

Wet Dune Slacks, Sea-level and Coastal Evolution in the South-western Portuguese Façade

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ABSTRACT

FREITAS, M. C., ANDRADE, C., FERREIRA, T., CRUCES, A. AND ARAÚJO, M. F. 2007. Wet dune slacks, sea-level and coastal evolution in the south-western Portuguese façade. *Journal of Coastal Research*, SI 50 (Proceedings of the 9th International Coastal Symposium), 231 – 236. Gold Coast, Australia, ISSN 0749.0208

Dune slacks are peculiar features of the Portuguese coast with evident scenic, ecological and geological value and yet the existing knowledge on their origin, evolution and dynamics is poor. A number of wet dune slacks in the South-western Iberian coast (Poços do Barbaroxa and Lagoa da Sancha) have been studied using sedimentological and geochemical proxies which, coupled with radiocarbon dating, were allowed to establish major steps of coastal evolution, environmental changes and relations with sea-level throughout the Holocene. The Barbaroxas basins are blind freshwater lakes while Lagoa da Sancha is, at present, connected with a small rivulet. The size and shape of interdune depressions reflect a palaeotopography inherited from a ridge and swale complex that accreted seaward in the Pleistocene. The interdune infill consists essentially of peat resting upon dune sand; accumulation of organic material initiated diachronically in the different slacks, between circa 7700 and 4160 cal BP, in dependence of piezometric level. At Barbaroxas this organic facies persisted until present, whereas at Lagoa da Sancha it was replaced circa 670 cal BP by minerogenic sedimentation. At the present state of knowledge it is unclear if this change represents a capture of the tributary stream, either natural or man-induced, or a massive release of top soil due to contrasting land-use in the watershed. At present, the peat surface in Barbaroxas stands 1 to 2 m above mean sea level and is fairly horizontal. Assuming similar relation in the past, then sea level should have been positioned at -3/-4 m and -0.5/-1.5 m by 7400 and 4100 cal BP, respectively. These figures are consistent with the most recent sea-level data published for the Portuguese coast.

ADDITIONAL INDEX WORDS: *Holocene, Peat, Sedimentology, Geochemistry, Piezometric level*

INTRODUCTION

Coastal dune fields may consist of a series of roughly shore-parallel ridges, with intervening troughs or slacks. The ridges usually correspond to beach-foredune pairs accreted in a prograding context and developed in a favourable condition of the local sediment budget. Dune slacks are fed by rain, surface and groundwater (GROOTJANS *et al.*, 2004) and are characterized by a pattern of pronounced annual fluctuation of the water table, which controls the wetness-dryness of the environment.

Wet dune slacks are widely but locally distributed throughout the coastal zone of the EU and Portugal is no exception. They constitute peculiar features of the south-western coast with evident scenic, ecological and geological value and yet the existing knowledge on their origin, evolution and dynamics is poor. This paper presents a sedimentological and geochemical study of the material accumulated in four dune slacks and the results are used to reconstruct aspects of the Holocene evolution of this coast.

The field area is located about 80 km south of Lisbon, in the southern half of the Tróia-Sines embayment (Fig. 1). The dune slacks of Poço do Barbaroxa de Baixo (BB), Poço do Barbaroxa

do Meio (BM) and Poço do Barbaroxa de Cima (BC) correspond to small (0.033, 0.016 and 0.027 km² respectively) and shallow freshwater lakes occupying segments of the same trough defined between N-S trending dune ridges of the Old Dune Complex (ODC) (Fig. 1). Further south, Lagoa da Sancha (LS) develops across 0.12 km² and is a peculiar freshwater lake occupying another slack of the ODC that retains the general N-S elongation of the containing ridges but is offset to the west in relation to the former features. The singularity of LS is its connection to the Barranco dos Bêbedos rivulet, which extends further upstream for about 15 km and develops a 35 km² wide watershed mainly in Plio-Pleistocene bedrock. The northern tip of the western ridges limiting the Barbaroxas and LS are cut by the present-day NE-SW aligned beach-foredune system, where the dune crest decreases in elevation. The different orientation of the actual and Pleistocene coastal features indicates variation in the equilibrium conditions of this coastal cell.

All slacks in general are flooded and the water level varies seasonally, as a function of the piezometric surface. During the rainy season the lake levels rise but the water column never exceeds about 1 m and during the dry season lake levels drop and occasionally total dryness can occur. Input of marine water is

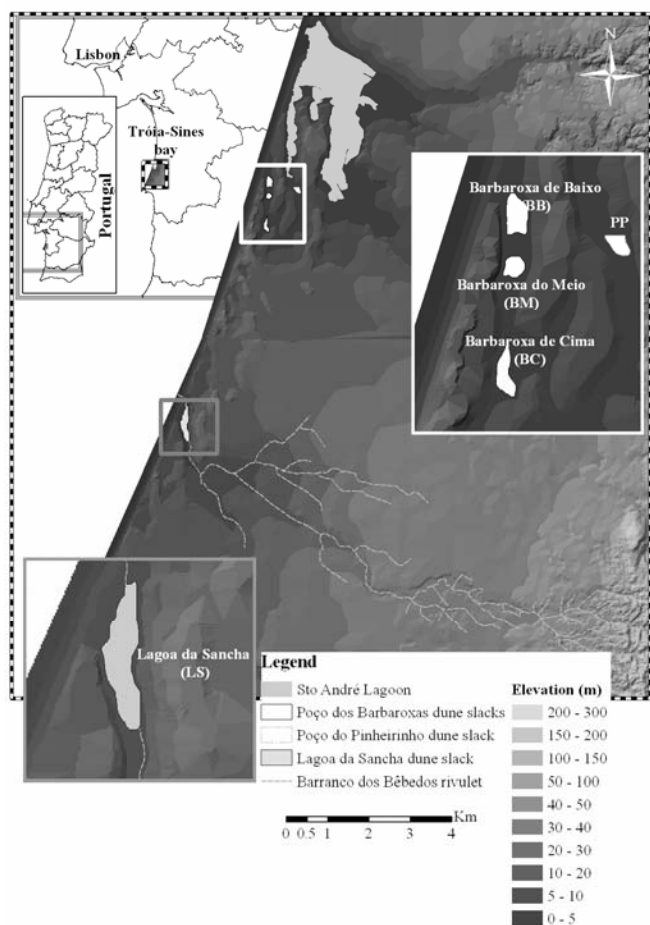


Figure 1. Location of dune slacks and detail of morphological framework.

sporadic and restricted to BB and LS, where the low height of the barrier separating the lowland from the sea allows overwash during severe storms. Water availability promotes plant growth (such as *Phragmites australis* and *Bolboschoenus maritimus* at LS and *Phragmites australis* and *Cladium mariscus* at Barbaroxas), favouring the accumulation of organic matter and the development of peat.

METHODS

In each wet dune slack, one coring transect was selected, perpendicular to the maximum axis of the depression (Table 1).

Hand-driven equipment (gauge auger, Dachnowsky, van der Staay and peat samplers) was used to perform boreholes, allowing reconstructing E-W cross-sections in each depression (Table 1). Each sedimentary sequence was described macroscopically in the

field and connected to a national geodetic grid to obtain the height of the topographic surface in relation to mean sea level (MSL). In each transect, one central borehole was elected as representative of the infill and totally sampled; a number of supplementary samples collected from other boreholes were used to refine the lithostratigraphic characterization. In the laboratory the sedimentary sequences were photographed, described and sampled for sedimentological and geochemical studies. The sedimentary analysis included: pH, determined by the electrometric method and classified following Pratolongo (in COSTA, 1991); organic matter (OM), determined through loss on ignition (LOI) at 500°C during 3h; CaCO₃ content, evaluated by eye inspection of reaction with diluted HCl; texture, determined by wet sieving (63 µm). In sandy material, sieving was performed and the graphic parameters of the size distribution were computed.

Geochemical analyses were also performed in the sedimentary sequence of LS. The concentration values of 10 elements (Mg, Al, Si, S, Cl, K, Ca, Br, Rb, and Sr) were determined by Energy Dispersive X-Ray Fluorescence Spectrometry following ARAÚJO *et al.* (2002) and using the certified reference materials GSD-9 and SRM2704. Elements have been grouped according to their significance. The geochemical signature of texture and composition relied essentially upon downcore variation of Si, Al, Ca, Sr, K, Rb, and Mg; Cl, Br and S were selected as proxies of palaeosalinity (CHESTER, 1999; LÓPEZ-BUENDÍA *et al.*, 1999).

The AMS ¹⁴C age of three peat samples was determined and calibrated by Beta Analytic Inc., USA.

RESULTS

The sedimentary infill found in all wet dune slacks presents an asymmetric lens shape, with a western steeper boundary leaning against the dune lee slope.

Sediments

The sedimentological and geochemical results (Table 2 and Figs. 2 and 3) allow considering two and three different units in the infill of the Barbaroxas and Lagoa da Sancha dune slacks, respectively. The basal one (Unit I) is essentially sandy, Unit II consists mainly of peat and Unit III at LS is basically muddy. Calcium carbonate is absent in all sediments.

- Unit I – This unit can be further divided in two sub-units:
 - Sub-unit Ia - It consists essentially of coarse to medium quartz sand (reflected in the higher Si and lower Al, Ca, Sr and Mg contents) with moderate sorting; this sediment is hyperacid to sub-alkaline at BB and BM and hyperacid to sub-acid at BC and LS and OM is always vestigial. S, Br and Cl show the lowest values of the whole sedimentary sequence.

Table 1: Characterization of the interdune transects, boreholes and number of analysed samples.

Dune slack	Transect extension (m)	Number of boreholes	Maximum borehole depth (m)	Number of samples		
				Sedimentology	Geochemistry	¹⁴ C
BB	134	13	4.50	48	0	1
BM	146	19	3.55	51	0	1
BC	110	14	4.10	54	0	0
LS	165	14	4.70	92	12	2

Table 2: Sedimentological characteristics of the interdune infill of BB, BM, BC and LS.

Dune slack	Unit	Max. thick.(m)	pH	% O.M.	%>63 µm	Mz (φ)	σ1 (φ)
BB	II	4.22	3.3 – 5.0	19.7 - 93.7	58 - 97	*	*
	Ib	*	3.1 – 5.4	2.0 – 17.8	92 - 99	0.39 - 0.95	0.70 – 1.04
	Ia		3.4 - 7.7	0.0 – 1.0	93 - 100	0.66 - 1.46	0.62 -0.81
BM	II	1.89	3.3 to 4.9	15.1 – 85.5	29 - 96	*	*
	Ib	*	4.0 – 6.6	2.4 – 8.6	40 - 100	-0.05 - 1.13	0.50 - 0.92
	Ia		3.6 – 7.2	0.0 – 1.7	79 - 97	0.37 - 2.11	0.43 - 1.01
BC	II	3.85	3.4 - 5.9	11.0 – 98.8	42 - 99	*	*
	Ib	*	3.9 – 5.1	2.4 – 9.9	93 - 99	0.12 - 1.00	0.56 – 0.73
	Ia		5.1 – 5.9	0.0 – 0.6	0 - 100	0.12 - 1.43	0.56 – 0.81
LS	III	1.04	2.2 – 3.2	11.8 – 34.4	1 – 10	*	*
	II	2.13	1.9 – 5.0	25.3 – 88.5	7 – 94	*	*
	Ib	*	2.3 – 5.3	1.0 – 12.7	85 – 99	0.05 - 1.29	0.67 - 0.98
	Ia		2.5 – 5.1	0.0 – 1.7	83 - 99	-0.72 - 1.36	0.51 - 2.03

* Not applicable

- Sub-unit Ib - It consists essentially of quartz sand similar in texture and geochemical signature to sub-unit Ia. This sediment is hyperacid to sub-acid and OM is higher than in the underlying sub-unit, reaching almost 20%.
- Unit II – It is essentially formed by hyperacid to acid peaty sediments and the organic component is made of fermented plant debris of variable dimension; most of the peaty horizons consist of coarse fragments of stems, leaves and roots while others include mixtures of mud and fine to very fine organic fibres in variable proportions. This contrast comes out in figure 2 as varying proportions of the > 63 µm size fraction. Wood fragments were occasionally found but charcoal was never observed. In the majority of the samples, the OM content exceeds 50%. The top horizon of the peat is usually enriched in quartz sand and scattered grains of this mineral were found within some peaty layers (which lower significantly the OM content). In this unit, the lowest values of Si, Al, K and Rb are found, together with enrichment in Ca, Sr and palaeosalinity proxies (Br, Cl and S attain maxima of 215 mg/kg, 2.4% and 12%, respectively).
- Unit III – This unit is exclusive of LS and is made of hyperacid mud (% < 63 µm exceeding 90%), essentially minerogenic silt, with OM content less than 35%. K and Rb show the highest values, Ca is almost absent and palaeosalinity proxies are present but with less expression in comparison with Unit II (Br, Cl and S attain 85 mg/kg, 0.2% and 4%, respectively).

Dating

The radiocarbon dates obtained in this work for BB and BM (Table 3) added to the dating reported in MATEUS (1999) for the contact between basal sand and peat in the deeper part of BC (circa 7700 cal BP) indicate that the infill of BB and BC are reasonable contemporaneous and started earlier than in BM (4160 cal BP). At LS the organic filling up started circa 5400 cal BP and

remained until 670 cal BP, when the minerogenic sedimentation took over.

DISCUSSION AND CONCLUSION

The infill of the studied wet dune slacks is essentially peaty and muddy and rests upon sand (Fig. 4), which is similar in texture to the surface sediment of the western adjacent ridge (FERREIRA, 2006; FERREIRA *et al.*, 2006). The shape of the trough accommodating the infill is compatible with the seaward accretion of pairs of successive beach-foredune ridges, the western margin of the basins corresponding to the precipitation face of the younger feature.

The change in facies between the lower sand and upper organic materials suggests the onset of a depositional environment dependent of frequent flooding and ponding of water that allowed the development and the *post-mortem* accumulation of abundant plants and plant debris, and inhibited post depositional oxidation of the organic matter. This sedimentation (Unit II) is impoverished in minerogenic components, indicating independency of an organized watershed. The palinological study of BC (MATEUS, 1999) indicates that this flooding persisted in dependence of fresh water and it is reasonable to assume a relationship between the mean lake level/ piezometric surface of the free aquifer formed by the coastal sand and MSL. The beginning of the organic deposition in the dune-slacks depends on the palaeotopography. It started earlier in BC and BB (circa 7700-7400 cal BP) due to deeper accommodation space, and later in BM (circa 4100 cal BP), and LS (circa 5400 cal BP), which stand at a higher elevation.

Sediments of LS Unit II show maximum concentration values in marine geochemical proxies (Fig. 3) and this suggests influence of ocean water during deposition of this unit. The absolute concentration values are similar to the ones found in surface sediments accumulating at present in the two N-S elongated and confined depressions associated to Santo André lagoon (Fig. 1). In these depressions, sporadic input of marine water occurs, rising the water salinity (CRUCES, 2001) and the confinement favours

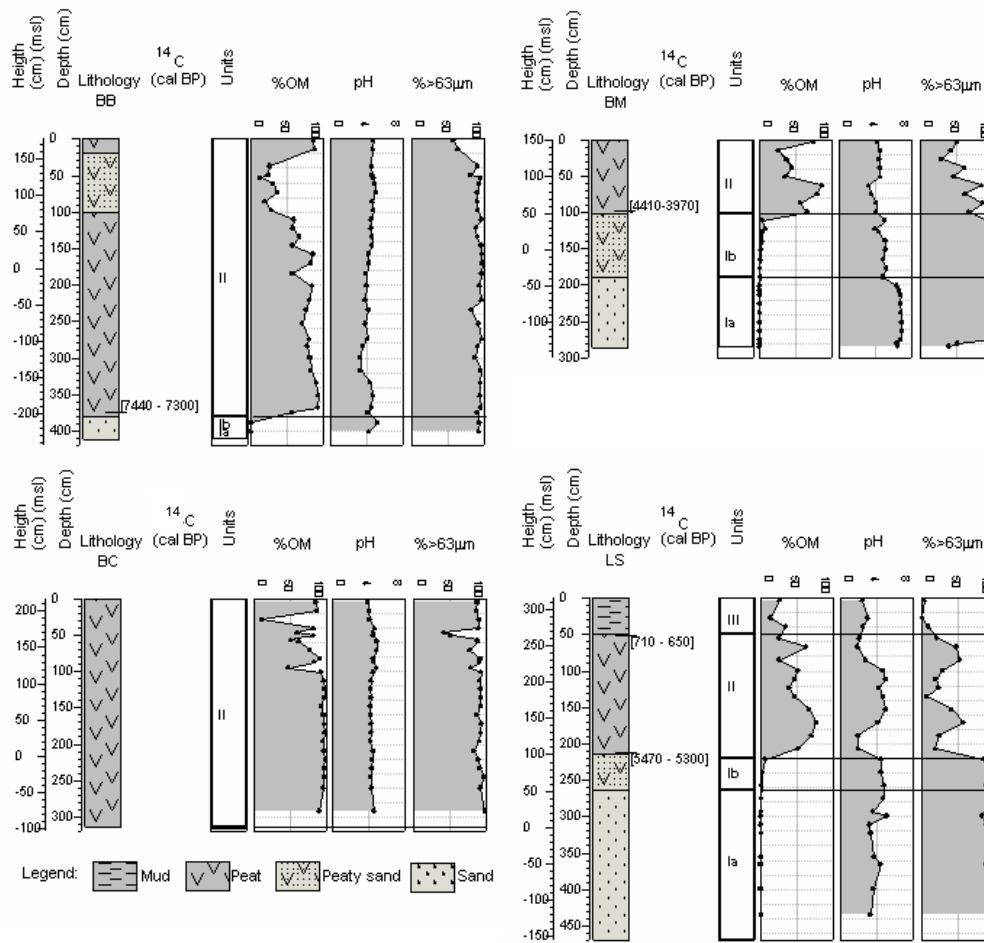


Figure 2. Vertical variation of texture and composition in Barbaroxas and LS infill.

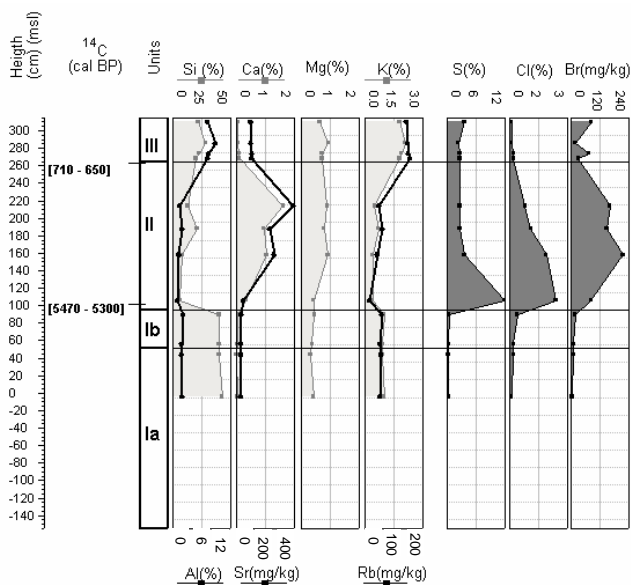


Figure 3. Downcore variation of elements at LS.

trapping of those elements in sediment. The study hypothesizes similar environmental conditions in LS during deposition of Unit II, the infrequent addition of marine water being guaranteed by overwash.

Unit II sediments accumulated until present in Poços do Barbaroxa but, at LS, a different litho and chemofacies (Unit III) developed after 670 cal BP. The transition to this upper unit is abrupt and marked by pronounced decrease in OM and partial replacement of organic material by minerogenic silt and clay. Unit III still preserves a marine signal, which reflects the proximity of the ocean and infrequent mixture of fresh with marine water by overwash. The texture and composition of sediment in Unit III reflects terrigenous sources in the watershed of Barranco dos Bêbedos. It is unclear if this change represents a capture of the stream, either natural or man-induced, or a massive release of top soil due to contrasting land-use in the watershed.

The scarce literature on dunes of the ODC (e.g. GOMES, 1992) indicates a Pleistocene age for this complex, which might have accreted seaward in relation with a falling sea-level preceding the Last Glacial Maximum. The ¹⁴C date of > 30000 BP recently obtained by the authors circa 6 m below surface in organic material from a buried deposit cored from Poço do Pinheirinho (PP) (Fig. 1), located east of the Barbaroxas slacks, and is compatible with this.

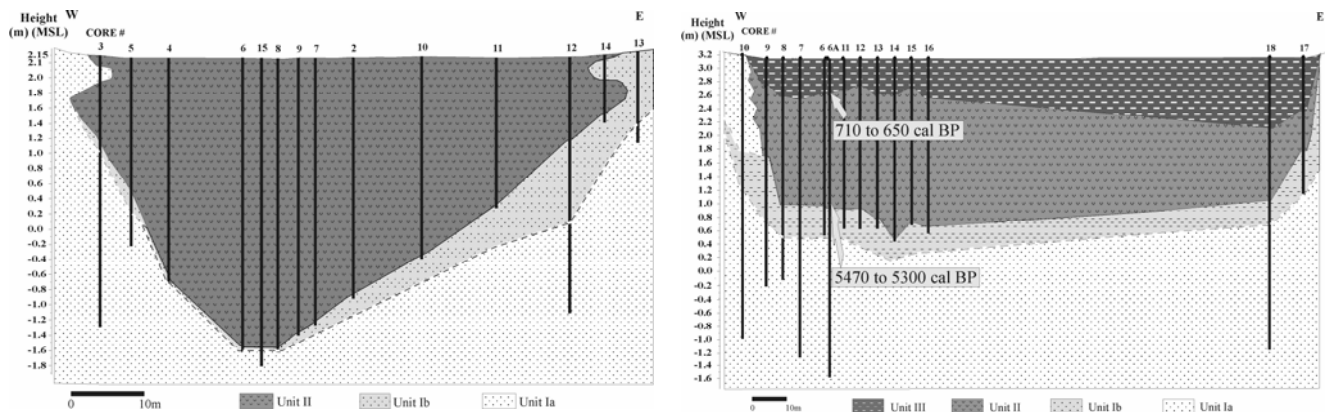


Figure 4. BC and LS dune slacks infill.

Table 3: Radiocarbon dates obtained in this work.

Dune slack	Height (m) MSL	Lab code (Beta -)	Conventional ^{14}C age (BP)	cal age BP (2σ)	Intercept point cal BP
BB3 3.74-3.75	-1.97 to -1.98	198014	6470 \pm 40	7440 to 7300	7420
BM3 0.96-0.98	0.56 to 0.54	206769	3790 \pm 70	4410 to 3970	4160
LS6 0.52-0.54	2.63 to 2.61	19645	730 \pm 40	710 to 650	670
LS6 2.13-2.15	1.02 to 1.00	19646	4650 \pm 40	5470 to 5300	5440; 5410; 5320

According to TEIXEIRA *et al.* (2005) MSL rose from about -5 m to almost its present position between 7500 and 4000 cal BP. At present, the peat surface in Barbaroxas stands 1 to 2 m above MSL and is fairly horizontal. If we assume a similar relation in the past, then, by 7400 and 4100 cal BP, MSL should be positioned at -3/-4 m and -0.5/-1.5 m, respectively; these figures are in general agreement with the sea-level curve mentioned above.

ACKNOWLEDGEMENTS

This paper is a contribution to the Research Project PDCTM/P/MAR/15231/1999-FCT/FEDER of the Portuguese Foundation for Science and Technology (FCT). The authors thank A. Vidal, V. Encarnação, B. Ribeiro, V. Lopes and J. Ferreira for assistance during fieldwork.

LITERATURE CITED

- ARAÚJO, M.F., JOUANNEAU, J.-M., VALÉRIO, P., BARBOSA, T., GOUVEIA, A., WEBER, O., OLIVEIRA, A., RODRIGUES, A. and DIAS, J.M.A., 2002. Geochemical Tracers of Northern Portuguese Estuarine Sediments on the Shelf. *Progress in Oceanography*, 52, 277-297.
- CHESTER, R., 1999. *Marine Geochemistry*. Oxford: Blackwell Science, 506p.
- COSTA, J. B. DA., 1991. *Caracterização e constituição do solo*. Lisbon: Serviços de Educação da Fundação Calouste de Gulbenkian. 6th ed., 527p.
- CRUCES, A., 2001. Estudo a micro e meso-escala temporal de sistemas lagunares do SW alentejano (Portugal): as lagoas de Melides e Santo André. Lisbon, Portugal: University of Lisbon, Master's thesis, 228p.
- GOMES, N.M.N., 1992. Dinâmica dunar no arco Tróia-Sines (Portugal). Lisbon, Portugal: University of Lisbon, Master's thesis, 121p.
- GROOTJANS, A.P., ADEMA, E.B., BEKKER, R.M. and LAMMERTS, E.J., 2004. Why young coastal dune slacks sustain a high biodiversity. In: MARTÍNEZ, M. and PSUTY, N., (eds.), *Coastal dunes, ecology and conservation*. Ecological studies, 171, Berlin and Heidelberg, Germany: Springer-Verlag, pp. 85-101.
- LÓPEZ-BUENDÍA, A.M.; BASTIDA, J.; QUEROL, X. and WHATELEY, M.K.G., 1999. Geochemical data as indicators of paleosalinity in coastal organic-rich sediments. *Chemical Geology*, 157, 235-254.
- MATEUS, P.F.Q., 1999. *Ecologia Histórica da Paisagem do Noroeste Alentejano*. Lisbon, Portugal: University of Lisbon, Ph.D. thesis, 300p.
- FERREIRA, T.M.A., 2006. *Evolução paleoambiental da Lagoa da Sancha (Litoral SW português) com base no estudo sedimentológico e de diatomáceas (Bacillariophyceae)*. Lisbon, Portugal: University of Lisbon, Master's thesis, 142p.
- FERREIRA, T., CRUCES, A., FREITAS, M.C. and ANDRADE, C., 2006. Holocene infill of Poços do Barbaroxa dune-slacks (SW Coast

of Portugal). *5º Simpósio sobre a Margem Ibérica Atlântica*, (Aveiro, Portugal), in press.

TEIXEIRA, S.B., GASPAS, P. and ROSA, M., 2005. Holocene sea-level index points on the Quarteira coast (Algarve, Portugal). *In: FREITAS, M.C. and DRAGO, T. (eds), Proceedings, Coastal Hope 2005 – Iberian Coastal Holocene Paleoenvironmental Evolution*, (Lisbon, Portugal), pp. 125-127.