can be attributed to the Younger Dryas stadial (García *et al*., 2005). Moreover, in the borehole CM5 on the Guadiana Estuary, the depth-age relation for the period between 12991 cal. BP and 7600 yr. cal. BP, comprising six dated points, fits a linear regression trend of 0.73 m per century with a squared correlation coefficient R^2=0.971. This correlation points to a remarkably constant sediment accretion rate and consequently, we do not find any evidence supporting the regional sea level drop during the Younger Dryas.

The overlying horizon, which extends to the depth of 24.5 m provides neither organic, nor carbonate shell, datable items. Nevertheless, the foraminifera assemblage indicates that this unit had been an intertidal salt marsh environment.

The local change of the sedimentary facies from the upper (salt-marsh) to the lower (mud flat) intertidal level with little or no halophyte vegetation covering the sediment surface is marked by the first appearance of macrofauna. The limit between these two lithofacies is placed therefore at 24.5 m depth i.e. the first appearance of bivalve *Scrobicularia Plana*.

From this level upwards, the continuous presence of macro and microfossils, combined with scarcity or absence of plant root traces and other vegetal remains, indicate that the sedimentary unit from 24.5 to 4.2 m depth had been deposited as a non-vegetated or very scarcely vegetated mud flat bordering the Beliche channel. The appearance of gypsum in the topmost segment is a clear signal for the terminal stage of sediment infilling within the estuary. At this stage, conditions are favourable for the formation of small water ponds, which could be replenished during the spring tides and subsequently subject to desiccation.

The uppermost part of the profile has much less macrofauna preserved than the underlying unit. Microfauna indicates confined environment in the final stage of infilling of the estuary, with the halophyte salt marsh vegetation covering the sediment surface.

The Borehole CM6:

This borehole was drilled recently and is the deepest one due to its proximity to the main channel axis. There is about 7 m of coarse gravel deposited directly on the Paleozoic basement. At 63 m depth starts an entirely silty- fine sand/silty horizon which extends to 17 m depth. There was a complete lack of datable items from the base upwards to 24 m depth. However, through the comparison with a well established age model of the nearby CM5 profile (Boski *et al*., 2008) we may assume that fully marine conditions, indicated by foraminifera at 63 m depth, must date back to a previous marine highstand. Towards the top of the horizon the marine influence is increasing to its maximum at 13.2 m depth, certainly at the apogee of the Holocene transgression ca 6970 yr. cal BP. The dominant foraminifera *are Amonia beccarii* and *Haynesina germanica* associated to the shelf forms, namely: *Cibicides lobatulus*, *Planorbulina mediterranensis*, *Asterigerinata mamilla*, *Brizalina sp.* and *Discorbis sp*. From that depth upwards the lithological column has variable texture with a rich foraminifera fauna.

Recent geological features of coastal change:

The present morphology of the Guadiana Estuary is a result of accumulation of fluvially supplied and drifting shelf sediments being deposited according the tidal and wave energy. Morales (1997) estimated that since mid-Holocene stabilization of the sea level, about 2490 x $l0^6$ m^3 of sediment have accumulated on a area of 10.5 km x 7 km (73.5 km), indicating a mean accumulation rate of 500 x $l0^3$ m^3/yr. This figure is approximately triple of the estimated (Boski, 2002) volume of longshore drifting sand. Figures 5 and 6 (Morales, 1997) show how the progradation occurred in a different way on either sides of the estuary mouth. A transverse growth of the Monte Gordo Beach spit took place on the western side, while on the east, the progradation occurred as new barrier islands formed from active sand bars. It seems that the final stage of infilling of the embayment accommodating present estuary could be well a consequence of anthropic activities, mainly deforestation, which was initiated, according to Fletcher *et al*. (2007), in the Middle Holocene. Castro Marim, according to the historical sources was an island in Roman Times and during the Middles Ages was encircled by intertidal flats. At present moment the sand drift from the east is stopped on the Portuguese side of the estuary by the jetty which was terminated in 1974. From the other hand the fluvial sediment supply is close to nil because of retention behind ca 50 dams, from which the most prominent is Alqueva. It was effectively closed in 2002 and formed since then a largest artificial lake in Europe. As a result the eastern part of the Guadiana delta is under severe erosion.

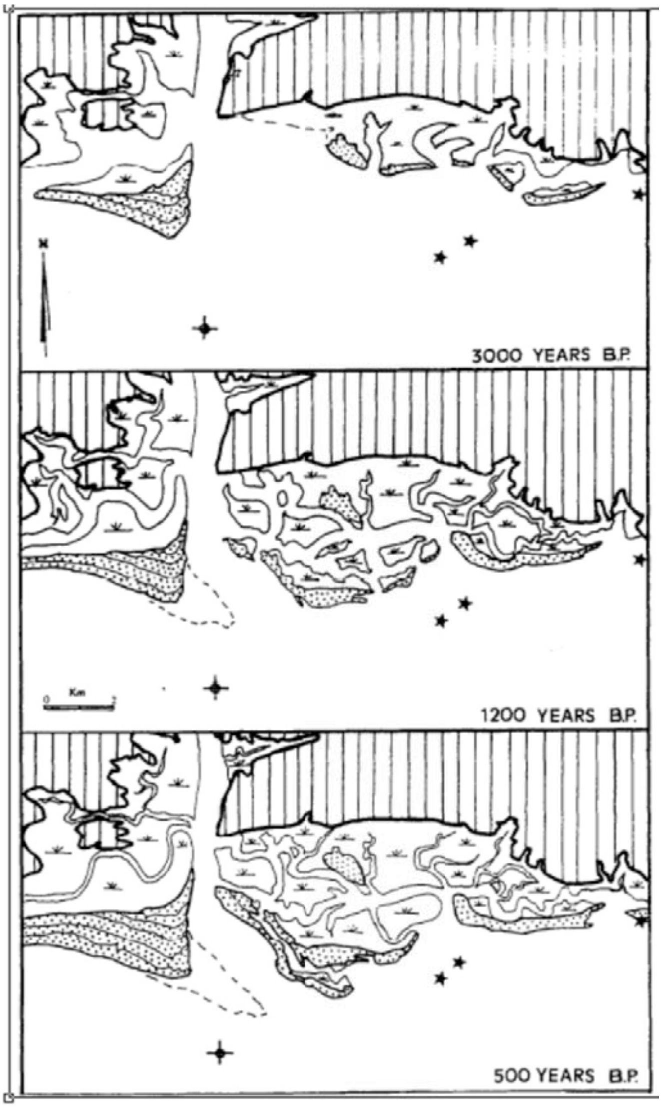


Figure 5. Reconstruction of the last 3000 years of Guadiana Estuary according to Ojeda (1988).

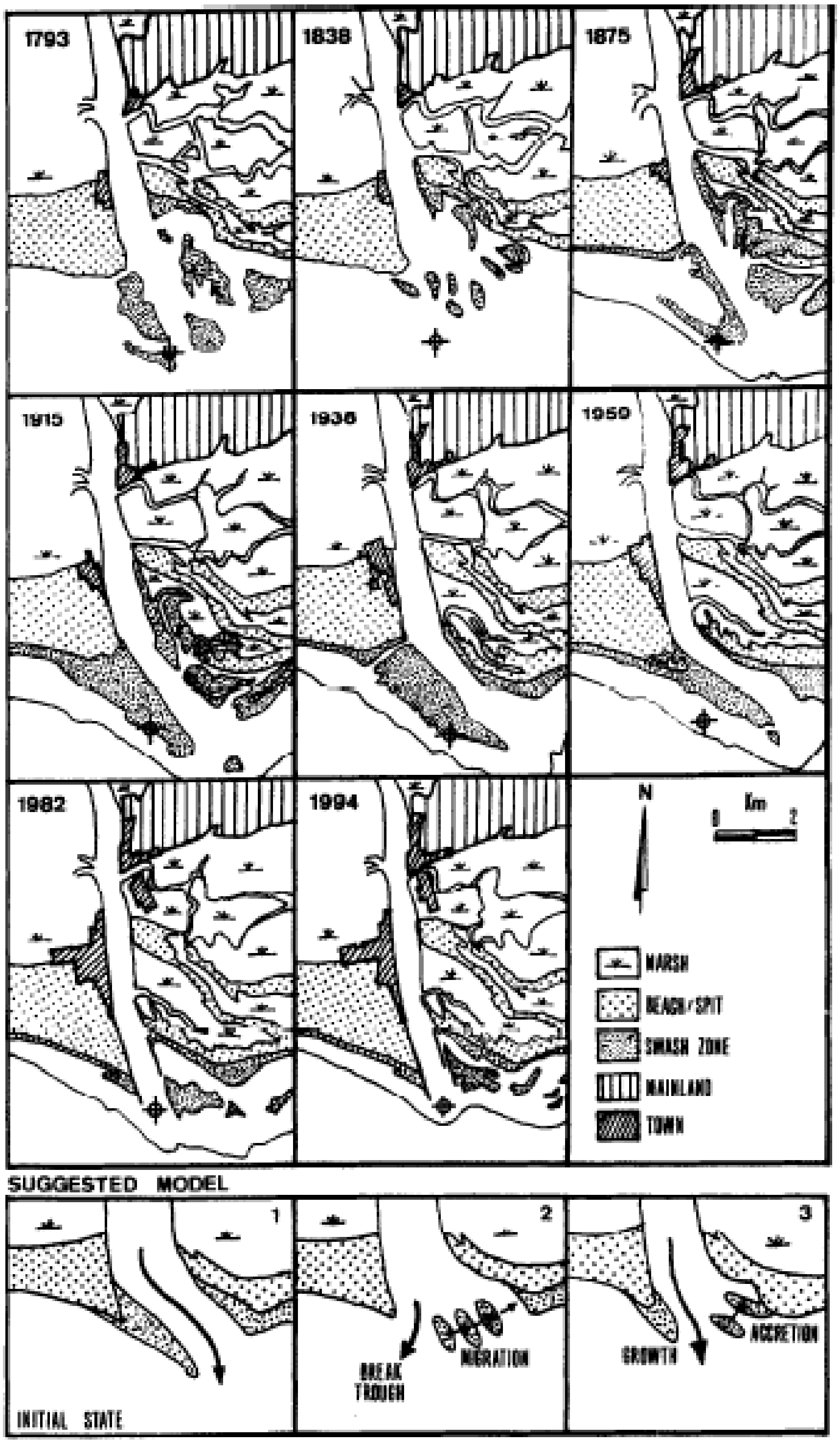


Figure 6. The last 200 years of Guadiana Estuary according to Morales (1997).

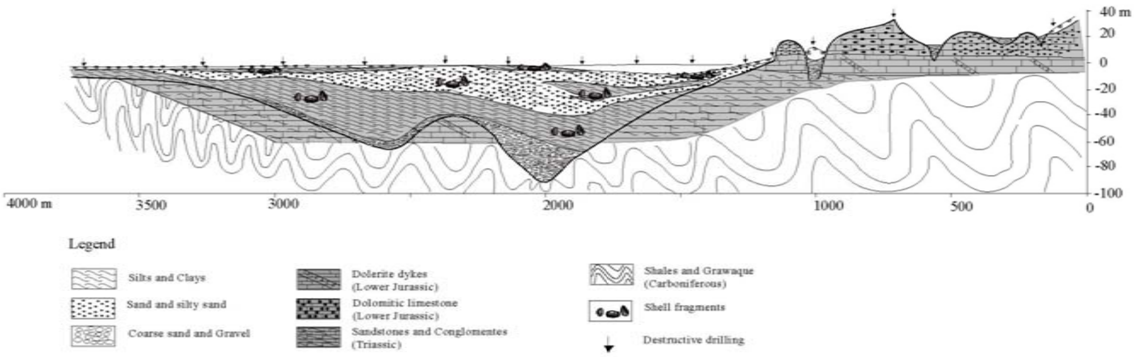


Figure 7. Interpretative geological profile A-A' – Guadiana estuary, based on destructive drilhole data for international bridge project.

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