

FIELD GUIDE

IX IBERIAN QUATERNARY MEETING

Fossil dunes as proxies for
environmental reconstruction

*A visit to the aeolianites of
Armação de Pêra Bay
Algarve*

Universidade do Algarve
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Editors

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FOSSIL DUNES AS PROXIES FOR ENVIRONMENTAL RECONSTRUCTION

A visit to the aeolianites of Armação de
Pêra Bay, Algarve

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PREFACE

This field guide aims to (i) introduce the dunefield of the Bay of Armação de Pêra located at the south coast of the Algarve, (ii) frame and compare the genesis and evolution of this dune system with other Portuguese coastal dunefields, and (iii) provide information on past sea levels and aeolian activity that encourages a stimulating discussion in the field concerning the dunefields generation and evolution.

Dunefields have a great potential to unravel past regimes of atmospheric circulation as they record direct traces of this component of the climate system. In addition, coastal dunes are good proxies of the coastline migration derived from changes in mean sea level. An excellent example of the potential of fossil dunes to reconstruct preterit wind regimes is the case of the west Portuguese coast. Here, transgressive dunefields represent relict features originated by intense and frequent westerly winds, and abundant sediment supplied to the coast that largely contrast with present conditions, clearly dominated by weaker northwesterly winds and sediment starved coasts. At the southern coast, fossil dunes are not as frequent as along the western coast and this field excursion aims to visit, explore and discuss the evolution of one of these systems located at the Armação de Pêra Bay. Yet, it is important to keep in mind that the evolution of this fossil dunefield should be understood in the general context of global changes and within the evolutionary spatial scenario of the Portuguese coast. For that, we present here a brief summary of the spatial and temporal distribution of those relict features along the Portuguese coast emphasizing the examples more intensively explored in the literature, as it is the case of the Caparica dunefield, which might represent a major part of the more important episodes of aeolian activity in the Portuguese coast, responsible for these massive and fossil features.

CONTENTS

PREFACE	iii
CONTENTS	v
1. Portuguese fossil coastal dunes and past aeolian activity	1
Susana Costas	
1.1 Distribution of coastal fossil dunes	1
1.2 Past aeolian activity – the cliff-top dune of Caparica	3
1.3 Pulses of aeolian activity	8
2. The Armação de Pêra Bay	11
Delminda Moura, Susana Costas & Cristina Veiga Pires	
2.1 General settings	11
2.2 Pre-Holocene evolution of the Armação de Pêra Bay	13
2.3 Holocene evolution of the Armação de Pêra Bay	15
REFERENCES	23

1. Portuguese fossil coastal dunes and past aeolian activity

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1.1 Distribution of coastal fossil dunes

Environmental conditions during the end of the last glacial created the necessary conditions to trigger the formation of coversands in northwest and central Europe (Kasse, 2002; Renssen et al., 2007), Great Britain (Bateman, 1995), south-west coast of France (Bertran et al., 2009), center of Spain (Bateman and Díez Herrero, 2001; Garcia-Hidalgo et al., 2002; García-Hidalgo et al., 2007), Atlantic Spanish coasts (Zazo et al., 2005), and some areas of the Portuguese coast (Costas et al., 2012; Costas et al., 2016; Danielsen et al., 2011; Granja et al., 2008; Ramos Pereira and Angelucci, 2004).

The Portuguese coast extends for more than 900 km, of which 60% are beaches and 36% exposes cliffs without beaches (Andrade et al., 2002). Currently, 28% of the coast experiences severe problems of erosion (EuroSION, 2004). Despite the starved character of the present Portuguese littoral, large stabilized or fossil transgressive dunefields dominate the coast (Figure 1). These deposits document periods of significant sediment availability within the littoral system, contributing to the formation of the Portuguese littoral belt (Ramos Pereira and Angelucci, 2004). The Portuguese littoral belt is formed by consolidated and non-consolidated dunes. After the early works on consolidated dunes of Portugal by Zbyszewski during the 40s, these deposits have been described and tentatively interpreted and dated by Ramos Pereira and Angelucci (2004). Attempts to determine the radiocarbon age of those dunes have been made by different authors at the outcrops found along the Alentejo-Algarve coast, Cascais and Sintra coast as summarized by Ramos Pereira and Angelucci (2004). In most of the cases, the ages were not determined over the dune deposit, but on overlying organic horizons. Examples are the case of the aeolionite of Morgavel (Sines, Alentejo Coast), which was assigned an age of 39490 ± 2.340 yr BP (Schröder-Lanz, 1971), and Oitavos (Cascais) with assigned ages between 31700 and 34830 yr BP (Moniz, 1992; Prudêncio et al., 2007). However, Prudêncio et al. (2007) suggested that the age of paleosoils may induce errors during age assignment if they are not previously treated.

New radiocarbon dating in the treated paleosoil, and Optically Stimulated Luminescence (OSL) dating performed in the dune of Oitavos suggested that the dune was deposited between 14500 and 12000 yr ago, being much younger than previous estimates. The age of fossil dunes near Sintra was estimated based on archaeological remains in paleosoils or organic horizons. The Magoito dune overlays an archeological horizon dated at 9580±100 yr BP (Daveau et al., 1982) and 9520±40 yr BP (Soares, 2003) while the occupation of Sao Julião is estimated to be between 7810±90 and 6820±100 yr BP (Soares, 1993).

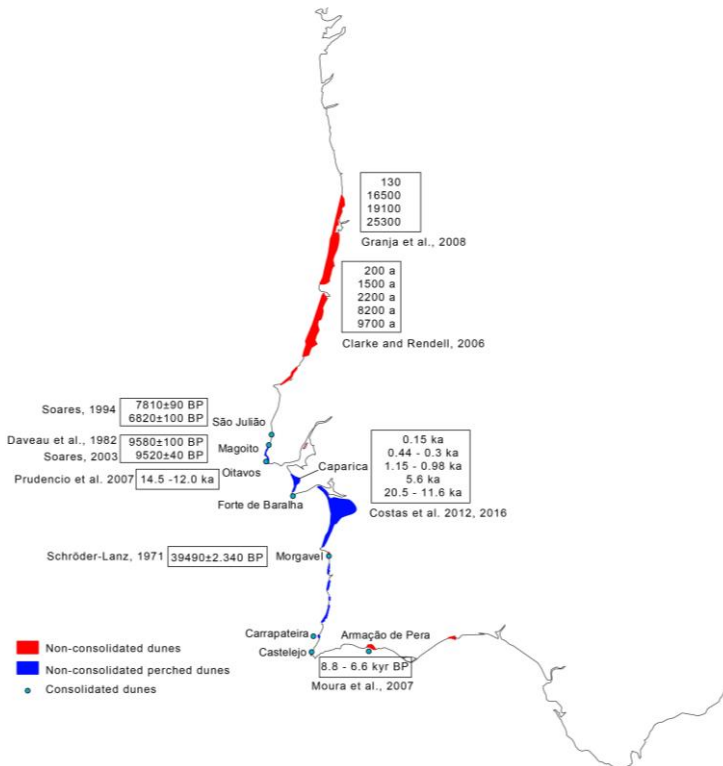


Figure 1. Spatial distribution and estimated ages of the fossil dunes along the Portuguese coast according to several authors (after Pereira and Correia (1985)).

1.2 Past aeolian activity – the cliff-top dune of Caparica

The occurrence of sand drift and dune building episodes along the Portuguese coast has been related to sediment availability (Ramos Pereira and Angelucci, 2004), changes in vegetation cover, water table and storminess induced by changing climatic conditions (Clarke and Rendell, 2006; Danielsen et al., 2011; Granja et al., 2008). The most recent episode of coastal dune building in Portugal was related to increased storminess during the Little Ice Age (LIA) and was coincident with a broader episode of dune construction in western European coasts (Clarke and Rendell, 2009).

The present conditions for aeolian activity in the Portuguese coast contrast with the environmental conditions that generated the ancient Portuguese littoral belt. The occurrence of active dunefields along the Portuguese coast is nowadays very rare with the exception of locations with orographically induced strong winds. The vast majority of the coastal dunes are either stabilized or eroding. This fact provides additional interest on the understanding of these ancient aeolian deposits as they may record contrasting environmental conditions or even different degrees of human pressure. As an example, we present the results from an intensive analysis of the evolution of the top-cliff dune and inland coversand found on top of the Caparica Cliff, south of Lisbon.

The Caparica cliff-top dune is a transgressive dunefield located within the western-central sector of the Setúbal Peninsula, about 20 km south of Lisbon, in the Portuguese Atlantic Coast. This transgressive dunefield is composed by perched dunes developed on the top of a terrace located around 50 m above mean sea level (MSL). The dunefield extends up to 4.5 km inland from the edge of the cliff and is 42 km² in areal extent. The coastal segment located in the base of the cliff is characterized by a 25 km long coastal plain, which stretches to the south (Fig. 1). The physical boundaries of the coastal plain are represented inland by a coastal cliff section 100-55 m high. The cliff consists of unconsolidated deposits interpreted by Azevedo (1983) as fluvial sediments deposited during the Pliocene and corresponding to the landward Tagus paleo-valley. The central section of the littoral arc, north of Fonte da Telha beach (Fig. 1), is characterized by two distinctive foredune fields. The inland foredune, reaching up to 200 m in width, is colonized by a well-developed forest, which was planted in the end of the 20th century to steady dunes. The seaward foredune is around 80 m width and fixed by *Ammophila sp.* Both dunefields may reach 12 m height. Contrasting with these low relief dunefields, the transgressive perched dunes comprise very large dune

buildings that may reach up to 30 m height (Costas et al., 2010). An isolated reference to the age of the top-cliff dunes situated their formation around 1190 ± 90 yr BP from dating organic horizons (Antunes and Pais, 1989). Aiming to understand the internal geometry of the Caparica fossil dunefield a Ground Penetrating Radar (GPR) survey was performed.

The GPR stratigraphy and chronology of the Caparica cliff-top dunefields allow us to detect discrete phases of aeolian activity separated by gaps in the overall OSL age errors distribution peaking at 0.35, 1.10, 5.60 and 17.5 ka (Figure 2). Time bins of 1000 years were applied to the Late-Pleistocene units (errors ranged between 600 and 1200 yrs) while Holocene units were clustered using time bins of 500 (errors ranging between 210 and 10 years). The older identified episode, which represents the encroachment of the inland coversand, was assigned to the last termination (time period between 22.0 to 11.5 ka according to Björck et al. (1998) and represents an almost continuous event extending from 20.5 to 11.6 ka. Aeolian activity during this episode was maximum at 17.5 ka, decreased after 15.1 ka and stopped after 11.6 ka.

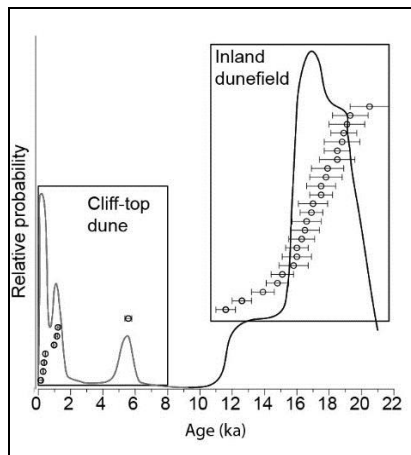


Figure 2. Relative probability plot of OSL ages. The entire dataset includes 24 OSL ages from the explored transgressive dunefield (i.e. the cliff-top dune and the inland dunefield). The peaks represent discrete phases of aeolian activity (Costas et al., 2016).

The dune GPR stratigraphy and morphology of the inland coversand indicates that dunes are spatially organized to form superimposed parabolic dunes

oriented eastward (orientations between 240 and 270°). The latter suggests successive pulses of aeolian sand as supported by the obtained stratigraphy, which shows aeolian buildings formed by one unit overlaying the Pleistocene terrace (Figure 3). Internally, units consist of several packages or subunits separated by second order surfaces, which define internal packages or sub-units interpreted as representing the migration of superimposed dunes. Additionally, third order bounding surfaces within the set of cross strata indicate reactivation surfaces formed by fluctuations in airflow.

The spatial distribution of the ages does not show a clear temporal segregation. Oldest dunes are partially covered and surrounded by younger dunes. The latter supports the eastward influx of aeolian sediment during different episodes of dune building rather than its continuous recycling. Sand encroachment on this area could be explained by the morphology of the Pleistocene terrace, which gently dips landward, creating a shadow area with wind power reduction that could force the dunes to settle and stop their landward migration.

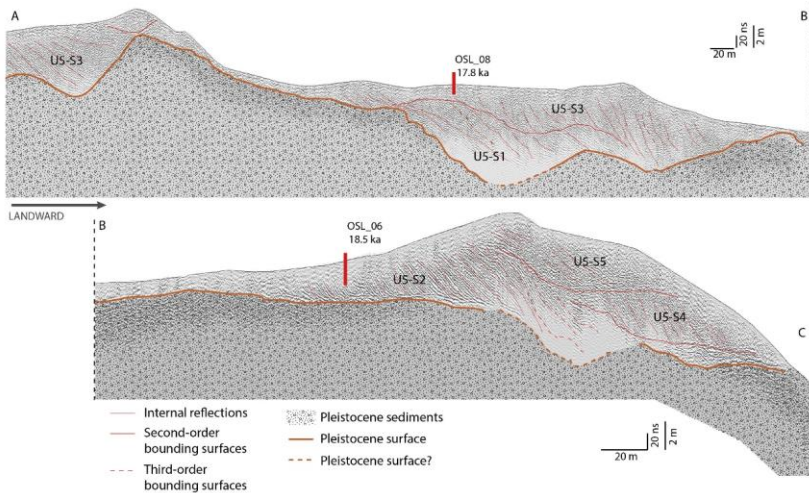


Figure 3. GPR line surveyed within the inland transgressive dunefield of Caparica (Costas et al., 2016).

The GPR stratigraphy of the cliff-top dune, combined with the analysis of its morphology from a digital terrain model, shows two vertically stacked units resulting from merged parabolic dunes advancing inland simultaneously (Costas et al., 2012). These are fixed once they reach the edge of the cliff to form the cliff-top ridge as they reach an area of flow separation just landward of the cliff. Stacking of units supports successive episodes of dune activity separated by periods of dune stabilization marked by the presence of a super-bounding surface (Costas et al., 2012). The latter marks the stabilization of the aeolian unit deposited 5.6 ka ago, during the Mid-Holocene, and the encroachment of a new sand unit during the Late-Holocene (1.20-0.98 ka). The last unit was reactivated between 0.44 and 0.30 ka, during the Little Ice Age (LIA) (Figure 4). Finally, the dune ridge appears locally fragmented as a consequence of the isolation of individual parabolic dunes that continue their migration inland. This was the case of the aeolian unit dated at 0.15 ka.

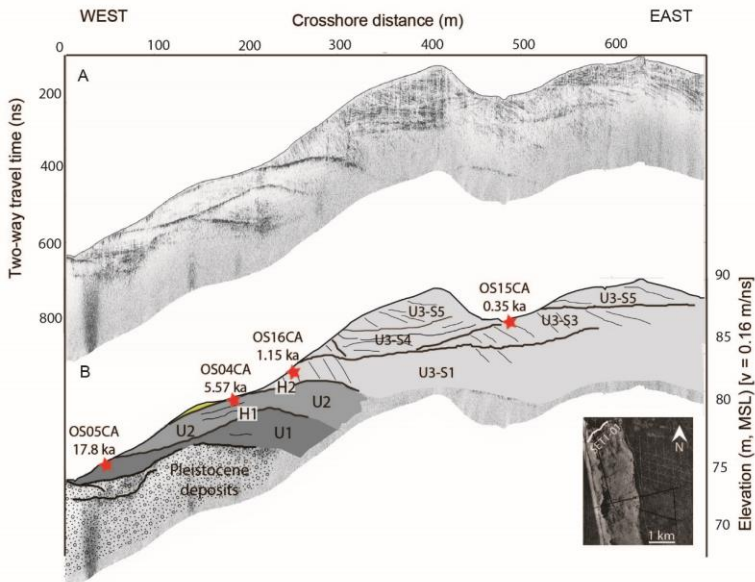


Figure 4. (A) West-east directed GPR profile SET1-02. (B) Interpretation of the radargram with the identified radar units. The location of the sediment sample for dating the radar units is also pointed as well as the resulting ages. Modified from Costas et al. (2012).

A major difference between the dunes within the cliff-top ridge and the inland coversand is the distances that they must have travelled before being fixed. If we assume that sediment is transferred inland through the migration of transgressive dunes fragmented from a former coastal barrier (Figure 5), the distance travelled by Late-Pleistocene dunes should range between 10 and 7 km while Holocene dunes should have migrated about 1 km. The longer transported distances occurred during the last termination when sea-level was lower but rising from about 120 to 50 m below MSL (Lambeck et al., 2014). Conversely, short distance Holocene transgressive dunes were formed after sea-level rise rate attenuated 6.5 ka ago (Costas et al., 2016).

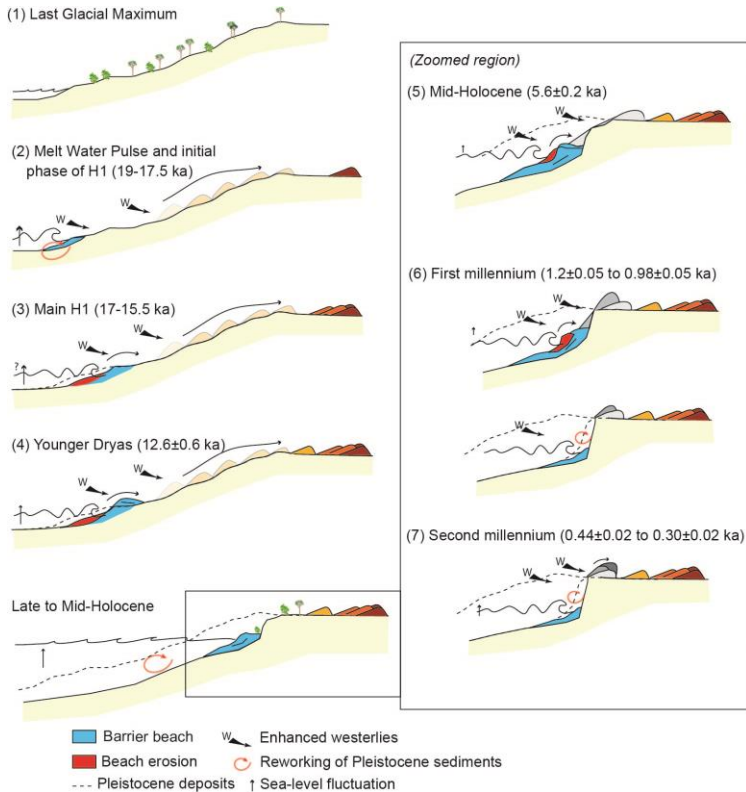


Figure 5. Reconstruction of the Caparica fossil dunefield (modified from Costas et al. (2012)).

1.3 Pulses of aeolian activity

The record of aeolian activity from the central coast of Portugal traces favourable conditions for dune building episodes over the last 20.5 ka centered at 0.35, 1.10, 5.60 and 17.5 ka (Figure 2). The identified episodes suggest the southward deflection of the NA storm track and the strengthening of the westerlies over southern Europe during well-known climatic extremes such as the Heinrich event 1 (HE1) (Hemming, 2004), the 5.6 ka event (Mayewski et al., 2004), the end of the Middle Ages (Helama et al., 2009), and the LIA (Bradley and Jones, 1993). At the South in the Armação de Pêra Bay, a very different morpho-climatic setting with respect to the Caparica dunefield, the optimal environmental conditions to form dunes lasted between 8800 and 6600 cal BP as further discussed (Moura et al., 2007).

The occurrence of discrete events of aeolian activity recorded through the Holocene suggests the onset of wind conditions enhancing aeolian activity during short periods of time. The record of aeolian activity represents periods of enhanced storminess (Costas et al., 2012), whose temporal distribution appears in phase with storminess periods affecting northern and central Europe (Orme et al., 2015; Sorrel et al., 2012; Trouet et al., 2012 and references therein). The synchronicity of these events is illustrated in Figure 6, which compiles the spatial and temporal distribution of storminess periods during the Holocene based on: (i) aeolian activity related to dune mobility (Bateman and Godby, 2004; Clarke et al., 2002; Clemmensen et al., 2009; Costas et al., 2013; Gilbertson et al., 1999; Wilson et al., 2004), loess deposition (Jackson et al., 2005), clastic material concentration on raised bogs (Björck and Clemmensen, 2004; Jong et al., 2006; Orme et al., 2015), or chemical species in polar snow (Mayewski et al., 1997), (ii) occurrence of storm-related coastal deposits (Degeai et al., 2015; Sabatier et al., 2012; Sorrel et al., 2012; Van Vliet-Lanoë et al., 2014), and (iii) glacier evolution (Bakke et al., 2008). The observed distribution claims periods of enhanced storminess across Europe during the LIA, the end of the Middle Ages and during the Mid-Holocene, supporting a pattern that conflicts with the typical dipole configuration displayed by the NAO.

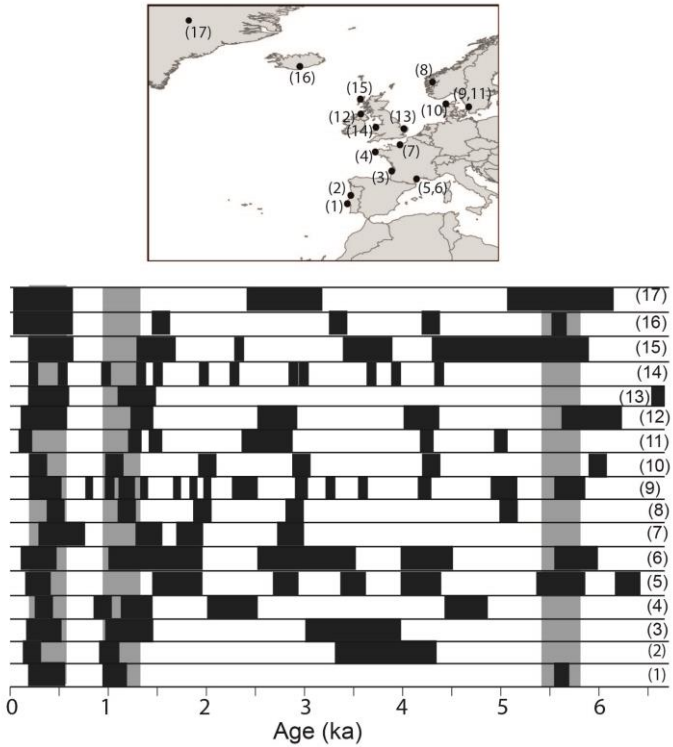


Figure 6. Temporal and spatial distribution of storminess periods over the Holocene (black boxes). The numbers in the map represent the different selected locations across Europe. Gray bars correspond to the aeolian peaks detected in the Caparica dunefield. After Costas et al. (2016).



2. The Armação de Pêra Bay

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2.1 General settings

The Armação de Pêra Bay is a zeta shaped bay with the longer stretch in the Galé headland direction. The Bay is a littoral cell constrained between the headlands of Cape of Carvoeiro and Galé showing a 5.36 km long shoreline (Figure 7). The cliffs that anchor the bay expose carbonate rocks from the Miocene Lagos-Portimão Formation. The paleo-relief imprinted by erosion into this Miocene substrate is filled by detrital sediment from silt to coarse sand. Thus, the cliffs contribute with little amount of sediment to feed the beach, mainly during erosional phases of the cliffs. Other external sources of sediment could be in the past the rivulets of Alcantarilha and Espiche located respectively at the W and E limits of the bay.



Figure 7. Geographic context of the Armação de Pêra Bay

At the present, the rivulets mouth are small estuaries and, in the case of the Espiche rivulet, there is no natural communication with the sea, and a coastal lagoon was formed being an important nesting site for limnivor birds (Figure 8). At least once a year a connection to the sea is artificially open to drain the water from the lagoon to avoid the mosquito pests. The Alcantarilha rivulet opens intermittently to the sea during storms and the seawater enters into the estuary during the spring tides. Nevertheless, artificial connections are frequently open for the same reason as in the Espiche lagoon. Due to this management practices the mouth of the Alcantarilha River relocates at different positions throughout the years (Figure 8).



Figure 8. A) estuary of the Espiche Rivulet also known as Salgados Lagoon, backed by the dunefield which extends to the Alcantarilha estuary (see Fig. 7); B) Alcantarilha Rivulet mouth in May 2007. After an artificial opening the mouth divided in two lobes and closed again. Two outcrops of beachrock (br1 and br2)) can be seen at the backshore in a topographically position higher than the current beach surface; C) and D) close-up of the beachrock 1, and examples of dated levels of shells (arrows).

According to the previous statement, the sedimentary nourishment of the bay-beach from allochthonous sources is quite limited. The main direction of the waves approaching the coast is from WSW (N232°) and thus not favourable to the longshore transport from the updrift adjacent littoral sectors due the natural barrier that the Cape of Carvoeiro headland represents. Furthermore, this barrier effect is aggravated by the consolidated spit bar of 1 km length submerged at 25-14 m depth. Therefore the cross-shore transport is the main sedimentary process promoting sedimentary exchanges between the beach and the nearshore.

Besides being a relatively straight coastal stretch, the nearshore circulation is cellular when currents are derived by the waves incoming from WSW (Oliveira et al., 2017). Hence, both the sediment transference from and to the adjacent littoral sectors is not efficient enough to guarantee the resilience of the beaches. We can assume that over the Holocene this pattern of circulation should not have been very different and, for this reason the main sedimentary source would be in charge of the streams that drain to the bay. However, this mechanism is dependent from the geomorphic limit, which, once exceeded, favors the deposition inside the estuaries more than the exportation to the shore. That geomorphic limit can be controlled by mean sea-level and climate changes, tectonics and anthropogenic activities. The described morphodynamic processes make the evolution of the bay dependent mainly on sea-level changes.

2.2 Pre-Holocene evolution of the Armação de Pêra Bay

A morphosedimentary structure anchored at the Cape of Carvoeiro runs approximately parallel (NW-SE) to the current coastline, has an alongshore length of ca. 1 Km, and is located between 25 m and 18 m below the mean sea level (Figure 9). This structure is nowadays strongly cemented by CaCO₃ cement (47% - 80% of the whole rock), karstified, and its geometry is compatible with a past spit-bar developed downdrift from Cape of Carvoeiro (Infantini et al., 2014). Spit-bars form by underwater accretion of sediments below the base level of the waves frequently downdrift of a river discharge (Costas and FitzGerald, 2011; Simms et al., 2006). The Arade and Alvor Rivers located updrift of Armação de Pêra Bay were probably the main sources of sediment to the alongshore transport, allowing the spit growth. The Cape of Carvoeiro acts as a natural groin leading to the decrease of the longshore currents velocity that loses the capacity to transport sediment. This is a common response occurring when the currents meet changes in the orientation of the coastline. Near a river mouth, spit-bars curve and may grow through multiples lobes, following the river mouth migration. The sand that forms

the consolidated spit off Armação de Pêra Bay, ranges from fine to medium moderately sorted sand. The submerged old spit-bar is currently a natural reef showing remarkable ecological value. According to the morphological and textural aspects here described, we can postulate several principles: (i) the spit-bar developed when the mean sea level was below the present one, (ii) the mouth of the Alcantarilha River and the coastline were positioned seaward from the actual estuary during the spit formation, (iii) the former spit bar was exposed to sub-aerial conditions and underwent cementation and karstification and, (iv) strengthened by the previous lithification the spit resisted to the subsequent sea-level rise.

The age of the spit-bar remains unknown but we can hypothesize about it, based on the principles above enumerated. The exposition of the spit-bar to aerial conditions leading to its cementation and karstification most likely occurred during the last glacial cycle (MIS 4-MIS 2). This assumption agrees with (Teixeira and Pinto, 2002) that point the Late Pleistocene as the age of the paleo-shoreline materialized by the lithified spit-bar. In addition, Infantini et al. (2014) got a radiocarbon age of 17581 yr BP in the cement. However, this dating must be interpreted with caution due to probable contamination by endolithic organisms. The grains of the cement are small and non-equigranular compatible with rapid cementation in sub-aerial environments (Infantini et al., 2014). Going back in time, the spit may have been formed during the last interglacial sub-stage 5a when the mean sea level was between ca. 8.5 and 10.5 m below the present (Creveling et al., 2017).

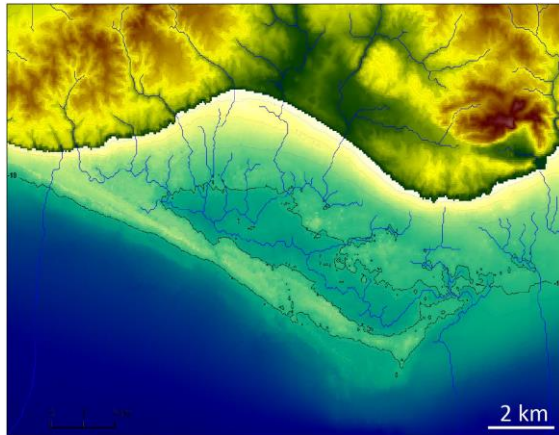


Figure 9. Underwater cemented sand spit off the Armação de Pêra Bay (after Infantini et al. (2014)).

2.3 Holocene evolution of the Armação de Pêra Bay

Between ca. 8800 and 6600 cal BP, transgressive dunes were formed coincident with the rapid sea-level rise favored by abundant volumes of available sand easing the aeolian sand recruitment from the beach (Moura et al., 2007). Cool and dry conditions between 8100 and 7900 cal BP, identified in pollen associations in the sediments of the nearby estuary of the Quarteira River (Schneider et al., 2016), could enhance aeolian activity in the area. Pereira and Soares (1994) pointed more recent ages to the aeolianites of the Armação de Pêra, between 5570 and 3920 BP. The same authors addressed the age of 3000 BP to the cliff quarrying that bounds the Bay of Lagos upcoast from de Armação de Pêra, when the mean sea-level stabilized at the same level than today (Pereira and Soares, 1993). This stabilization led to the siltation of the Alvor, Bensafrim and Odiáxere estuaries (Pereira and Soares, 1993). Teixeira and Pinto (2002) report an earlier stabilization of the mean sea level at ca. 5 ka and suggest that the Armação de Pêra Bay showed a similar morphology to the current one at 3500 BP. In good agreement with Teixeira and Pinto (2002), the work by Moura et al. (2007) found ages between 5035 ± 30 BP and 3970 ± 25 BP to the generation of a beachrock located near the Alcantarilha Rivulet mouth just where the beach berm locates nowadays (Figures 10 and 11). This means that after ca. 5000 BP the beach width

and the morphology of the bay were similar to the present and therefore not favourable to form dunes due to the small aeolian fetch (Moura et al., 2007). Thus, we can chronologically constrain the first generation of dunes (now consolidated) in the Armação de Pêra Bay, between ca. 8800 BP and no more than 5000 BP.

The Magoito paleodunes are younger than 9520 BP while São Julião paleodunes were formed previously to 7810 BP (both near Sintra, section 1.1). A phase of dune generation lasting from 7000 to 5000 BP at the Spanish SW coast in the Doñana National Park was identified by Rodríguez-Ramírez et al. (1996). Accordingly, we can point an important phase of dune construction since the early Holocene until ca. 5 ka ago. In coastal contexts, mean sea-level is a key- parameter as its relation to the sediment availability determines the response of the shoreline and the configuration, growth and type of dunes.

The global mean sea-level rose very rapidly between ca. 19 ka and 7 ka when it reached levels between 3 and 5 m below present. After 7 ka the global sea level did not change significantly (Fleming et al., 1998), being local and regional climate, isostasy, tectonic, the main causes of sea-level change.

The siltation of the estuary of the Alcantarilha Rivulet started at 7500 cal BP and showed a drop in the sedimentation rate between 6000 and 3000 cal BP (Schneider et al., 2016). These data based on palinological analysis completely agree with the previous works (above summarized) based on morphosedimentar evidences, which allow us to trace the evolution of the first generation of Holocene coastal dunes backing a beach as is the case of Armação de Pêra Bay:

1) From ca. 9 ka to ca. 5 ka (maximum) the coastal plain and beaches were wide enough to configure deflation areas able to feed dunes. The existence of an older beach beneath the first generation of dunes at the Armação de Pêra Bay, was identified in Ground Penetrating Radar (GPR) images in Costa et al. (2016) (Figures 12, 13 and 14). The rapid sea-level rise led to the elevation of the base level of the net drainage thus reducing the fluvial sediment exportation to the shore. This conceptual model is in good agreement with the results of Schneider et al. (2010) that point the beginning of the estuarine infilling at 7500 cal BP with higher accumulation rates inside the estuary until 6000 cal BP.

2) After ca. 5 ka the stabilization and lithification of dunes occurred when the beach morphology and sea level were similar to the present. Contrasted seasons are supposed to be favorable to the carbonate cement generation. From 6270 to 4290 cal BP, the *Quercus suber* and other trees typical of humid climate

conditions colonized the area, and the *Vitis vinifera*, a cultivated species was also present. After 4290 and up to 3500 cal BP the climate of the Mediterranean type led to the development of maquis and garrigue species (Schneider et al., 2016). These species develop where former broadleaf or coniferous trees receded.



Figure 10. A) artificial aperture of the connection between the Alcantarilha Rivulet and the sea; B), C) accumulation of sand in the backshore that overlies the beachrock (br). This situation is not permanent occurring mainly during winter storms.

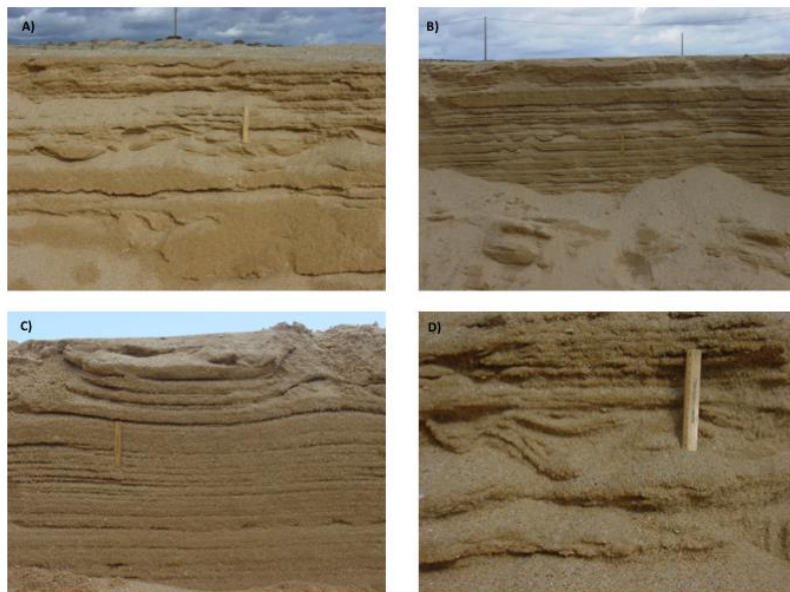


Figure 11. Sedimentary structures in the current beach berm, carved during a storm that helped to interpret the sedimentary facies of the beachrock.

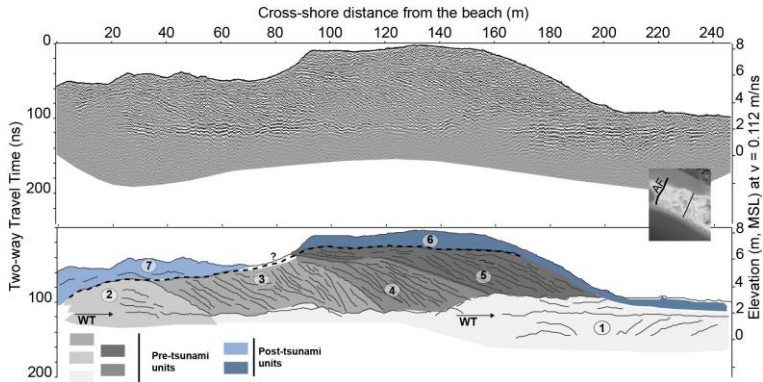


Figure 12. GPR profile measured at the vicinity of Alcantarilha Inlet. Top image presents the raw data. Lower image presents the interpretation based on the definition of major units. Dashed black line represents an erosive or deflation surface separating the pre- and post-tsunami. The numbers indicate the chronological classification (Costa et al., 2016).

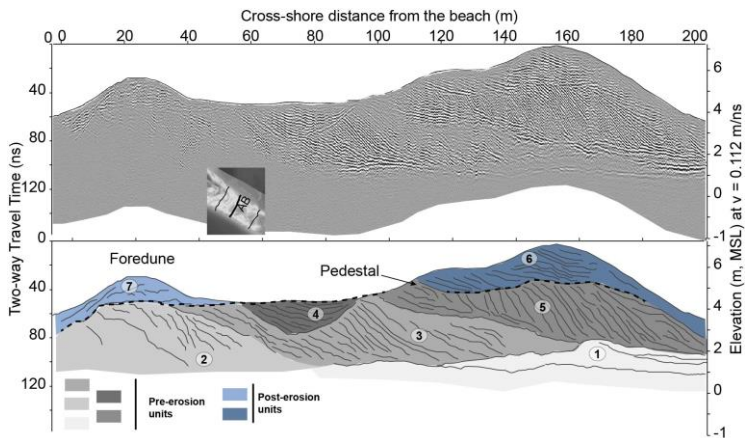


Figure 13. GPR profile measured at the vicinity of Salgados Inlet. Raw data presented in the top. Lower image presents the proposed stratigraphic interpretation based on the definition of major units. Dashed black line represents an erosive or deflation surface separating the pre- and post-tsunami units. The number labels indicate the chronological classification of the identified units labels (Costa et al., 2016).

3) After 3200 cal BP (age of the top of the beachrock), the sediment availability made possible a new phase of dune construction. Dunes of this new edification are in phase with the aeolianites, which traduces a quite constancy of the wind field and deflation area (Figure 15). This last phase of dune generation should be related to the seaward migration of the shoreline and was probably due to a sedimentary fluvial input resulting from increasing erosion in the watershed derived from increasing rain or anthropogenic impact. After 2130 cal BP cultivated plants such as cereals and *Vitis vinifera* are present in the estuarine sediments (Schneider et al., 2016).

4) The last main episode within the area is marked by the impact in the region of the 1755 Lisbon earthquake and associated tsunami. Recent works have identified tsunami deposits at Armação da Pera Bay, in Salgados (Costa et al., 2012) and Alcantarilha (Quintela et al., 2016; Schneider et al., 2010) rivulets. The coastal barrier was apparently also impacted by the tsunami whose relatively high estimated runup (around 7 m above present mean sea level) partially inundated the barrier provoking the instability of the vegetation cover. After vegetation was impacted, the sand surface was exposed to the winds and a new deflation surface was generated (Figures 12 and 13) as a consequence of the inland migration of blown sand through the formation of blowouts and parabolic dunes (Costa et al., 2016).

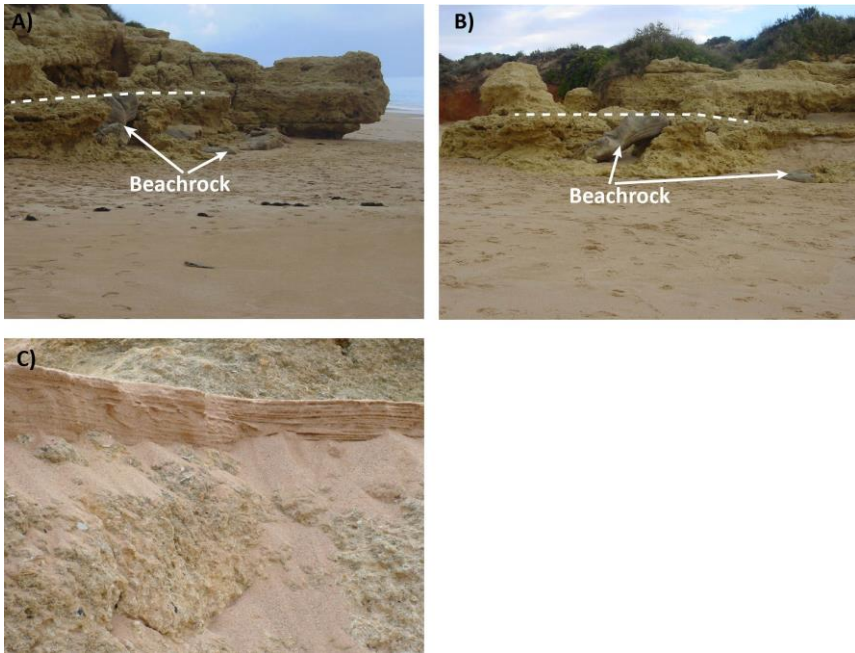


Figure 14. A) and B): Fragments of the eroded beachrock (backshore) with sands nested in the karstic holes of the cliffs exposing the Miocene Lagos-Portimão Formation. Dashed lines represents the paleo surface of the backshore. C) modern analogue.



Figure 15. A), B), and C): aeolianite crests (arrows) topographically higher than the free dunes; D) detail of the aeolianite.



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