

## PRESENT-DAY HYDRO-AEOLIAN PROCESSES IN THE SERRA DO GERÊS, NW PORTUGAL

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### Abstract

Micro-scale features developed in coarse sand deposits present in the higher interfluvies of the Serra do Gerês are studied. Two main types of features were identified: simple lag-surfaces and micro-accumulations against obstacles. A morphological typology for the later is presented. The morphological study, grain-size analysis and comparison of the aspect and location of the micro-accumulations against obstacles with shrub anemomorphisms allowed a first genetical interpretation for the studied features. This approach emphasises the importance of water and wind erosion in the Serra do Gerês higher areas. The role of water erosion in the genesis of simple lag-surfaces and micro-accumulations against obstacles is mainly by washing of the fines. Wind erosion acts twofolds through accumulation and deflation of fines.

**Key-words:** Hydro-aeolian processes, lag-surface, micro-accumulation against obstacle, Serra do Gerês, mountain environments.

### Resumo

*Processos hidro-eólicos actuais na Serra do Gerês* - O estudo geomorfológico de pormenor de um interflúvio localizado próximo do sector mais elevado da Serra do Gerês (Outeiro do Pássaro), tornou evidente a importância morfogenética do vento nas áreas mais elevadas daquela serra. Foram estudados depósitos de areia granítica grosseira localizados nas áreas mais expostas ao vento. Dois tipos principais de depósitos foram identificados: as *lag-surface* simples e as micro-acumulações de encontro a obstáculos.

As *lag-surface* simples correspondem a depósitos de areia granítica, normalmente presentes em áreas aplanadas, como pequenos canais de escoamento, sectores planos de vertentes graníticas ou pias amplas e com rebordo degradado. A superfície destes depósitos é constituída por uma fina camada de areia grosseira e grânulos, que contrasta com o material subjacente, mais fino e heterométrico. Os dados discutidos no presente artigo apontam para que sejam superfícies resultantes da lavagem dos sedimentos mais finos, embora seja possível que o vento, através da deflação, também esteja na sua origem.

As micro-acumulações de encontro a obstáculos são os depósitos que apresentam uma génese mais complexa. Tratam-se de pequenos taludes decimétricos a métricos que se acumulam de encontro a um obstáculo, que pode ser um afloramento rochoso ou um pequeno arbusto. No que respeita à morfologia, foram identificados três tipos principais deste depósito: as micro-acumulações incipientes; as línguas de grânulos; e as línguas de grânulos com *blow-out*. Os primeiros são acumulações de 10 a 20cm do topo à base, que bordejam muitas vezes pequenos canais de escoamento. Apresentam-se normalmente depositados de encontro à vegetação que os limita e podem-se estender lateralmente por vários metros. As línguas de grânulos surgem associadas às micro-acumulações incipientes, constituindo sectores com um nítido desenvolvimento longitudinal, que corresponde a um avanço sobre a vegetação. Têm na base, cerca de 20 a 30cm de largura, estreitando para o topo, sendo o comprimento geralmente inferior a 1m. Quanto às línguas de grânulos com *blow-out*, estas correspondem a uma ampliação das anteriores, originada essencialmente pelo avanço dos grânulos, podendo chegar a 1,5m de comprimento e a uma largura de 1m. Podem alargar para o topo e são raras na área estudada.

Uma característica importante das micro-acumulações de encontro ao obstáculo que é facilmente observável no campo, é a diferença granulométrica entre o material presente à superfície e a camada subjacente. O material superficial corresponde a uma camada homométrica de cerca de 1cm de espessura de areia grosseira e grânulos, enquanto a camada sub-superficial é heterométrica, mais fina e rica em matéria orgânica. A análise granulométrica das duas camadas em vários depósitos, e em posições distintas no mesmo depósito, possibilitou a sua caracterização e confirmou as observações macroscópicas de campo. Permite ainda identificar um aumento na dimensão dos grãos, longitudinalmente, do topo para a base das micro-acumulações.

Foi ainda elaborada uma cartografia de pormenor das micro-acumulações de encontro ao obstáculo na área estudada, tendo sido identificada a exposição das micro-acumulações. Estas apresentam uma orientação exclusiva entre Sul e Sudoeste, a qual corresponde às anemomorfoses de arbustos de *Calluna vulgaris* e *Erica spp.* que foram cartografadas ao longo de um percurso escolhido na área de estudo.

Considerando os dados morfológicos, granulométricos e os resultantes da cartografia de pormenor, é proposto um modelo para a génese das micro-acumulações de encontro ao obstáculo. Seria necessária uma fase inicial de acumulação, de origem eólica, que originaria um talude de encontro a um obstáculo. Seguir-se-ia a deflação e lavagem dos sedimentos mais finos da sua superfície, dando origem a uma película grosseira, com um grânulo de espessura. Para que esta película se torne mais espessa, é necessária a ocorrência de novos episódios de acumulação, intercalados com episódios de lavagem e deflação dos sedimentos mais finos anteriormente acumulados sobre a película grosseira.

O micro-modelado estudado ilustra de forma clara a importância do vento como agente morfogenético nas áreas elevadas e com fraca cobertura vegetal da Serra do Gerês.

**Palavras-chave:** Processos hidro-eólicos, *lag-surface*, micro-acumulação de encontro ao obstáculo, Serra do Gerês, ambientes de montanha.

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## 1. INTRODUCTION

The Serra do Gerês is a granite mountain range in Northwest Portugal, located between 7°55'W and 8°10'W and 41°41'N and 41°53'N (Figure 1). It reaches a maximum altitude of 1545 m a.s.l. and the higher interfluvies form a plateau that gently slopes to Southwest, between about 1500 and 900 m a.s.l. This plateau is dissected by deep valleys following tectonic lineaments. The valleys are in most cases V shaped reflecting tectonic uplift conditions and the importance of linear erosion processes.

A very significant characteristic in the Serra do Gerês is the difference in the vegetation between the upper (upper slopes and plateaus) and the lower areas (lower slopes and valley bottoms). The latter have usually a well developed vegetation cover in many cases with forest, while the former are almost totally naked areas where granite is directly exposed to sub-aerial processes. In the plateaus only small shrubs grow, normally in a discontinuous fashion, being continuous vegetation restricted to small and scattered accumulation basins. In this way, the mesoscale vegetation pattern reflects the overall distribution of bare-rock vs weathering mantles, being the former dominant in the higher parts of the mountain and the latter in the lower parts. The border between both, although variable is normally at about 800/900 m a.s.l.

The position of the Serra do Gerês in the Portuguese Northwest is very significant to its climatic characteristics. The area benefits from the influence of wet Atlantic air masses and also from a marginal Mediterranean climate. Thus it is extremely wet

with dry and warm summer intervals. Mean annual precipitation reaches 3500 mm in the upper areas. The mean number of days with rain varies from 110 to 160 per year (DAVEAU *et al.*, 1977).

The significance of water erosion processes can be estimated from the maximum daily rainfall. A maximum of 337 mm in one day was measured at Juncêda's rain gauge, while intensities between 126 and 200 mm per day correspond to the 5 year return period. Most of the precipitation falls in winter, autumn and spring, being snowfall low and almost insignificant as a morphogenetic agent.

Thermal records are few and absent to the higher areas. The meteorological station of Gerês (480 m a.s.l.) with a six year record shows a simple thermal regime with a mean annual temperature of +14°C. In August the mean is +21°C and in February +8°C. An estimation of the thermal characteristics of the higher areas by DAVEAU and col. (1985) point to more than 40 days with minimum air temperature under 0°C and to an average minimum temperature of the coldest month lower than +1°C. For summer temperatures the same authors point to less than 20 days with maximum above +25°C and maximum mean temperature of the warmest month under +23°C. Unfortunately no other safe information on climate characteristics of the upper areas exists.

The study of the morphogenesis in the Serra do Gerês revealed an altitudinal zoning of the active morphogenetic processes in the mountain range (VIEIRA, 1995). Three distinct belts were identified: the forest belt; the intermediate slope belt; and the upper belt in which this paper focus. This belt includes the bare-rock plateau surfaces and appears

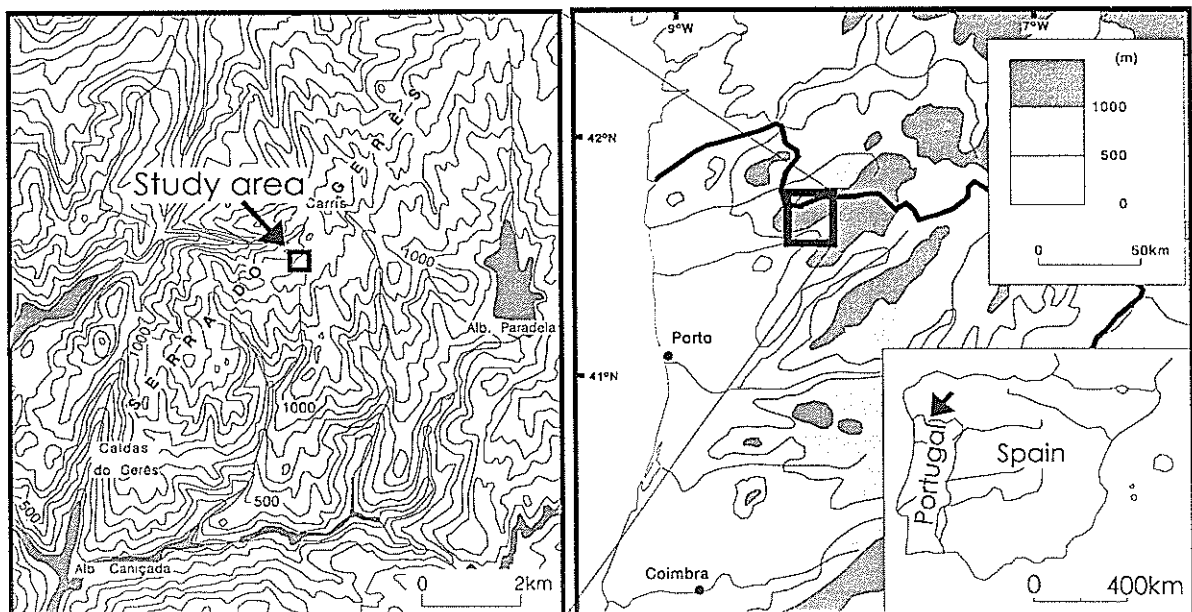


Figure 1 - Location of the Serra do Gerês and the Outeiro do Pássaro area.

Figura 1 - Localização da Serra do Gerês e da área do Outeiro do Pássaro.

above the intermediate slope belt. In the external areas its lower limit is at about 900m a.s.l. and in the inner parts of the massif at about 1100m a.s.l. Slopes of low to medium gradient are clearly dominant. Vegetation cover is very sparse and bare-rock almost omnipresent. Coarse-grained sand deposits can be found in badly drained basins and in the flatter areas. The main active processes in the upper belt are rock weathering (both chemical and physical), overland flow, aeolian erosion and slow rock-slides (VIEIRA, 1995).

## 2. THE OUTEIRO DO PÁSSARO AREA

The research focused in a small area (0.5km<sup>2</sup> - Outeiro do Pássaro) which was studied in detail. From a morphological point of view the area forms an irregular interfluvium with rock domes and small basins (Fig. 2). Its height varies between 1430 and 1482m a.s.l. Convex units correspond normally to bare-rock areas with a weathering-limited situation.

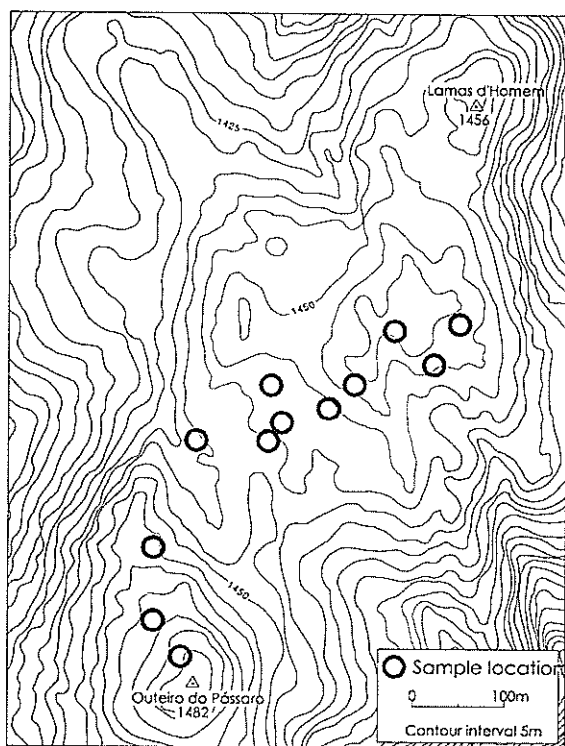


Figure 2 - The Outeiro do Pássaro area and location of the sampling spots.

Figura 2 - Localização das amostras na área do Outeiro do Pássaro.

In the concave and flatter areas a transport-limited situation dominates originating coarse sand accumulations. These differ substantially from site to site, their characteristics depending mainly on topographic position and surrounding landforms, which induce different transport energies. These morphogenetic environments were characterised elsewhere (VIEIRA, 1995). The ones which are more important to this study are the "well-drained coarse-grained sand accumulations" which develop mainly in low gradient sectors (normally less than 5°). These areas present thin accumulations of granite sand (<20cm) colonised by short shrubs (30-40cm) which cover about 50-60% of the area. *Calluna vulgaris*, *Erica spp* and *Chamaespartium tridentatum* are the more representative species.

Shrubs grow in elongated tufts bordering small runoff channels. These erode the coarse sand deposit, normally not reaching the *in situ* granite. The channels are 1 to 2m wide and present a very smooth longitudinal profile. The vegetation that borders them is lying in most cases about 10cm higher than the channel bottom, contacting with the coarse sand deposit.

Maybe the more interesting aspect of the above described micro-environment is the presence of distinct micro-morphological features with a complex hydro-aeolian genesis. In this group of micro-forms, we can include from simple lag-surfaces to micro-accumulations against obstacles, which are described below. These features are not exclusive from the "well-drained coarse-grained sand accumulations" and are also found in bare-rock slopes, where a thin veneer of coarse-sand is present.

## 3. MORPHOLOGICAL CHARACTERISTICS OF THE HYDRO-AEOLIAN FEATURES

The micro-morphology developed in the sandy deposits of the Outeiro do Pássaro area is diverse and complex. Its genesis seems controlled by both aeolian and wash processes. A very significant characteristic of the deposits where these features develop is a typical double-layer grain-size differentiation. The top 1cm layer is a coarse-grained, homometric and clearly positive skewed deposit of coarse sand and granules; while in the lower layer, granulometric characteristics vary a lot, being this, usually finer and more heterometric than the former (Fig. 3). Grain-size curves from this layer are very variable, as is described below.

In this first approach, the micro-morphological features are divided in two major groups: simple lag-surfaces and micro-accumulations against obstacles.

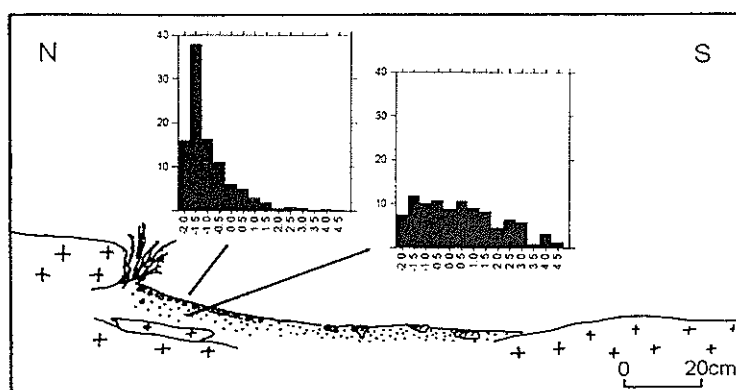


Figure 3 - Typical profile of a micro-accumulation against an obstacle and typical grain-size curves for the superficial and subsuperficial layers.

Figura 3 - Perfil e curvas granulométricas típicas de uma micro-acumulação de encontro a um obstáculo.

### 3.1 Simple Lag-Surfaces

The simple lag-surfaces are flat superficial deposits of coarse sand and granules, normally one-granule thick, lying over an heterometric sandy-silt deposit. The simple lag-surfaces present in the Outeiro do Pássaro area should not be considered genetically as aeolian, being the result of the combined action of wind (deflation) and water erosion (wash). They appear in sand deposits in areas under  $2^\circ$  of gradient, many times in runoff channel bottoms, this suggesting a water related genesis. Although, simple lag-surfaces are also found on bare-rock surfaces with a coarse sand cover, this being especially frequent inside wide gnammas.

Laterally the characteristics of the lag-surfaces are very variable. Ground surface can be totally covered by coarse sand and granules, or, as it is common in the runoff channels bottom, by a sparse granule cover over finer and more compacted sand. In most cases, lag-surfaces develop in sectors contacting with micro-accumulations against obstacles, functioning also as sediment feeding areas to the later, mainly by deflation.

The distinction between simple lag-surfaces and the micro-accumulations against obstacles is not always clear, once many times there is a spatial continuity between them. In a sedimentological perspective, it is difficult to distinguish between both, because the upper layer of the later is also a lag-surface. In this way, the characteristic which differentiates them is eminently morphological. Simple lag-surfaces present a flat or almost flat surface ( $<2^\circ$ ), while micro-accumulations against obstacles present a small slope, usually with a gradient between  $10$  and  $22^\circ$ . The former are erosional features, while the later are mainly accumulation forms with selective erosion rework of the fine material.

### 3.2 Micro-accumulations against obstacles

The micro-accumulations against obstacles are the more interesting kind of hydro-aeolian deposit found in the study area. They are small accumulations of coarse-sand that occur lying against small shrubs or rock outcrops. An easily observed macroscopic characteristic is the grain-size difference between a superficial layer of about 1cm thick and the underlying material. The top layer is coarse-grained and homometric, while the lower deposit is finer, more heterometric (Fig. 3) and has a bigger organic matter content. This difference is continuous all over the surface of the accumulation.

The size of these features is variable, with a longitudinal length ranging from a few decimetres to more than 1 metre. They can be classified according to their size and morphology. Following this criteria, three types of features were identified: incipient micro-accumulations, climbing tongues and climbing tongues with blow-out (Fig. 4).

The incipient micro-accumulations are the more common of the three types of features. They are small accumulations with a slope of 10 to 20 cm length, that border runoff channels, showing many times a lateral continuity for several metres (Fig. 4 and 5). The accumulation is originated by the obstacle caused by the vegetation which borders the channels (normally *Calluna vulgaris* or *Chamaespartium tridentatum*). The small longitudinal size of these features is probably a consequence of the availability of material in the source sector.

Climbing tongues are forms that appear associated to the incipient micro-accumulations, interrupting their lateral continuity. Morphologically, they are tongue shaped sectors of coarse sand material with a typical longitudinal development, that climb over the vegetation (Fig. 4). They are about 20 to 30 cm wide (in the lower sector), straightening

towards the top. The observed features are less than 1 metre long. Their genesis can be related to higher sediment input sectors, this resulting from more material available in the source sector or from higher wind speeds resulting from micro-scale channelling. Vegetation characteristics (i.e. leaf density or branch resistance) as well as morphological factors, can be also determinant to their location.

Climbing tongues with blow-out are rare. They can be more than 1 metre long and have a variable width, normally with 40-50cm in the lower sector, and widening in some cases towards the top (Fig. 4

and 6). They clearly indicate a significant advance of the sediments over the vegetation.

It is easy to note a grading between the three types of features described, corresponding probably the incipient micro-accumulations to an initial stage, and the climbing tongues with blow-out to a late evolutionary stage. The sequence is not necessarily a function of time, but a conjugation with several factors (i.e. sediment sources and their characteristics, vegetation characteristics and micro-scale wind patterns).

The above presented typology is a generalisation attempt. Several hydro-aeolian features with intermediate characteristics were not included (i.e. stair-like micro-accumulations)

#### 4. SEDIMENTOLOGICAL ANALYSIS

Grain-size analysis was carried out at the Laboratory of Physical Geography of the Centro de Estudos Geográficos. Different features were sampled taking in account the vertical grain-size differences pointed above. In this way, the superficial layer was sampled, as well as the underlying layer. This allowed a characterisation of vertical grain-size changes. Some features were also sampled in their upper and lower sectors, being possible to characterise longitudinal grain-size changes.

Samples were subject to a submersion in water with hydrogen peroxide for organic matter destruction. Grain-size analysis of the coarse fraction ( $<62\mu$ ) was done by gravitic sieving using  $0.5\phi$  interval sieves.

Grain-size distributions were characterised using the following statistical parameters (FRIEDMAN & SANDERS, 1978, p.75):

Graphic mean:

$$M_z = \frac{\phi_{16} + \phi_{50} + \phi_{84}}{3}$$

Inclusive graphic standard deviation:

$$\sigma_1 = \frac{\phi_{84} - \phi_{16}}{4} + \frac{\phi_{95} - \phi_5}{6.6}$$

Inclusive graphic skewness:

$$SK_1 = \frac{\phi_{84} + \phi_{16} - 2\phi_{50}}{2(\phi_{84} - \phi_{16})} + \frac{\phi_{95} + \phi_5 - 2\phi_{50}}{2(\phi_{95} - \phi_5)}$$

Graphic kurtosis:

$$KG = \frac{\phi_{95} - 5}{2.44(\phi_{75} - \phi_{25})}$$

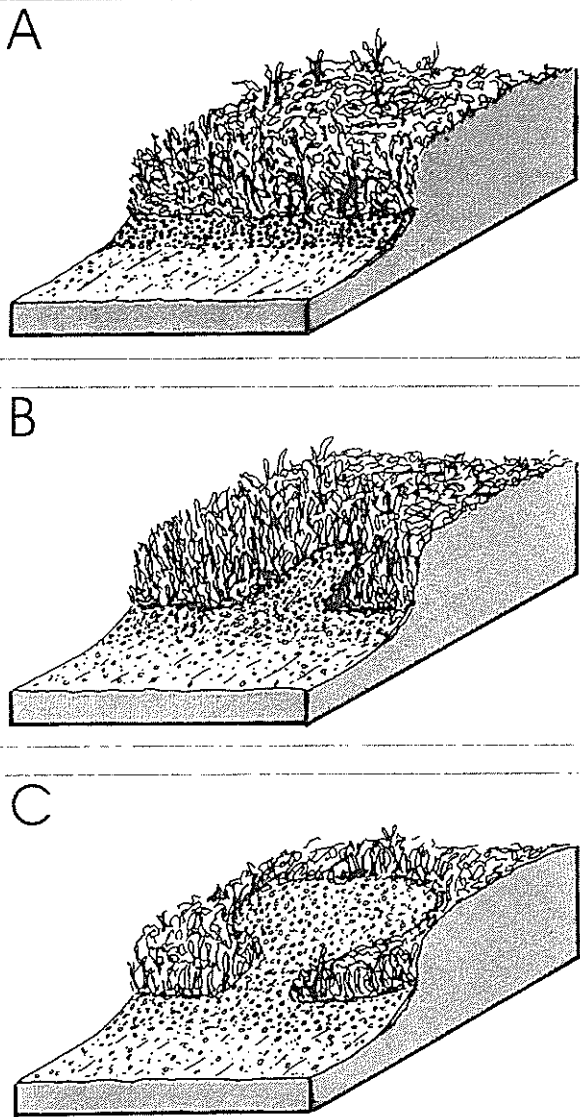


Figure 4 - Morphological types of micro-accumulations against obstacles. a) incipient micro-accumulation against obstacle; b) climbing tongue; c) climbing tongue with blow-out.

Figura 4 - Tipos de micro-acumulações de encontro ao obstáculo. a) micro-acumulação incipiente; b) língua de grânulos; c) língua de grânulos com blow-out.



Figure 5 - Incipient micro-accumulations against obstacles in the Outeiro do P3ssaro area (95/02/04).  
Figura 5 - Micro-acumula3es incipientes na 3rea do Outeiro do P3ssaro.



Figure 6 - Climbing tongue with blow-out in the Outeiro do P3ssaro area (95/02/04). Note the longitudinal development of the accumulation, clearly climbing over the small shrubs.  
Figura 6 - L3ngua de gr3nulos com blow-out na 3rea do Outeiro do P3ssaro. Note-se o desenvolvimento longitudinal da acumula33o avanando sobre pequenos arbustos.

	Very well-sorted	Well-sorted	Moderately-sorted	Poorly-sorted	Very poorly-sorted
$\sigma I$					
	Negative-skewed	Nearly symmetrical	Positive-skewed	Very positive-skewed	
SKI					
	Very platykurtic	Platykurtic	Mesokurtic	Leptokurtic	Very leptokurtic
KG					

Table I - Shadings applied in tables II, III and IV.

Tabela I - Sombreados usados nas tabelas II, III e IV.

#### 4.1 Vertical grain-size analysis

##### a) Superficial layer

The grain-size analysis of the superficial layer of different micro-accumulations against obstacles (MAO) and also from simple lag-surfaces (SLS) over bare-rock shows the coarse character of these layers. Two groups of deposits can be distinguished: one from the MAO's and one from the SLS's.

Samples from the upper layer of MAO's show very similar curves and always a very positive skewness (Fig. 7, Table I and II). However, if we take in account the modal class and kurtosis, they form two distinct groups. One group of samples has the mode in the class  $-1.5\phi$  (Type 1 - A4, A9, A15, A18, A24, A31, A32 and A40) and other, in the class  $-2\phi$  (Type 2 - A20, A36 and A39), being coarser than the former. Type 1 presents mesokurtic to very leptokurtic curves, while type 2 shows higher sediment concentration in the modal class, being leptokurtic to extremely leptokurtic. Both types are moderately-sorted to very well-sorted, except the samples A15 and A32 which are in the lower limit of the poorly-sorted class.

In what respects to SLS's, the sampled deposits have different characteristics when compared to MAO's, and also between them. The curves are positive to very positive skewed and are also coarse-grained (Fig. 8 and Table II). Sorting is poor and the grain-size distribution is platykurtic, these being important differences when compared to MAO's.

The characteristics shown above may indicate a greater dependence of the SLS's superficial layer on the disintegration of the mother rock and directly from site characteristics. In what respects to the MAO's superficial layer, the similarity of the samples seems to indicate a common genesis, not directly dependent on site characteristics. As it will be pointed below, the difference in the modal class which allows the distinction of two types in the MAO's may be related to different site energies or evolutionary stage.

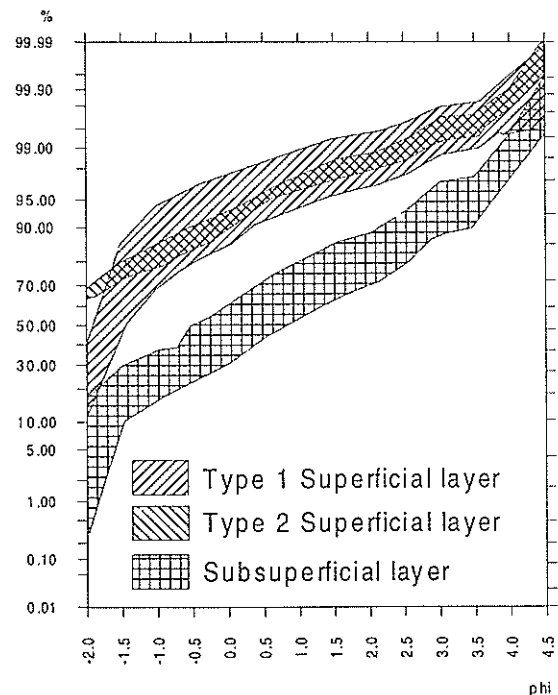


Figure 7 - Grain-size cumulative-frequency curves of micro-accumulations against obstacles from the Outeiro do Pássaro area.

Figura 7 - Curvas granulométricas de frequências cumulativas de micro-acumulações da área do Outeiro do Pássaro.

##### b) Subsuperficial layer

The analysis of the samples from the subsuperficial layer of MAO's has shown that this layer does not present a typical grain-size curve, with significant changes in the modal class and overall grain-size distribution (Fig. 7 and Table III). Samples are finer and worst sorted than the superficial layers. Skewness and modal class sediment concentration (kurtosis) are very variable. Samples are mesokurtic to very platykurtic. If we compare the grain-size curves with the curves from the overlying samples, they are

	Mz	$\sigma_1$	SK <sub>t</sub>	K <sub>G</sub>
EG1A	-1.60	<b>0.22</b>	<b>0.00</b>	1.84
EG1B	-1.50	<b>0.29</b>	0.25	1.37
EG1C	-1.50	<b>0.49</b>	0.35	<b>0.72</b>
EG1D	-1.30	<b>0.46</b>	0.20	1.06
EG1E	-0.40	1.04	0.33	1.20
EG1F	0.57	1.78	0.13	0.90
EG2A	-1.90	<b>0.24</b>	1.00	2.05
EG2B	-1.70	<b>0.36</b>	0.55	0.98
EG2C	-1.50	<b>0.40</b>	0.49	1.23
EG2D	-1.40	0.56	<b>0.00</b>	<b>0.77</b>
EG2E	-0.60	1.26	0.27	1.09
EG2F	-0.50	1.51	0.37	<b>0.86</b>

Table II - Grain-size characteristics of superficial samples of micro-accumulations against obstacles and simple lag-surfaces of the Outeiro do Pássaro area.

Tabela II - Características granulométricas das amostras superficiais de micro-acumulações de encontro a obstáculos e de lag-surfaces simples da área do Outeiro do Pássaro.

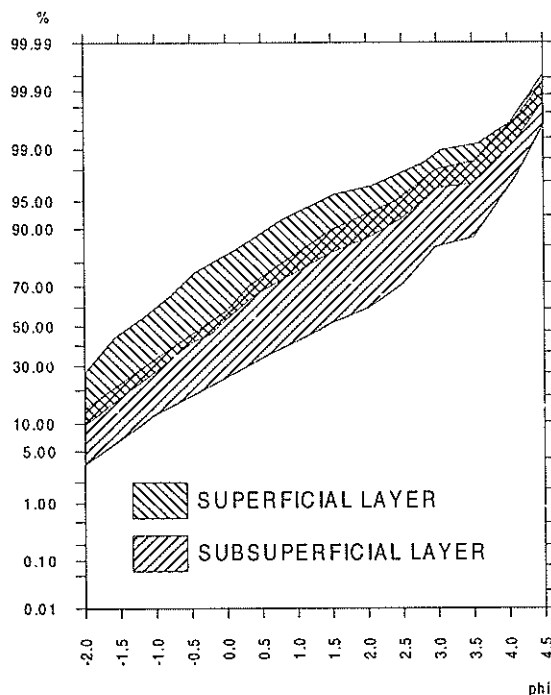


Figure 8 - Grain-size cumulative-frequency curves of grain-size of simple lag-surfaces from the Outeiro do Pássaro area.

Figura 8 - Curvas granulométricas de frequências cumulativas de lag-surfaces simples da área do Outeiro do Pássaro.

very distinct and it is clear the layering pointed above (Fig. 7).

The subsuperficial samples from SLS's evidence also a vertical sorting. The studied samples are still few but show the same kind of characteristics of the subsuperficial layers of MAO's (Fig. 8 and Table III). Comparing these samples with the ones from the superficial layer, a distinction between both is clear (Fig. 8). Although an overlapping exists between the grain-size curves of the studied samples. This may also reflect the greater genetical proximity between the superficial layer and the underlying parent deposit.

#### 4.2 Longitudinal grain-size analysis

In order to characterise longitudinal grain-size changes in a MAO, samples were taken from the lower and upper sector in one site. The vertical grain-size variation was also analysed.

The two superficial samples (A39 and A40) present the typical grain-size curves of this layer. A longitudinal coarsening from the upper to the lower sector is however present. The upper sector has a mode of  $-1.5\phi$  and a graphic mean of  $-1.4\phi$ , while the lower sector presents a mode of  $-2\phi$  and a graphic mean of  $-1.7\phi$  (Fig. 9 and Table II). Both samples are moderately sorted, very positive-skewed and very leptokurtic. Although these parameters are more extreme in the lower sector.

The subsuperficial samples (A41 and A42) in both sectors are finer and weakly sorted (Fig. 7 and Table III). The lower sector is positive-skewed and the upper sector is very positive-skewed. It is specially interesting to note the similarity of the grain-size curves of the subsuperficial layers above  $-0.5\phi$  (70% of the weight of the samples) when plotted in the cumulative-frequency graph. The same happens for the superficial samples, although in this case the similarity is not so clear and only affects about 10% of the samples' weight. The meaning of this similarity is not yet established.

#### 4.3 Analysis of a climbing tongue with blow-out

The climbing tongue with blow-out studied here is located in a coarse-grained sand accumulation micro-environment North of the Outeiro do Pássaro. It is a climbing tongue with blow-out in an early evolution stage (still in the transition from a climbing tongue). It is situated in the margin of a small runoff channel, and presents a Southwest aspect. It measures about 180cm from bottom to top and



	Mz	$\sigma_1$	SK1	KG
A4	-1.2	0.80	0.43	1.19
A6*	-0.1	1.51	0.15	<b>0.88</b>
A9	-1.4	0.68	0.41	<b>0.97</b>
A15	-1.1	1.00	0.60	1.20
A18	-1.3	0.89	0.59	1.17
A20	-1.7	0.59	1.00	4.26
A22*	-0.7	1.36	0.32	<b>0.79</b>
A29*	-1.0	1.06	0.47	<b>0.81</b>
A31	-1.8	<b>0.31</b>	0.44	1.28
A32	-1.3	1.00	0.60	1.60
A36	-1.5	0.79	1.00	1.45
A39	-1.7	0.60	1.00	2.30
A40	-1.4	0.62	0.53	1.50

\* LSB's

Table III - Grain-size characteristics of subsuperficial samples of micro-accumulations against obstacles and simple lag-surfaces of the Outeiro do Pássaro area.

Tabela III - Características granulométricas das amostras sub-superficiais de micro-acumulações de encontro a obstáculos e de lag-surfaces simples da área do Outeiro do Pássaro.

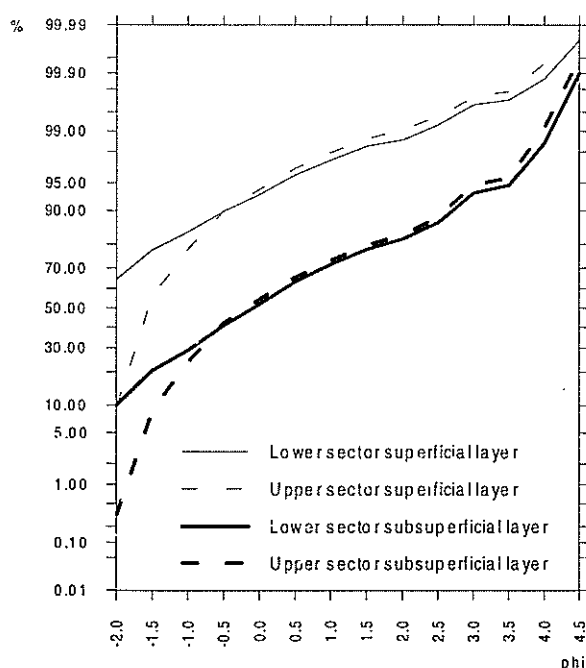


Figure 9 - Grain-size cumulative-frequency curves illustrating the longitudinal differences in a micro-accumulation against an obstacle from the Outeiro do Pássaro area.

Figura 9 - Curvas granulométricas de frequências cumulativas ilustrando as diferenças verificadas longitudinalmente numa micro-acumulação de encontro ao obstáculo na área do Outeiro do Pássaro.

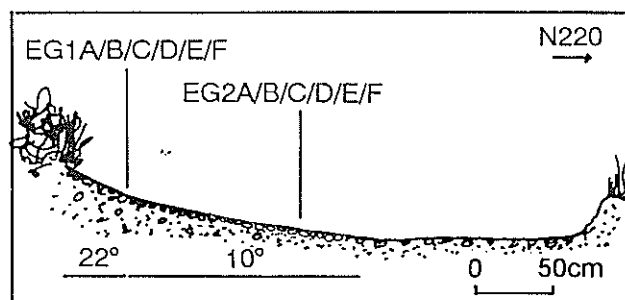


Figure 10 - Profile of a climbing tongue with blow-out and position of the samples.

presents two distinct sectors in a longitudinal cross-profile: the lower and intermediate sector have a 10° gradient; and the upper sector presents about 22° gradient. The accumulation is about 1m wide in the lower sector, straightening towards the intermediate sector, where it has about 40cm. This width is maintained towards the top.

Deposits were sampled according to the technique presented by THORN & DARMODY (1985) and used to study aeolian lag-surfaces in the Colorado Front Range, USA. Six samples were taken from two sectors of the accumulation (Fig. 10), in order to study grain-size changes from its top to bottom (longitudinal changes) and also with depth (vertical changes). The deposit was sampled in each sector by the application of four consecutive 22x22cm stickers over the soil surface. In this way, it was possible to analyse the granulometric properties of the deposit in layers one granule thick. After this procedure, the underlying 1cm depth material was carefully sampled and also the 2cm beneath it. This last two samples intended to characterise the underlying more heterometric material.

The samples obtained with the sticker were subject to a submersion in hot and dionised water in order to set free the material. The granules which did not set free were unsticked using a wooden spatula.

The obtained grain-size curves does not show a regular grading with depth, nor considering their longitudinal position in the accumulation (Fig. 11 and 12). In fact, the relations are not simple, being only possible to identify a rough tendency to a grain-size and sorting reduction with depth. The samples of the upper sector (EG1) always present their mode in the  $-1.5\phi$  class, while in the lower sector (EG2) it varies between  $-2\phi$  and  $-1.5\phi$ .

Considering the statistical graphic parameters (Table IV), it is clear a general lowering of the graphic mean with depth, this meaning that there seems to exist a general coarsening towards the

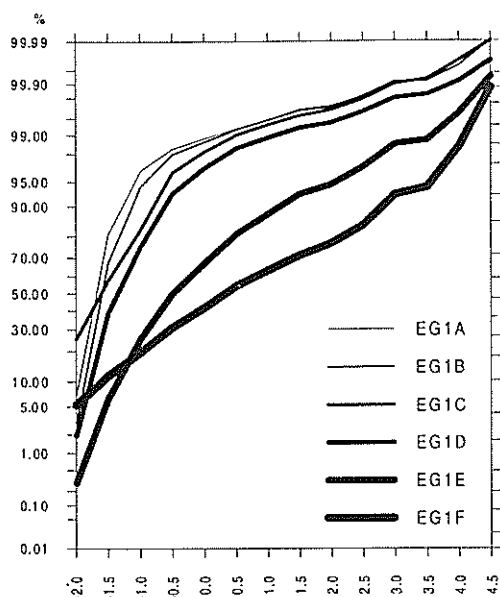


Figure 11 - Grain-size cumulative-frequency  $\phi_{hi}$  curves of the upper sector of a climbing-tongue with blow-out: EG1A - 1st one-granule thick layer; EG1B - 2nd one-granule thick layer; EG1C - 3rd one-granule thick layer; EG1D - 4th one-granule thick layer; EG1E - 1cm thick layer under EG1D; EG1F - 2cm thick layer under EG1E.

Figura 11 - Curvas de frequências cumulativas do sector inferior de uma língua de grânulos com blow-out: EG1A - 1ª película com 1 grânulo de espessura; EG1B - 2ª película com 1 grânulo de espessura; EG1C - 3ª película com 1 grânulo de espessura; EG1D - 4ª película com 1 grânulo de espessura; EG1E - camada com 1 cm de espessura abaixo de EG1D; EG1F - camada com 2 cm de espessura abaixo de EG1E;

surface. This is true both for the upper and lower sectors.

The graphic mean supports the longitudinal reduction in grain-size from bottom to top (Table IV). The inclusive graphic standard deviation shows a decrease in sorting with depth and also longitudinally, from the top to the accumulation's lower sector. In the upper sector the first two layers are very well-sorted and the two underlying layers are well-sorted. In the lower sector, according to the sorting decrease, the superficial layer is very well-sorted, the second and third layers are well-sorted and the fourth layer is moderately-sorted. In both sectors, the two deeper samples are poorly-sorted reflecting an abrupt change in grain-size. This can be caused by a change in the sampling method, but also reflects the dual layering observed macroscopically in the field. The other two graphic parameters (SKI and KG) show an overall irregular variation, being possible to identify a tendency for a positive skewness in the upper sector samples and for a very positive skewness in the lower sector

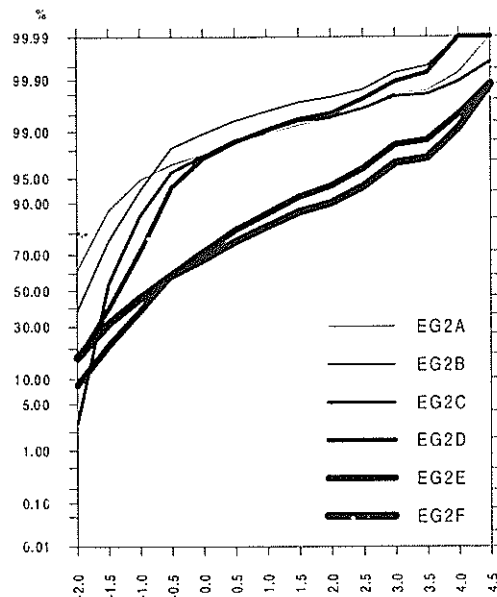


Figure 12 - Grain-size cumulative-frequency  $\phi_{hi}$  curves of the lower sector of a climbing-tongue with blow-out: EG2A - 1st one-granule thick layer; EG2B - 2nd one-granule thick layer; EG2C - 3rd one-granule thick layer; EG2D - 4th one-granule thick layer; EG2E - 1cm thick layer under EG2D; EG2F - 2cm thick layer under EG2E.

Figura 12 - Curvas de frequências cumulativas do sector inferior de uma língua de grânulos com blow-out: EG2A - 1ª película com 1 grânulo de espessura; EG2B - 2ª película com 1 grânulo de espessura; EG2C - 3ª película com 1 grânulo de espessura; EG2D - 4ª película com 1 grânulo de espessura; EG2E - camada com 1 cm de espessura abaixo de EG2D; EG2F - camada com 2 cm de espessura abaixo de EG2E;

	MZ	$\sigma_1$	SKI	KG
A5	0.40	1.90	0.20	<b>0.80</b>
A7*	0.40	1.70	0.10	1.10
A10	-0.20	1.40	0.37	0.99
A19	0.27	1.78	0.18	<b>0.87</b>
A21	0.90	1.80	<b>0.00</b>	0.90
A23*	1.20	1.80	<b>-0.10</b>	0.90
A30*	-0.50	1.37	<b>0.04</b>	<b>0.87</b>
A33	0.30	2.00	0.10	<b>0.60</b>
A37	0.15	1.41	<b>0.01</b>	1.12
A41	0.23	1.61	0.40	0.90
A42	0.22	1.89	0.22	0.92

LSB's

Table IV - Grain-size characteristics of a climbing tongue with blow-out of the Outeiro do Pássaro area.

Tabela IV - Características granulométricas de uma língua de grânulos com blow-out da área do Outeiro do Pássaro.

## 5. DISTRIBUTION OF THE MICRO-ACCUMULATIONS AGAINST OBSTACLES AND THE WIND PATTERNS

The deformation of the vegetation is widely used in climatology studies, allowing the interpretation of micro-scale wind patterns. The results obtained with this method are normally very reasonable in determining topographic influence in the wind flow and dominant wind directions (FERREIRA, 1984; ALCOFORADO, 1984). The application of this technique for geomorphological purposes, as far as it is known by the author, is not very common. RUDBERG (1968) used joint observations from aeolian morphology, anemomorphic deformations and vegetation scars to determine erosive wind directions. The method used here is different. Deformations in the vegetation cover which are considered of aeolian origin are used to support an aeolian genesis for the accumulations.

Mapping of the MAO's was done exhaustively at a scale 1:2,500 which was later reduced to 1:5,000. The map scale did not allow the individual identification of the accumulations. The solution was to group nearby features and to map them punctually.

The same scale change procedure was used for the vegetation deformation map. The mapping is not spatially exhaustive, but the chosen path allowed the characterisation of the main local wind patterns. Morphological and leaf dissimilarities in small bushes of *Calluna vulgaris* and *Erica spp* are easily identifiable and because of topographic, climatic and ecological characteristics of the study area, attributable to having an aeolian origin. Sometimes *Chamaespartium tridentatum* individuals were also used.

The cartography at 1:2,500 scale of the distribution and aspect of the micro-accumulations against obstacles in the Outeiro do Pássaro area was a very important aid to their genetical interpretation. The map shows clearly a dominant South to Southwest aspect of the accumulations indicating the predominance of an unidirectional process in their genesis. This is a good support to the aeolian hypothesis which was confirmed when the deformation of the vegetation was mapped and compared to the cartography with the distribution and aspect of the MAO's (Fig. 13). In fact, a very good relationship exists between shrub anemomorphisms and the MAO's aspect.

## 6. DISCUSSION

The morphology, grain-size analysis and the detailed mapping of the micro-accumulations against obstacles

of the Outeiro do Pássaro area allow a first genetical interpretation for those micro-forms.

Two main types of features were identified: simple lag-surfaces and micro-accumulations against obstacles. From these, may be the more interesting ones in a process perspective are the micro-accumulations against obstacles.

Grain-size characteristics of the studied features show two significant aspects: the vertical layering and the longitudinal grain-size variation. The first characteristic seems to be the most important with a clear distinction between a thin superficial layer of coarse and homometric material and a subsuperficial layer of finer and more heterometric material. The second characteristic is a coarsening of the grain-size from top to bottom of the accumulation.

Detailed field mapping of the micro-accumulations against obstacles showed a dominant South to Southwest aspect of these features. When compared with the shrub deformation mapping, a very satisfactory correspondence exists between both variables.

The above summarised characteristics seem to indicate a genetical grading from the simple lag-surfaces to the micro-accumulations against obstacles.

Simple lag-surfaces seem to be predominantly the result of the washing of fines, a fact well supported by the climatic characteristics of the area. Deflation may also be important to their genesis, but is not a necessary process for their explanation. Washing and deflation of fines can thus contribute to a coarsening of the superficial layer forming the simple lag-surface.

Micro-accumulations against obstacles are clearly the more difficult features to explain. The correspondence between their aspect and the anemomorphic deformations of small shrubs is a good basis to attribute them an aeolian genesis. This would emphasise the importance of the accumulation in their genesis. The vertical sorting, which is continuous from top to base may result from the washing and deflation of fines that occurs after the main accumulation phase (Fig. 14a, b and c). However, the thickness of the superficial layer (usually about 1cm) makes it an atypical lag-surface more than one granule thick. This fact suggests that this layer may be the result of an overlapping of one granule thick lag-surfaces which evolved from multiple small accumulation episodes over an original major accumulation (Fig. 14d). It is thus necessary that a major initial accumulation phase occurs (originating the microform), followed by multiple wash and deflation episodes intercalating with smaller accumulation events (repetition of the sequence shown in Fig. 14c and 14d). This would allow the thickening of the superficial layer.

It is also possible that needle-ice plays a role in the sorting process, but this hypothesis is still being studied.

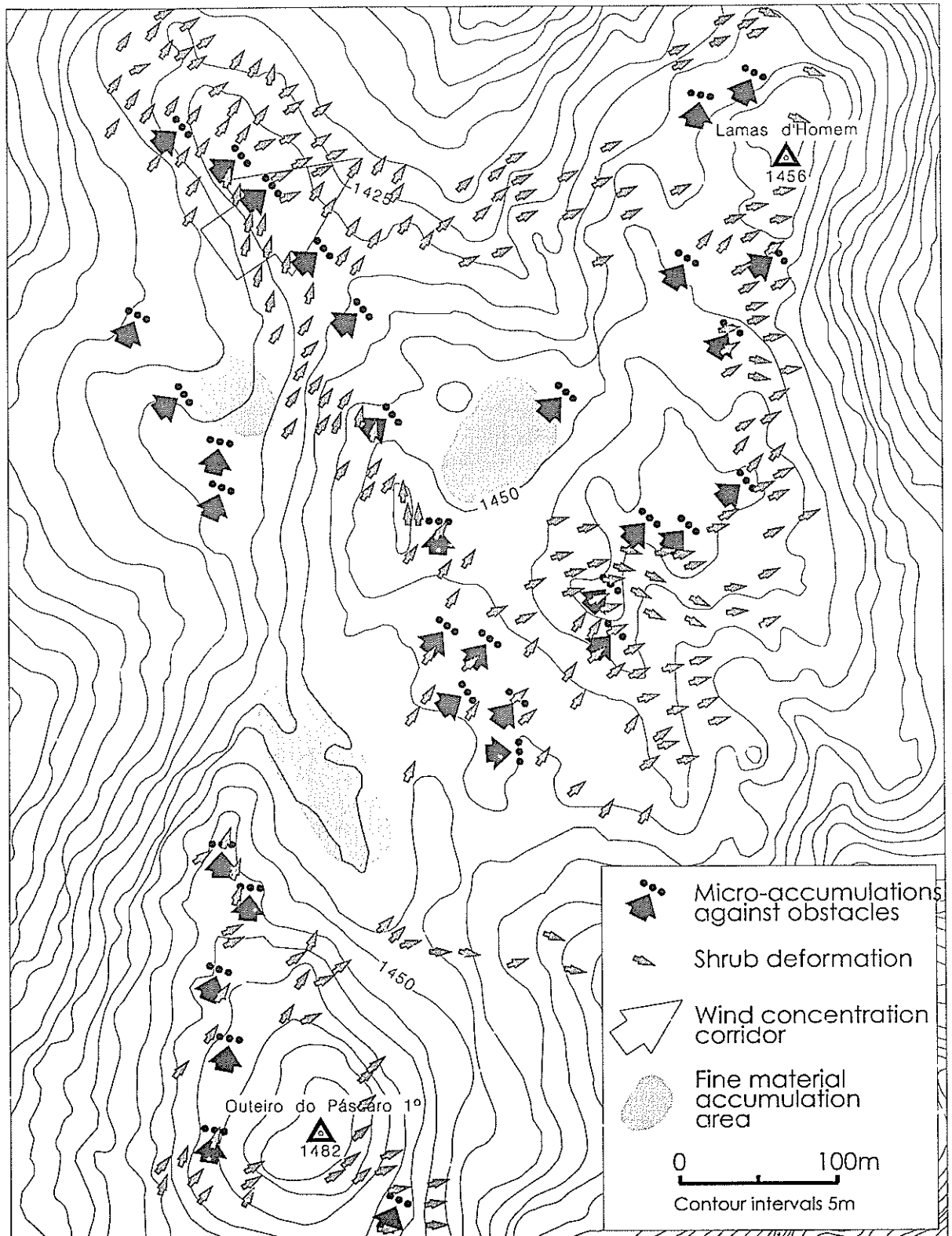


Figure 13 - Aeolian dynamics map of the Outeiro do Pássaro area (February 1995).  
 Figura 13 - Dinâmica eólica da área do Outeiro do Pássaro (Fevereiro 1995)

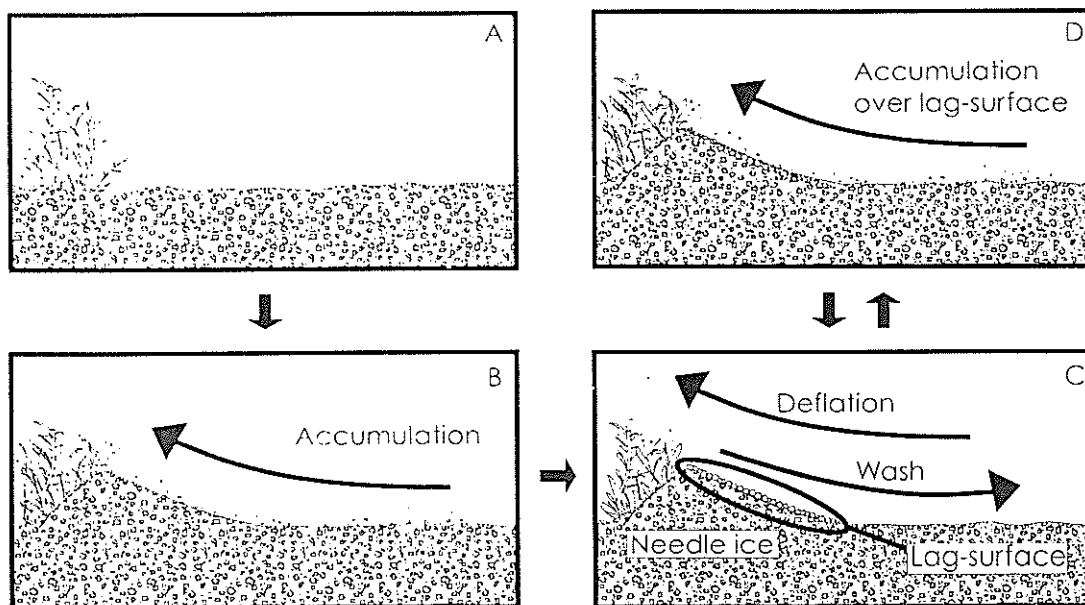


Figure 14 - Hypothesis for the genesis of micro-accumulations against obstacles.  
 Figura 14 - Hipótese para a génese das micro-acumulações de encontro a obstáculos.

It is also possible that needle-ice plays a role in the sorting process, but this hypothesis is still being studied.

The longitudinal differentiation may be related to an higher wash energy near the accumulation's bottom (sometimes accumulations lay at runoff channels margins) and also to wind sorting during accumulation events (the smaller granules are easier to transport to the upper sectors of the MAO's).

The finer and more heterometric characteristics of the subsuperficial layer may be related to the first accumulation event, being afterwards protected from deflation and washing by the superficial layer. A downwards migration of fines from the surface is also an hypothesis. Chemical weathering may also contribute to the characteristics of this layer, once it is older and has a higher water content than the superficial one.

The hydro-aeolian hypothesis presented here is still preliminary and based on the available data. It seems however that wind through deflation and accumulation, and water mainly through washing, are very important processes in the present-day morphogenesis of the upper interfluvies of the Serra do Gerês.

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