Carbonate Dunes as Heritage Features in Mainland Portugal: A Review

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Abstract

Carbonate dunes are relevant coastal landforms and record sedimentary and geomorphological past conditions, frequently related to archaeological and paleopedological evidence. The study of these landforms contributes to the comprehension of paleoenvironmental and paleogeographical modifications. The carbonate dunes are common features on Mediterranean coasts, but in the international literature, they are almost unknown in the littoral of Portugal. The excellent state of the art presented by Brooke (Brooke Earth-Science Reviews 55:135–164, 2001) only mentions the Eolianites of Madeira Island (Goodfriend et al. Palaeogeography, Palaeoclimatology, Palaeoecology 120:195–234, 1996).

Keywords

Climatic fluctuations • Coastal dunes • Paleoenvironment • Geodiversity • Portugal

1 Introduction

It is now possible to say that carbonate dunes are well represented in Portugal, and the studies developed so far allow us to define its: (i) geographical distribution; (ii) the morphological eolian features and some of their conditioning factors (namely the infra-dune morphology and wind direction and speed), (iii) the stratigraphic framework, the main aeolian episodes and (iv) that most of them are cut in cliff, as expected being inherited (Ramos-Pereira, 1987; Ramos-Pereira & Angelucci, 2004).

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2 Methodological Approaches and Tools

The study carried out includes an extensive field survey (all the Portuguese mainland coast), identification of the different eolian landforms, the structure of the eolianites, analysis of the sets and laminae, samples collected for sedimentological treatment at the laboratory (carbonate content, granulometry, sedimentological parameters), and dating of interlayer soil content, shells and the sands, by radiocarbon (Ramos-Pereira, 1987; Ramos-Pereira & Angelucci, 2004; Soares et al., 2012) (OSL not yet available).

3 Results

- The Occurrence

The aeolianites and the dunes remnants are present in the middle south of the Western coast and in Algarve (Fig. 1). They can be present up to 3 km inland and as islands a few km from the coastline. They cover distinctive bedrock; limestones, sandstones and turbidites (shales and greywackes).

- The Aeolian Features Present

The remnants of these heritage features comprise (i) aeolian slopes as climbing dunes against fossil cliffs or leeward over sheltered slopes, (ii) transgressive sand sheets, (iii) dune field with almost four recognized ridges of transversal dunes (in the SW coast), (iv) shapeless dunes, most of them partially eroded by the sea, by fluvial entrenchment or simple splash remaining only rhizoliths.

In the Lisbon Peninsula, the aeolianites are sparse because of natural erosion and anthropogenic land use. They are absent in the middle North of the mainland country (Fig. 1). On the southwest coast, they are protected under a Natural Park.

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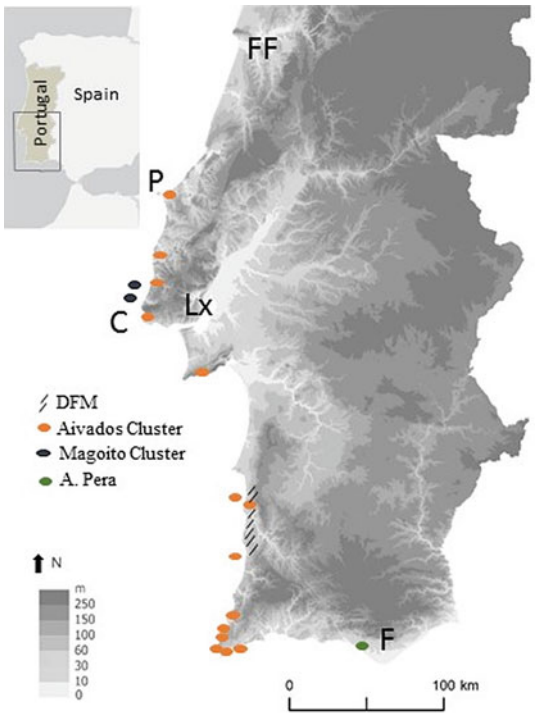

Fig. 1 Carbonate dunes along the Portuguese coast. DFM- Dune Field of Malhão, C—Cascais, F—Faro, FF—Figueira da Foz, Lx-Lisboa, P—Peniche. For the legend, please see Fig. 2

- The Structure of the Aeolianites and the Wind Drivers

The aeolianites comprise quartz grains of 0.67 and 0.14 mm and fragments of shells and, sometimes calcareous oolits recognized in the Peninsula of Lisbon, all cemented by calcium carbonate. It can reach 87% of the sample and is never under 60%.

The structure is complex: tubular-planar bedding with thick sets (especially in the SW), wedge bedding and sometimes avalanche structures. In the sand sheet megaripples are recognized. Field work was performed to analyse the sets and laminae, which show a dominance of northwesterlie winds (N 360°–300°) in 85% of the measure's laminae being 5% N 360°–350°. Some laminae (5%) indicate westerly winds (310°–260°). In the SW and S coast some laminae reveal southwest winds (10%), namely in some sheltered bays.

- Aeolian Mobilization Phases

The aeolianites can be over and under archaeological layer or soils, which allow establishing their relative radiocarbon date. Several AMS results of the aeolianites provide numerous data, all calibrated and analysed with ocean reservoir effect (Soares et al., 2012). OSL is not yet available.

Despite some uncertainty, existing data and stratigraphic and geomorphic framework permit to identify four main phases of aeolian mobilization (after carbonated), from the Middle Pleistocene to the Holocene: the most ancient probably of the Middle Pleistocene (MIS6, no data available) (Ramos-Pereira & Angelucci, 2004); one aeolian phase is recorded in the Upper Pleistocene, during MIS3; and two during the Holocene, one in Boreal-Atlantic times and a more recent one (central Algarve) (Fig. 2). The older phase is only represented in the SW coast (DFM (Fig. 1); the second one called Aivados Cluster is represented also in Lisbon Peninsula and, the radiocarbon dating reveal an aeolian episode between 42.5 ky and 37 ky (Monge Soares et al., 2006; Ramos-Pereira, 2005; Schröder-Lanz, 1971). In the Lisbon (Lx) Peninsula, with the so called Magoito Cluster (Fig. 2), the aeolian phase arise from 9.5 and 5.6 ky (Daveau et al., 1982; Monge Soares et al., 2006; Ramos-Pereira, 2005; Ramos-Pereira & Angelucci, 2004; Soares et al., 2012). The younger one is present in central Algarve and has 2.5 ky (Ramos-Pereira & Soares, 1994).

In all these phases aeolian accumulation matches with low standing sea level episodes (Gibbard & Hughe, 2021), exception made to the younger one that is covered by the foredune in equilibrium with present day sea level (Ramos-Pereira & Soares, 1994).

- Changes undergone by the Dunes/Aeolianites

In the SW coast, the DFM have imprints of *Cervus* and *Elephas (Palaeoloxodon) antiquus* (Carvalho et al., 2020) (e.g. deer and elephant).

The climatic amelioration during MIS5 allows the installation of a vegetation cover (even trees), shown by the abundance of rhizolhits and calcified stem of trees and the beginning of the downward percolation of rainwater in a wet environment, with diagenetic processes, which mobilizes the carbonate from bioclasts, after redepositing as interstitial cement[3]. The DFM was submitted to tectonic deformation with a subsided compartment near the sea. This compartment was invaded by the sea, as shown by the partial destruction of the DMF and a marine deposit (Ramos-Pereira & Ramos, 2020).

The MIS4 is represented by fluvial erosion with small grooves in the aeolianites and a deep karstification affecting the aeolianites along the scarp fault.

The MIS3 is characterized by temperature and precipitation fluctuations, although with low sea level. During this stage was built what we call the Aivados Cluster, present not only in the SW coast but also in Estremadura Peninsula (Fig. 1). The available data evidence an intense mobilization between 42.5 and 37 ky (Monge Soares et al., 2006; Ramos-Pereira, 1987, 2005; Ramos-Pereira & Angelucci,

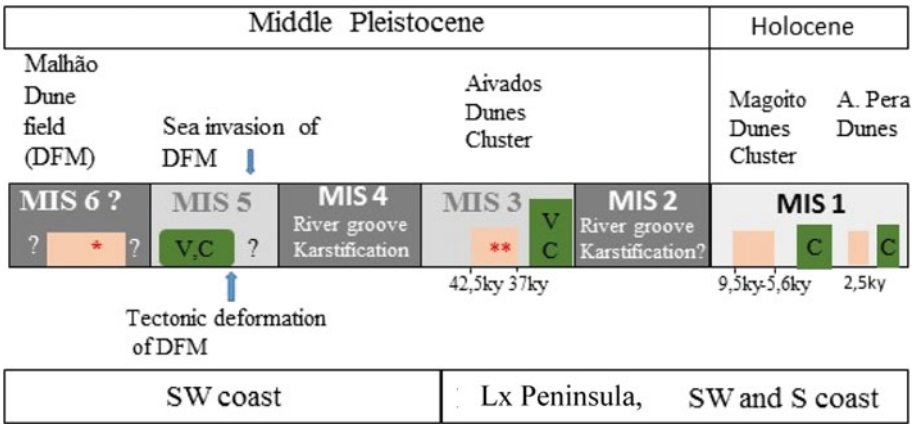

Fig. 2 Most important aeolian mobilization, light pink (Fig. 1 for the location), episodes of vegetation cover (V) and, carbonation (C) during the Middle Pleistocene and Holocene. * for the imprints of *Elephas antiquos* and ** also with *Bifidipes* imprints

2004; Schröder-Lanz, 1971; Soares et al., 2012). In SW coast they have imprints *Bifidipes* (hoofprint) and *Elephas antiquus*, (Carvalho et al., 2020) though the imprints of the latter must be confirmed (Mol et al., 2007). The carbonation must have occurred during a positive amelioration at MIS3.

The late glacial maximum promote fluvial erosion and in a particularly place deep karstification in the W coast.

- Final Remarks

The data emphasize possible synchronicity of aeolianite formation with other mid-latitude regions, a strong correlation with palaeoclimatic proxy-data and the recurrence of episodes of aeolianite formation, matching specific climatic and environmental conditions. They fit a low stand sea level, but with sea environmental proximity to permit a wet atmosphere, although under xeric conditions in such a way that the water remains inside the sands and is not exported out of them. This can explain the climatic threshold on the Western coast of the country, aeolianites being absent in the N coast with Atlantic climatic influences. The sand abundance decreased during the analysis period, suggesting a narrowing of sand sources, mainly from NW and W. The same trade is shown by the carbonation degree. The Pleistocene dunes have been covered by vegetation, and the old ones even with trees. DFM has been tectonically faulted, partially invaded by the sea, uncertain if this invasion was caused by a high stand of the sea (MIS 5e?) or the down lift of the compartment.

Further research is needed even as a robust dating with other techniques.

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