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Coarse sand accumulations in granite mountains: the case-studies of the Serra do Gerês and Serra da Estrela (Portugal)

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with 9 figures

Summary. Previous studies of coarse sand accumulations have underlined the importance of aeolian and runoff processes in the upper areas of the Serra do Gerês (NW Portugal). These are responsible for the existence of a distinct morphogenetic belt in the higher plateaus of the mountain range. Recent fieldwork has shown that similar processes are widespread in the granite sector of the Serra da Estrela range (Central Portugal).

After the characterisation of the coarse sand accumulations in both mountains, their sedimentological properties are analysed and the aeolian and water activity in the two mountain ranges is compared. From this study it is evident that aeolian processes are also important in the Serra da Estrela granite plateaus. The coarse sand accumulations found in the Serra da Estrela are very similar to the ones from in the Serra do Gerês. This fact points towards a similarity in the processes occurring in the two study areas.

1 *Introduction*

The Serra do Gerês is a granite mountain range in Northwest Portugal (Fig. 1). It reaches a maximum altitude of 1,545 m a.s.l. and the higher interfluves form a plateau that slopes smoothly to the southwest, between about 1,500 and 900 m a.s.l. This plateau is dissected by deep valleys in most cases 'V' shaped.

The position of the Serra do Gerês in the Northwest of Portugal significantly affects its climatic characteristics. The area benefits from the influence of wet Atlantic air masses and from a marginal Mediterranean climate. Mean annual precipitation reaches 3,500 mm in the upper areas, falling mainly during winter, autumn and spring. Summer months are usually dry. The mean number of wet days varies from 110 to 160 per year (Daveau et al. 1977) and water erosion is the dominant geomorphological process (Vieira 1995). Snowfall is low and insignificant as a morphogenetic agent.

Temperature records are few and absent in the higher areas. The meteorological station of Gerês (480 m a.s.l.), with its insufficient six-year record, shows a simple temperature 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 temperature of the higher areas by Daveau (1985) points to more than 40 days with a minimum air temperature below freezing point and an average minimum temperature for the coldest month of under +1°C. Summer show less than 20 days with maximum temperatures above +25°C and an average maximum temperature

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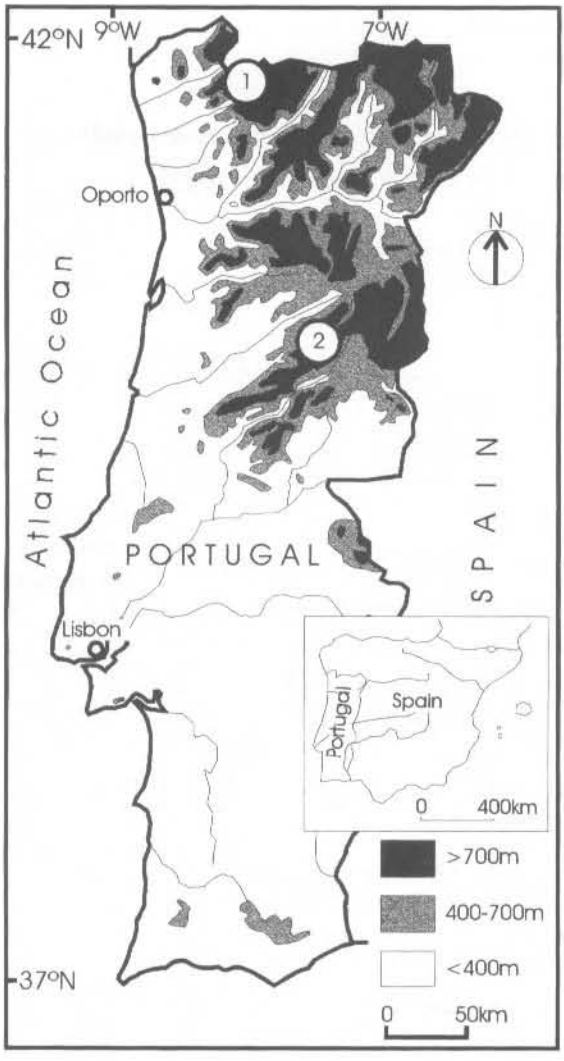

Fig. 1. Location of the Serra do Gerês (1) and Serra da Estrela (2).

of the warmest month under +23°C (Daveau 1985). No other information on climate characteristics of the upper areas exists.

The Serra da Estrela is located in Central Portugal (Fig. 1) and at 1,993 m a.s.l, it is Portugal's highest mountain. The central and upper areas are granitic and parts of the marginal sectors are constituted by metasediments. In the granite area the mountaintop presents distinct steps between about 1,900 and 1,500 m a.s.l. These flat areas correspond to ancient planation surfaces subject to uplifting and faulting during the Cenozoic (Ferreira 1991). They form distinct blocks still closely related to the original tectonic morphology (Ribeiro 1954, Daveau 1969). The steps are separated from each other, either by gently sloping surfaces, or by sharp edges and together they form a plateau limited by long and steep slopes.

Despite the higher altitude, precipitation is lower in the Serra da Estrela than in the Serra do Gerês, reaching an annual mean of about 2,500 mm on the higher plateaus (Daveau et al. 1977). Autumn is generally the wettest season, but precipitation is frequent and regularly distributed in the winter and spring months. In summer, the Mediterranean characteristics of the climate result in a decrease of the rainfall, being July and August the driest months. The mean annual temperature in the highest active meteorological station of the Serra da Estrela (Penhas Douradas, 1,380 m a.s.l.) is +8.3°C and snowfall occurs on an average 33 days per year. The upper parts of the mountain present lower temperatures and more days with snowfall (Andrade et al. 1992).

Daveau (1985) classified the higher areas of the Serra da Estrela in the same group of the higher sectors of the Serra do Gerês. However, because both mountains were included in the coldest class, it is not possible to accurately evaluate their differences. It is important to consider that the Serra da Estrela has lower temperatures and a longer lasting snow cover.

Daveau (1973, 1978) and Brosche (1978) suggest a lower limit for the periglacial belt in the Serra da Estrela between 1,750 m and 1,850 m a.s.l. This belt is not present in the Serra do Gerês. In both mountains, freeze-thaw events are especially of the needle-ice type. The ice needles form during cold nights and usually melt with morning sunrays (Vieira 1995, 1996). No present-day glaciers and perennial snow-patches exist in the mountains of Portugal.

As well as other Portuguese granite mountains, the Serras da Estrela and do Gerês present their higher areas without forest. In the former, the present-day timberline lies at about 1,500 m a.s.l. and the later about 900 m a.s.l. These are human induced limits and are dependent on the site history. Above the timberline, rock outcrops are numerous. In the lower sectors the granite presents a weathering mantle about 1 metre thick, but in the higher areas, it disappears and fresh-granite outcrop dominates. For the present-day morphogenesis, above the timberline the most important factor is the convex or concave character of the terrain (considered in a scale ranging between 1–1,000 metres). In the concave areas, sediment accumulation dominates. These sectors are wetter and present small shrubs. The convex areas are erosion sectors where the weathered material is rapidly transported. Flat sectors in an interfluve position also exist and there a shallow sedimentary cover may accumulate, protected in some places by small shrubs or herbaceous vegetation. They are characterised by important geomorphological dynamics, where runoff, aeolian erosion and freeze-thaw processes dominate. The coarse sand accumulations appear especially in the two later sectors and not withstanding the 180 km distance between the Serras da Estrela and do Gerês and their distinct altitude and latitudinal position, the features are very similar.

2 *The coarse-sand accumulations*

2.1 *The Serra do Gerês*

Coarse sand accumulations in the Serra do Gerês were first described by the author (Vieira 1995, 1998). An area of 0.5 km^2 in the Outeiro do Pássaro interfluve (1450 m a.s.l.) was carefully analysed from a geomorphological perspective. This analysis incorporated detailed

Fig. 2. Incipient coarse sand accumulations in an off-road vehicle track in the Lagoa Comprida area (Serra da Estrela). Wind direction from right to left.

geomorphological mapping at a scale of 1:2,500, allowing spatial interpretation of micro-scale features and by the sedimentological analysis of the main types of deposit.

Maybe the most interesting characteristic concerning the present-day morphodynamics of the area are the widespread accumulations of coarse sand and granules that appear in the concave and flat areas of the Outeiro do Pássaro and other interfluves. These small accumulations are deposited against small shrubs or rock outcrops. Variable in size, they have longitudinal lengths ranging from ca. 20 cm to more than 100 cm. They were classified according to their size and morphology and three distinct types of features were identified: incipient accumulations (Figs. 2 and 3), climbing tongues (Figs. 3 and 4) and climbing tongues with blow-out (Fig. 5). An easily observed macroscopic characteristic, is the grain-size difference between the superficial layer (usually about 1 cm thick) and the underlying material. The superficial layer is coarse-grained and well sorted, while the subsuperficial material is finer, more poorly sorted and organic rich. This difference between the superficial and subsuperficial layers is continuous over the accumulation's surface.

The incipient accumulations are the most common of the three types of features. They are small accumulations with a slope of 10 to 20 cm length that many times border runoff channels, often showing a lateral continuity of several metres. The accumulation is caused by the vegetation that bounds the channels (normally *Calluna vulgaris* or *Chamaespartium tri-*

Fig. 3. Incipient coarse sand accumulations with small climbing tongues in the Outeiro do Pássaro area (Serra do Gerês). Wind direction from lower left to upper right corner of the picture.

dentatum). The small longitudinal size of these features is probably a consequence of the availability of material in the source sector or of differences in near-ground wind speed.

Climbing tongues appear associated to the incipient accumulations and interrupt their lateral continuity. Morphologically, they are tongue shaped sectors of coarse sand material with a typical longitudinal development that climb over the vegetation. They are about 20 to 30 cm wide (in the lower sector), straightening towards the top and less than 100 cm long. Their genesis can be related to higher sediment input sectors, resulting from more material available in the source sector or from higher wind speeds following micro-scale channelling. Vegetation characteristics (i.e. leaf density or branch resistance) as well as morphological factors, also determine their location.

Climbing tongues with blow-out are rare. They can be more than 100 cm long and have a variable width, normally with about 50 cm in the lower sector, widening in some cases towards the top. They indicate an advance of the sediments over the vegetation.

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

Fig. 4. Climbing tongue in the Outeiro do Pássaro area (Serra do Gerês). Wind direction towards the upper left corner of the picture.

Even though the accumulation morphology suggests an aeolian genesis, the importance of these processes has never been stressed before in the Portuguese mountains. The precipitation regime with heavy and concentrated rainfall events with subsequent slopewash was considered as almost the dominant process for the present-day mountain morphogenesis. Furthermore, the coarse-grained character of the accumulations still induced some doubt on an aeolian genesis. However, evidence from the detailed geomorphological mapping of the area, supports the aeolian hypothesis. The accumulations had always a very similar aspect, evidencing a direction of transport from the south/southwest. This pattern was independent of the topographic position and is furthermore supported by the wind-influenced deformations of small shrubs, which were subsequently mapped (Fig. 6).

In order to characterize the grain-size difference between the superficial and subsuperficial layer, several accumulations were sampled and their grain-size characteristics studied.

2.2 *The Serra da Estrela*

Accumulations similar to those found in the Serra do Gerês are widespread in the Serra da Estrela granite plateaus, especially above 1,400 m a.s.l. They are found in concave and flat areas and essentially accumulate against small shrubs suggesting a morphogenetic wind

Fig. 5. Climbing tongue with blow-out in the Outeiro do Pássaro area (Serra do Gerês). Wind direction from the observer towards the upper limit of the picture.

direction from southwest to west. Despite being conspicuous, the accumulations are usually smaller in the Serra da Estrela range than in the Serra do Gerês. Although unclear, this may be related with distinct parent material, climate characteristics or different geomorphological rates of the processes (Serra da Estrela is higher and the nival and periglacial processes are more important).

Unlike in the Serra do Gerês where coarse sand accumulations usually appear in sectors with 50–60% vegetation cover, in the Serra da Estrela they are also found over surfaces covered entirely by short herbaceous vegetation. Granules appear in small depressions at the surface where water accumulates and small plants and moss cover the ground. The reason for the granules appearing above the vegetation is unclear but appears to be related to ice growth processes that displace the granules from the underlying soil. These sediments are then transported by wind and accumulate in the depression's edge.

Wind data from the meteorological station of Lagoa Comprida (abandoned since the 80's) located in the west limit of the plateau are in agreement with the directions of the accumulations in the Serra da Estrela. The stronger wind speeds are from the south and southwest and the more frequent directions are west and east. This fact supports the aeolian genesis for the accumulations and suggests that the events with high wind speed are more significant than the more frequent but lower wind speed episodes.

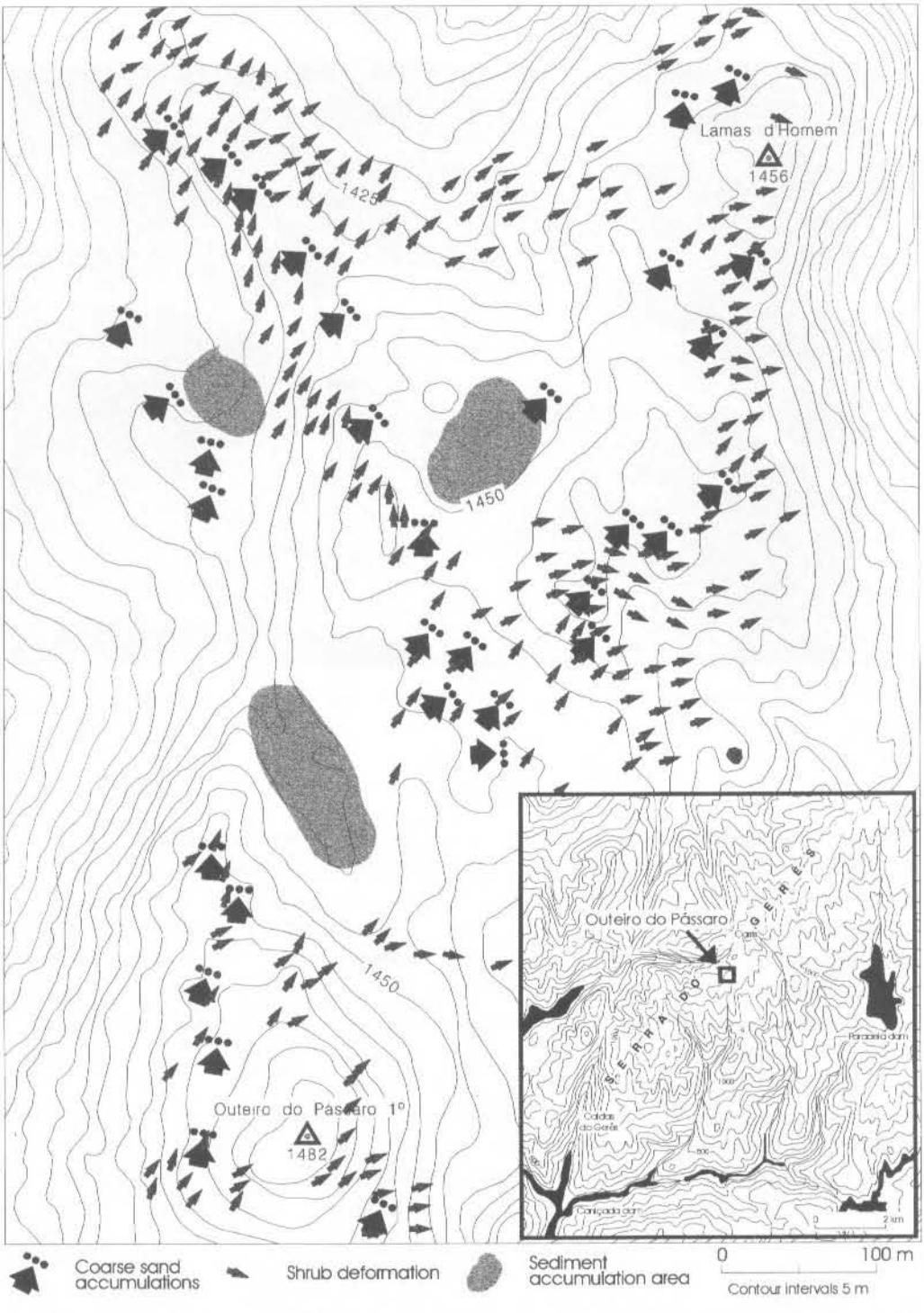

Fig. 6. Aeolian dynamics map of the Outeiro do Pássaro area, Serra do Gerês, NW Portugal (February 1995).

3 *Comparative grain-size analysis*

3.1 *Methodology*

The accumulations found in the Serra do Gerês and Serra da Estrela, are located about 180 km apart and are macroscopically very similar. In order to study their sedimentological properties, samples from the superficial and subsuperficial layer were taken from the two study areas and were subjected to coarse-fraction grain-size analysis. All analysis was carried out in the laboratory of physical geography at the Centro de Estudos Geográficos of the University of Lisbon using sieves at 0.5ϕ intervals.

Grain-size distributions were characterised using the graphic mean, inclusive graphic standard deviation, inclusive graphic skewness and graphic kurtosis, following Friedman and Sanders (1978, p.75). The samples were also subject to a hierarchical classification using Ward's method. This method involves the construction of a hierarchical tree diagram where sample data (relative weights of each grain-size class) is used and plotted according to their Euclidean linkage distances using an analysis of variance.

3.2 *Grain-size analysis*

(a) Superficial layer

As can be seen in the cumulative grain-size curves, the curves from the superficial layer of the accumulations found in the Serra do Gerês and Serra da Estrela are very similar (Fig. 7-a). In this *ca.* 1 cm thick layer it is typical to find the mode in the –2 or –1.5ϕ classes, a fact that generally depends on the position of the accumulation from where the sample was taken. It is rare to find sediment coarser than –2.5/–3ϕ. A sample from the lower sector is coarser than one from the upper part of the accumulation (Vieira 1995, 1998). The modal class in the coarse fraction originates a steep grain-size curve in these classes, indicating better sample sorting. The sediment distribution is usually unimodal with a regular decrease in weight towards the finer classes.

In what respects to the statistical grain-size properties of the samples from the superficial layer, the graphic mean varies between –1.10ϕ and –1.80ϕ highlighting the coarse character of this layer. The samples are usually moderately sorted, in some cases well-sorted and very well sorted with one sample lying in the upper limit of the poorly sorted class. The inclusive graphic skewness reflects the coarse character of the layer, with the majority of the samples showing a very positive skewness and two positively skewed. The graphic kurtosis shows that samples are usually leptokurtic or mesokurtic with some cases very leptokurtic or extremely leptokurtic.

The samples from the superficial layer in the two mountain ranges are so similar that it is difficult to identify the differences between them. In the graphic kurtosis, it is possible to identify a rough leptokurtic tendency for samples from the Serra do Gerês.

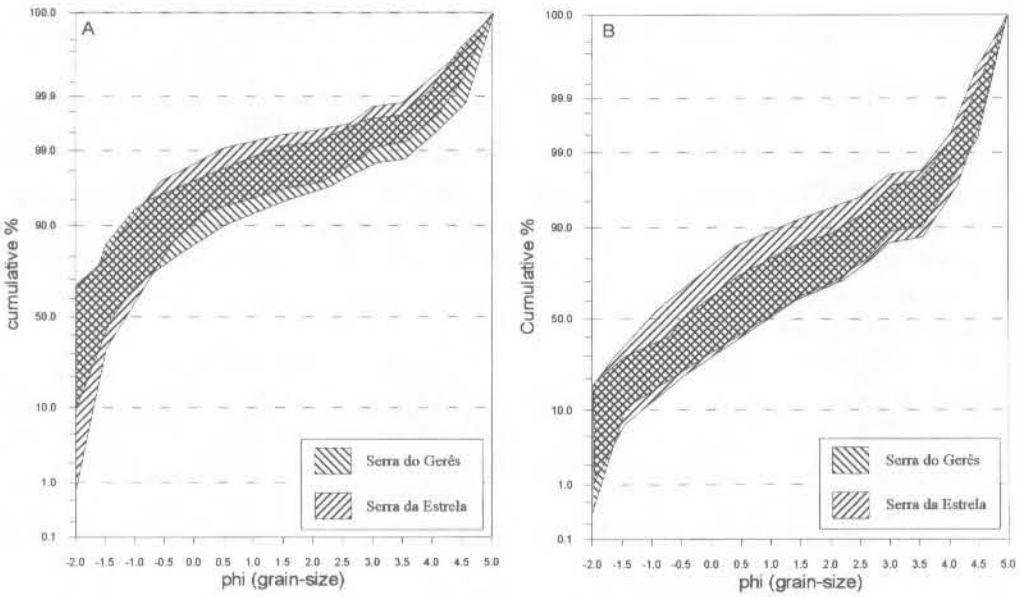

Fig. 7. Grain size curves for superficial (a) and subsuperficial (b) samples from coarse sand accumulations of the Serras da Estrela and Gerês.

(b) Subsuperficial layer

The subsuperficial layer appears below *ca.* 1 cm depth in the accumulations and is very different from the superficial well-sorted layer. Its poorly sorted character is visible macroscopically and supported by the statistical grain-size parameters. Grain-size distributions are variable, but when plotted on a cumulative basis using a Gaussian y-scale, the curves show some similarity and typically low sorting (Fig. 7-b). Additionally, they are finer and more poorly sorted than the samples from the superficial layer.

The graphic statistical parameters support the observed in the grain-size curves. The graphic mean varies between 1.02ϕ and –0.77ϕ demonstrating the finer character of this layer. Inclusive graphic standard deviation shows that all the samples are poorly sorted to very poorly sorted. This contrasts with the superficial layer samples, which were usually moderately sorted. The skewness index indicates that grain-size distribution varies between nearly symmetrical and positively skewed, showing a net tendency for the later type to dominate in the samples from Serra da Estrela. Finally, the graphic kurtosis shows the greatest variation, reflecting the heterogeneity of the subsuperficial layer. Although very leptokurtic to very platykurtic samples occur, the majority is mesokurtic, and very platykurtic.

(c) Analysis of the tree-diagram

The tree diagram isolates two major sample groups, highlighting the grain-size differences between the superficial and subsuperficial layers (Fig. 8).

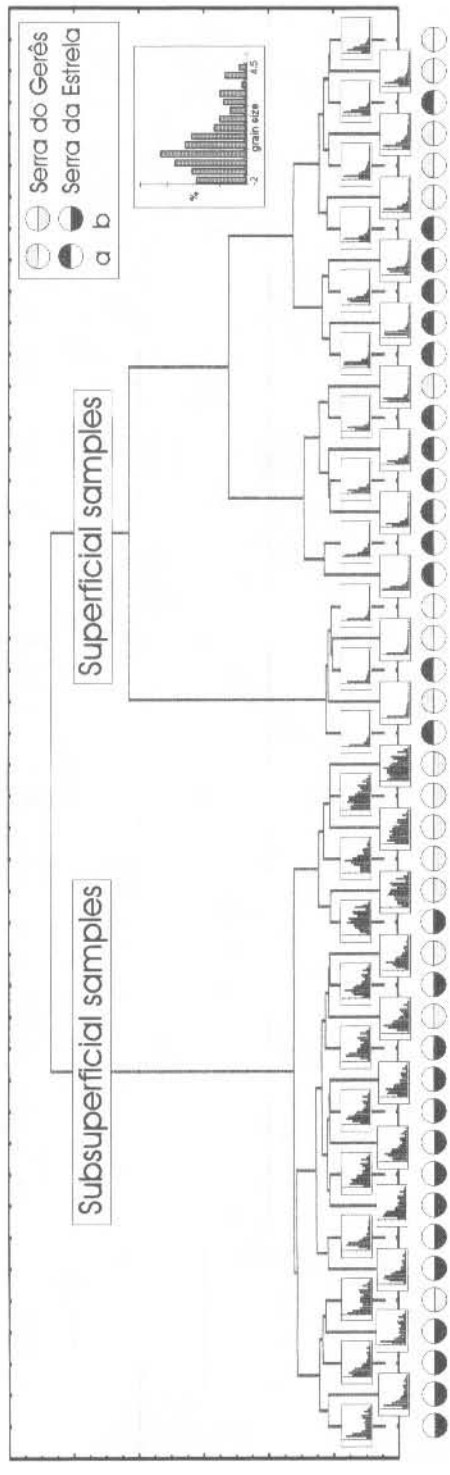

Fig. 8. Tree diagram for the superficial (a) and subsuperficial (b) layers samples from the Serra da Estrela and Serra do Gerês.

It is also noticeable that there is no major spatial organisation with respect to grain-size characteristics. This suggest that the samples reflect a more process-dependent than space-dependent genesis. However, some superficial and subsuperficial samples from the Serra do Gerês have a more poorly sorted character.

Most of the partitions in the tree-diagram appear at small Euclidean distances, reflecting the overall similarity of the samples inside the two major groups and is especially clear in the subsuperficial samples. In the superficial layer group, a minor partition occurs at a significant distance, isolating individuals that are particularly coarse-grained. From the five samples that represent the group, three correspond to the lower sector of the accumulations (for the other two the positioning is unknown), where samples are typically coarser. A second division occurs in the main group of the superficial samples reflecting the coarse character of the samples. Although finer than the other ones, they are distinctly coarser than the other superficial samples. Because the majority of the samples from this partition also correspond to the lower sector of the accumulations, a similar interpretation is proposed.

4 *Evidence, discussion and future work*

The field evidence gathered from the Serra da Estrela and Serra do Gerês makes it possible to propose a genetical model for the coarse sand accumulations. This evidence can be synthesised briefly:

- Coarse sand accumulations are widespread in the wind-exposed interfluves of both mountain ranges;
- Three main types of accumulation were found and appear to be related to different evolutionary stages;
- The accumulations show two layers: a superficial one, coarser, relatively well sorted usually ca. 1 cm thick layer and a subsuperficial, and poorly sorted layer;
- The lower sector of the superficial layer is usually coarser than the upper sector;
- The aspect of the accumulations is very stable in the studied areas and coincident with the wind deformation of small shrubs;
- Wind data from the Serra da Estrela supports an aeolian genesis for the accumulations;
- Grain-size analysis supports the macroscopical similarity observed between the accumulations from areas about 180 km apart, the Serra do Gerês and Serra da Estrela.

The facts presented above stress the importance of wind in the accumulation and genesis of the described features. The vertical sorting, which is continuous from top to base may result from the washing and deflation of fines that occur after the main accumulation phase (of aeolian origin), and resulting in a lag-surface (Fig. 9-a, b and c). However, the thickness of the superficial layer (usually about 1 cm) makes it a more than one granule thick, atypical lag-surface. This fact suggests that this layer may be the result of an overlapping of the lag-surfaces which have evolved from multiple small accumulation episodes over an original major accumulation (Fig. 9-d). It is thus necessary that a first accumulation phase occurs (originating the microform), followed by multiple wash and deflation episodes intercalating

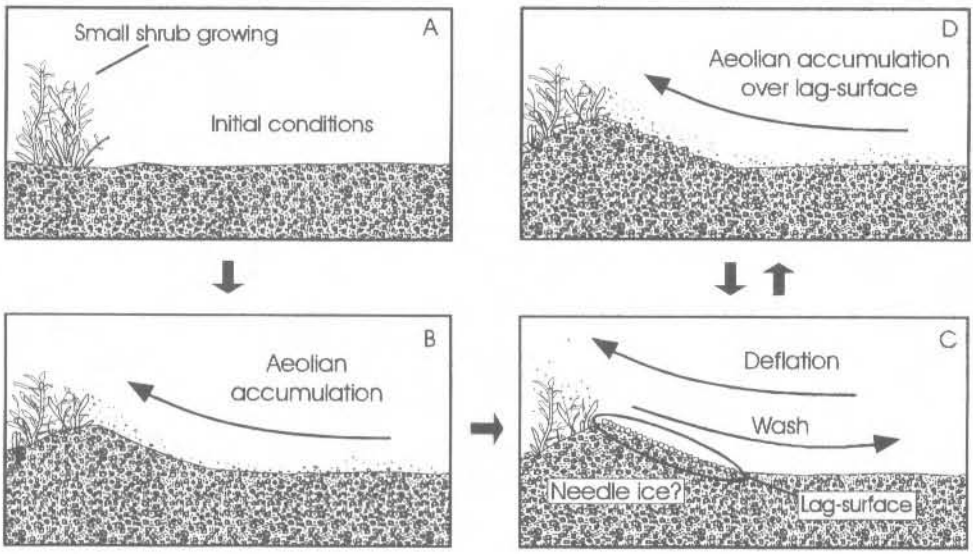

Fig. 9. Genetical hypothesis for the coarse sand accumulations.

with smaller accumulation events (repetition of the sequence shown in Fig. 9-c and d). This would allow for the thickening of the superficial layer. Fines downwashing must also be an important process. Furthermore, needle-ice, which is a frequent process in the studied mountains (Vieira 1995, 1996) may also play a role in the upward movement of the coarse particles.

The longitudinal differentiation between the superficial layer in the upper and lower sector may be related to an higher wash energy near the accumulation's bottom (sometimes accumulations lay near runoff sectors), that depletes the fines, and additionally to wind sorting during accumulation events (the smaller granules being easier to transport to the upper sectors).

This article shows the geomorphological significance of aeolian and water processes in higher sectors of the Serras da Estrela and Gerês. However, it falls short at indicating the rates of accumulation or their true genesis. Future research following the completion of work in the Serra da Estrela area hopes to better understand, support or discard the hypothesis presented here.

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