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THE INTERACTION BETWEEN MARINE AND SUB-AERIAL PROCESSES IN THE EVOLUTION OF ROCKY COASTS. THE EXAMPLE OF CASTELEJO - SW, PORTUGAL

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THE INTERACTION BETWEEN MARINE AND SUB-AERIAL PROCESSES IN THE EVOLUTION OF ROCKY COASTS: THE EXAMPLE OF CASTELEJO - SW, PORTUGAL*

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ABSTRACT

The rocky coast of Castelejo (located in a Natural Park - Parque Natural do SW Alentejano e Costa Vicentina) its an excellent example of the complexity that is connected with the actual evolution of those type of coasts. The fieldwork supported by cartographic analysis, by aerial and land photographs, allowed us to produce a detailed geomorphological map (scale 1:5 000) where the landforms and processes of this area are indicated. At Castelejo we have a very active actual dynamic, where erosion and accumulation processes either marine or sub-aerial, combine with changes in frequency and magnitude. The work developed in the last 3 years, together with punctual surveys in the last 15 years, show that there is a cyclic sequence of processes that depend on the wave climate (that controls the presence or absence of sand in the beach) and on the climatic regime, mainly the wind and the intensity and concentration of the rain.

KEYWORDS

Rocky coasts, geomorphological processes, Portugal.

1. INTRODUCTION

In the last decades a large amount of money has been spent in protection works, whenever a sea storm or a heavy rainfall cause damages in urbanized areas located at the coast. Those works rarely solve the problem because they are often made in the ignorance of the causes that are provoking the local retreat of the coast. In the particular case of the rocky coasts the

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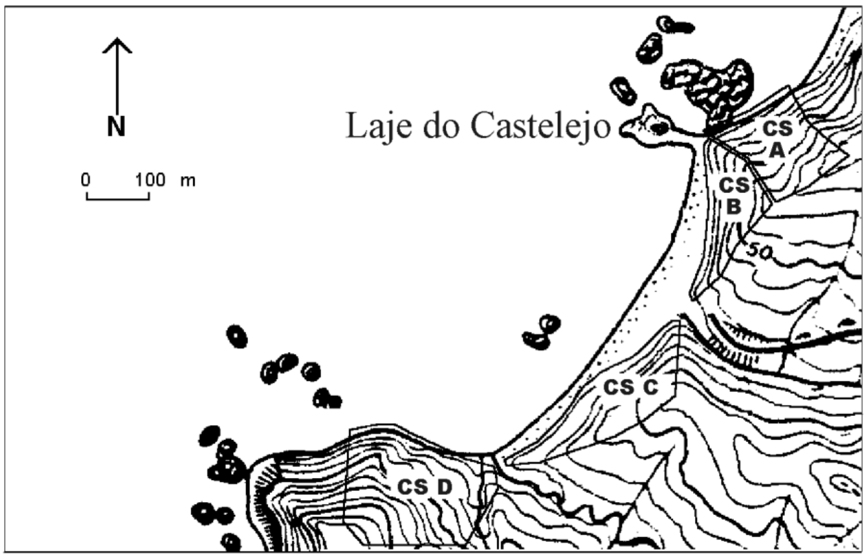
causes are generally multiple and they change spatially and temporally. Therefore, the determination of all the factors and processes that control the actual dynamic of the rocky coasts is a fundamental step not only for understanding how these coasts evolve today, but also to predict their future evolution.

In the SW of Portugal there are several examples of rocky coasts with a particular actual dynamic (Neves, 1995; Neves, 1996). In this case, we chose Castelejo, because of the complexity and richness of the actual evolution of this area, inserted in a Natural Park - Parque Natural do SW Alentejano e Costa Vicentina.

2. Material and Methods

The research on the rocky coast of Castelejo was based mainly in fieldwork supported by cartographic and air photograph analysis. We point out the use of land photography taken in different years at the same places as a complement that gives us useful information in the coastal dynamic research. With all the elements collected it was possible to compose a detailed Geomorphological Map, at the scale 1:5 000, reduced afterwards (fig. 1). We decided to include in the map some of the processes that occur in the margins of two small valleys that exist in the area because the landforms created by those processes and their evolution could affect the future coastal slope morphology. We divided also the coastal slope (CS) in four sectors (A, B, C, D) aiming to make the explanation easier (fig. 2).

Figure 2 - Division of the coastal slope of Castelejo in four sectors (CS A, B, C, D)



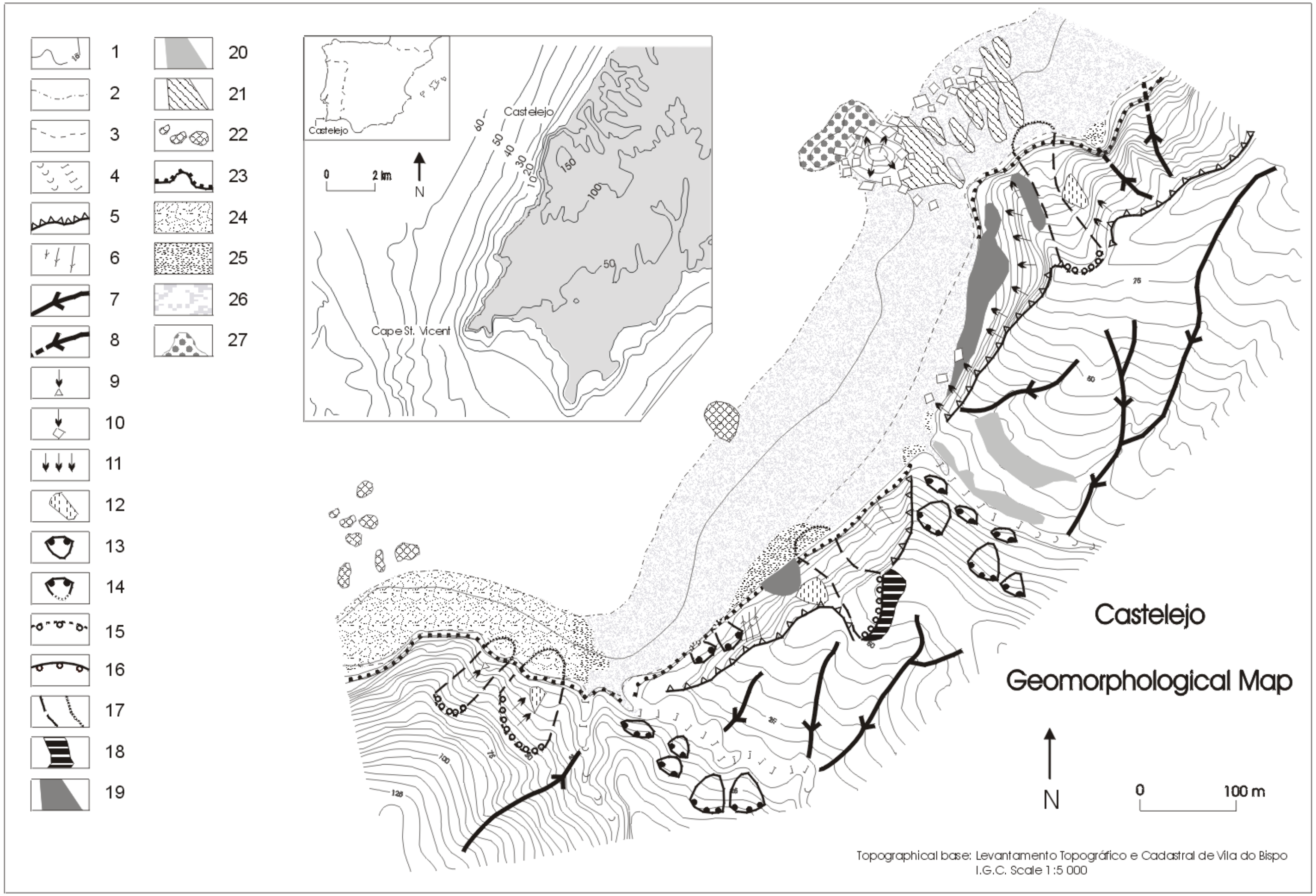


Figure 1. Geomorphological map of Castelejo. 1-contour line (in metres); 2-mean level of low tide; 3-mean level of high tide; 4-small valleys with the bottom in U and flat; 5-top and base of the coastal slope; 6-rill erosion; 7-gully; 8-suspended gully; 9-high magnitude rockfalls in the turbidites; 10- high magnitude rockfalls n in the aeolianites; 11-low magnitude rockfalls in the turbidites; 12-talus slope; 13-superficial landslide; 14-lobe of superficial landslide cut by marine erosion; 15-old translational landslide scarp; 16-recent translational landslide scarp; 17-slide limit (certain; probable); 18-very unstable sector (with cracks); 19-climbing dune in the coastal slope (with a coluvio-aeolic deposit); 20-climbing dune in the margins of the valley (with a coluvio-aeolic deposit); 21-shore platform; 22-skerries; 23-cliff; 24-blocks and boulders; 25-cobbles; 26-sand; 27-"plateforme à vasques"in the aeolianites

The rates of retreat presented were calculated comparing aerial photographs of different years (1982 and 1989) and using pegs placed near the top of the coastal slope in 1994. We must also point out that in this article we consider the coastal slope as the part of the slope facing the sea that was cut mainly by sub-aerial processes, while the cliff is the base of that slope that was shaped mainly by marine processes.

3. Geomorphological Analysis of Castelejo

The rocky coast of Castelejo is located 10 km NE from the Cape S. Vicent in the western coast of Algarve (fig. 1). The entire portuguese SW coast presents a dynamic that clearly individualizes it from the rest of the portuguese littoral: the sedimentary balance is negative, both in the coastal platform and in the continental shelf (Pereira, 1990), mostly due to a weak supply from the watercourses (in this region they have small importance), and to a lack of sediments in the continental shelf, that is also relatively narrow (width less than 40 km, even not superior to 10 km) and with a very strong slope angle - superior to 10m/km- (Pereira, 1993). Therefore, it is a coast with scarce and narrow beaches, where cliffs are predominant (Pereira, 1996).

The waves that reach the SW coast are generated in the North Atlantic and they come from NW in 80% of the situations (Pires, 1989). More rare, but also important are the waves coming from SW which correspond frequently to storm events.

Near to Castelejo, coastal platform reaches heights of 100 to 130 m and is deeply cut by some small valleys. The studied area, which includes some 1000 m of coastline (with a NE-SW orientation), presents a shore platform-cliff-coastal slope system, with the shore platform mostly covered by a sand beach with 600 m length and 150 m maximum width (spring low tide). All the system is cut into the Flysch Group of Baixo Alentejo (Carboniferous turbidites composed of an alternation of grauwacke and schists with a variation in thickness, usually less than 200 mm, but in some sectors with layers of more than 600 mm thick). This material is very folded and intensely faulted by the countless tectonic efforts to which the all region has been submitted during its long geologic history. There is also in some sectors of this area (Laje do Castelejo - fig. 2 - and the NE margins of the small valleys) a group of aeolianites, with a medium consolidation degree (Pereira, 1987).

The slopes facing the sea at Castelejo present some morphological characteristics which allow us to consider that in its evolution the action of continental processes are prevailing, in particular mass movements - slides and rockfalls - (Neves, 1995). In spite of the intense fragmentation in this area, which introduces modifications in the resistance and permeability of the materials, and of the constant changes of stratification characteristics from a sector to another, it is possible to establish some distribution patterns of the different slope erosion processes (Table 1). Therefore, in the places where schists and grauwacke are of small thickness (<200 mm) and stratification is opposite to the sea, the slope evolves by rockfalls of low magnitude but high frequency. This process affects particularly the CS C (fig. 1). Only in three years of measurements the retreat of the coastal slope top due to this process, is established between 50 and 150 mm/year. In sectors not reached by the sea, this rockfalls can produce talus (fig. 1) composed by heterometric and angular material with a 34º/35º slope equilibrium angle, which is confined between the limits indicated by Selby (1982) when he states that "most talus slopes have angles between 30º and 38º ". In the sectors where the outcrops, particularly the grauwacke, reach a thickness of more than 600 mm, and the stratification is also opposite to the sea, the tendency is to the occurrence of rockfalls of high magnitude and low frequency. This type of rockfalls occurs particularly in CS D (fig. 1). On the other way, the retreat of the coastal slope cut in grauwacke and schists leaves the aeolianites overhanging in some sectors. The cornices formed that way are going to evolve by rockfalls (fig. 1), usually of large blocks, also in a high magnitude and low frequency process.

Table 1 - Main erosion processes acting at the Castelejo coastal slopes

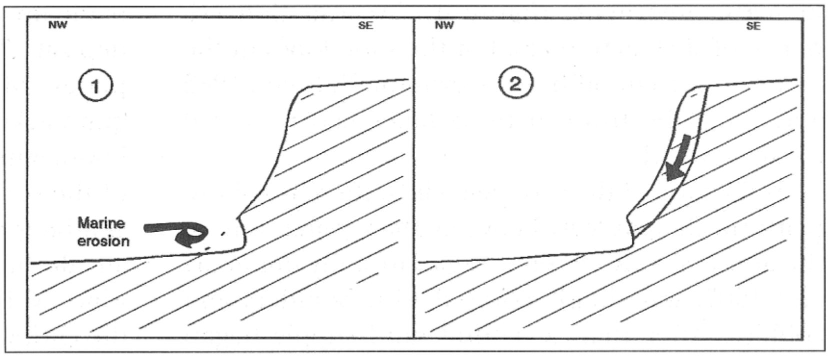
<table>
<tr><th></th><th>Type of erosion</th><th colspan="2">Lithology and structure</th><th colspan="2">Evolution processes</th></tr>
<tr><td>Base of the coastal slope</td><td>Marine erosion</td><td colspan="2">Turbidites
Aeolianites</td><td colspan="2">Abrasion (cliff formation)</td></tr>
<tr><td rowspan="4">Rest of the coastal slope</td><td rowspan="4">Sub-aerial erosion (mass movements)</td><td>Turbidites of small thickness (<200 mm)</td><td rowspan="2">Stratification opposite to the sea</td><td rowspan="3">Rockfalls</td><td>Low magnitude and high frequency</td></tr>
<tr><td>Turbidites of high thickness (>600 mm)</td><td rowspan="2">High magnitude and low frequency</td></tr>
<tr><td colspan="2">Aeolianite cornices</td></tr>
<tr><td colspan="2">Turbidites with a stratification towards the sea</td><td>Rockslides</td><td>High magnitude and low frequency</td></tr>
</table>

Another kind of mass movement - the slides - also occur in Castelejo, with a significant importance to the evolution of the area, since there is only one of the coastal slopes (VC B) where those types of mass movements don't take place. Despite an annual average precipitation less than 500 mm, sometimes heavy and concentrated rainfalls occur in this region, that can cause a slide event. In those situations the daily precipitation exceeds, in many cases, the monthly average values (for instance, in Sagres, near Cape S. Vicent, it was recorded 185,4 mm in 24/11/88, while the November average precipitation value for that station is less than 70 mm). In the margins of the two small valleys of the area, several superficial slides were registered affecting only the deposits that cover those slopes. On the contrary, in the coastal slopes only two superficial slides were found, because here most of the slope is cut in the substratum. Thus, all the rest of the slides registered, following the classification proposed by Varnes (1984), belong to the translational rock slide type, hitting the substratum in places where the stratification tends towards the sea, and affecting large volumes of material. They all occurred before 1982, but almost all show evidences of subsequent reactivation. Particular attention must be given to the CS C where, between 1982 and 1989, several reactivation of the translational slide located there caused a 7 to 9 metres retreat of the top of the slope; adding to this fact, the area above the main scarp is deeply unstable, with several cracks parallel to the slope top, separating compartments that already suffered some displacements. This facts point to a strong probability of the occurrence of new mass movements on this sector in a near future.

There are not much landforms in the coastal slopes of Castelejo connected with the action of the hydric erosion. We registered two small sectors in the CS C affected by rill erosion and two gullies in the north sector of the CS A (fig. 1). The channels formed by rill erosion in the CS C have depths and widths that usually don't surpass 250 mm and they occur in sectors where the slope is covered by deposits, composed mostly by millimetric schist clasts that give an increased impermeability to the slope; the slope angle is strong in the south sector - 30º - and very strong in the north sector - 56º. Here, the rill erosion is evenly affecting the cliff. This fact indicates that, though the waves are responsible for the general cutting of this part of the slope, lately the wave climate was not so active to surpass the erosion caused by the few rainfall episodes registered in the area. The two gullies indicated in the CS A (fig. 1), that were not measured because they are located in a dangerous access place, present the particular characteristic of being suspended. This feature can suggest that the rate of retreat of the coastal slope base had exceeded the cutting capacity of the rainfall running waters.

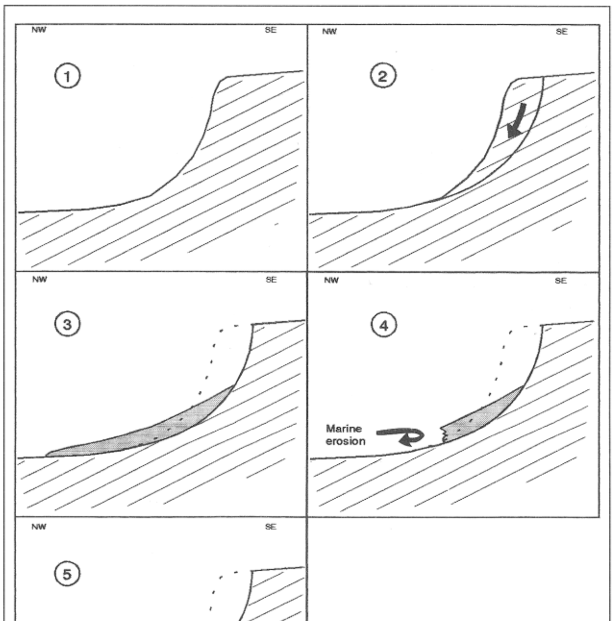
The base of the coastal slope morphology, in some sectors, presents evidences that it was cut by the action of the sea, forming in this way a cliff. This action of the sea can also regulate the evolution of the entire slope with a direct or an indirect influence. In a direct way, the cutting of the slope base increase here its angle, contributes to the instabilization of the rest of the slope by loss of its base support and, as Sunamura (1992) also concluded, may provoke the occurrence of mass movements (fig. 3). The rock slides that take place in the CS D (fig. 1) can be included in this case.

Figure 3 - Direct action of the sea in the destabilisation of the coastal slope



The wave action is also important in the carrying away of the materials accumulated at the coastal slope base coming from the mass movements that occurred in the slope. Those deposits when covering the slope, act has a protection buffer against the slope erosion, as was also stated by Dias & Neal (1992). Then, the transport role of the waves unprotect again the slope and therefore indirectly is advantageous for the reactivation of the mass movements (fig. 4).

Figure 4 - Indirect action of the sea in the destabilisation of the coastal slope



We can find evidences of this action in all of the slides lobes in the area that are cut off by wave erosion. Between 1982 and 1989 the front of those lobes had retreated 3 to 6 metres (Table 2).

Table 2 - Retreat of the rockslides lobes between 1982 and 1989 at Castelejo.

Coastal slope	Retreat
A	6 m
C	4-6 m
D	3-4 m

At the base of the cliffs of Castelejo one can find a shore platform, that, at least between 1983 (when one of the authors - A.R.Pereira - began to study this area) and 1987, was simply covered with boulders and cobbles. After that, there began a natural sand supply that covered the shore platform with a thickness of more or less 1,5 meter, forming a beach. The strong wind that is felt in this coast (from December to March, the SW and W winds and in summer the N wind, reach an average speed that surpasses 20km/h) supported the transportation of the fine sand grains and its deposition at the base of the coastal slope fossilizing by this way the cliffs, and forming climbing dunes that sometimes rise above 20 metres high. These dunes are not only made up of aeolic sands, but they include also slope deposit. This deposit, composed of small thin plates of schist and heterometric pieces of grauwacke, comes mainly from the high frequency and low magnitude rockfalls that occur in some sectors of the coastal slope. If we make an incision in the climbing dunes, it is possible to remark that there is an alternation between short (?) episodes of strong wind, that provokes a sand accumulation against the cliff, with periods where the arrival of slope deposits is predominant. Consequently, these climbing dunes are the result of the interaction between two processes (aeolic and mass movement) and they present therefore, a particular sedimentological composition.

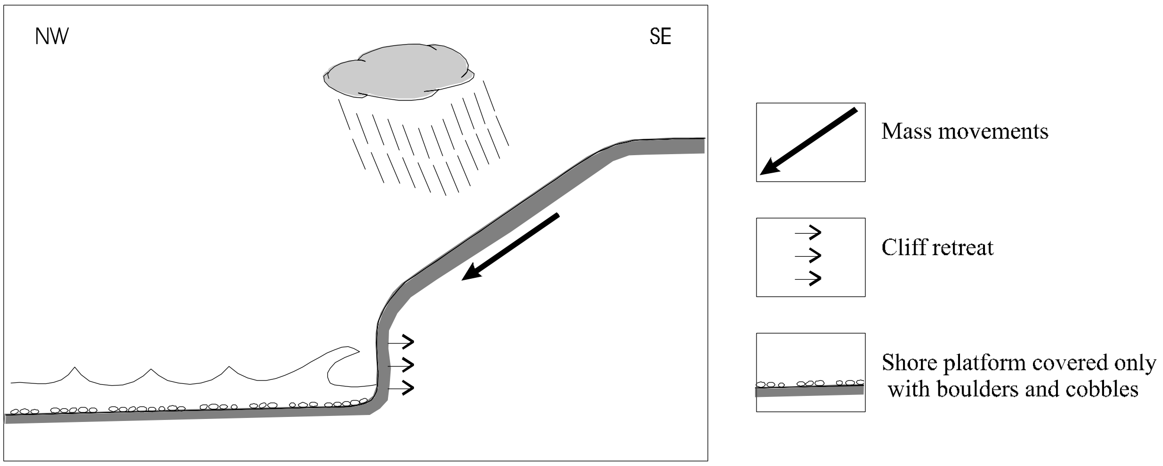
4. CONCLUSION

The observations carried out in this area, that we briefly reported, allow us to consider that the coastal slope evolution is strictly connected with the beach dynamic, namely with the shore platform covering, sometimes with boulders and cobbles and sometimes with sand.

It was clearly recognized the existence of a cycle with two phases. These phases shouldn't be connected with human actions, because there were no major human changes in the sediments transport of the regional watercourses, nor important coastal occupation that can disturb the coastal dynamic. The duration of each of these phases seems, therefore, to rely essentially on the wave climate, namely on the frequency and intensity of the sea storms.

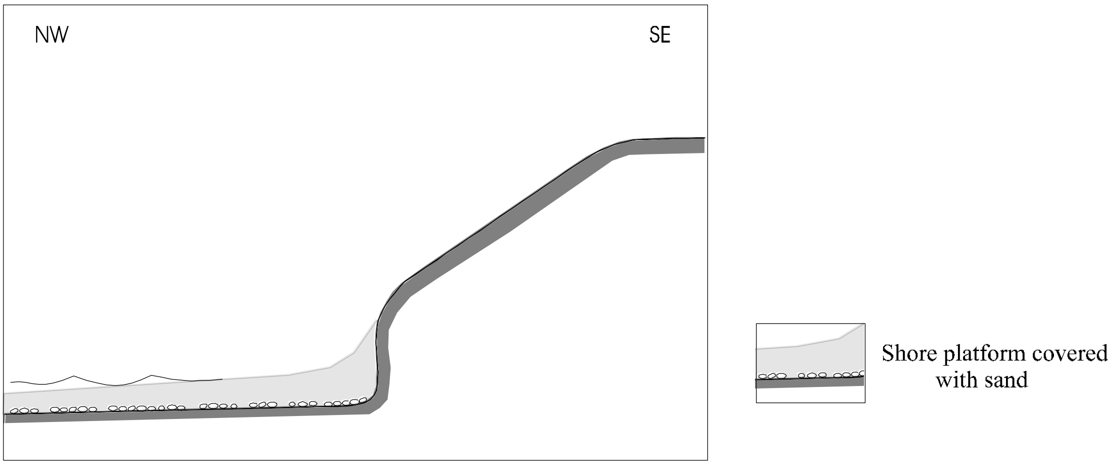
There is a sea storms phase, correlative of a period of fluctuating duration, where series of sea storms reach the area, sufficiently energetic to take away the sand and leaving the shore platform only with the boulders and the cobbles (fig. 5). In this situation the cliff stays unprotected, the waves reach it with violence, and use the boulders and the cobbles to attack its base. The cliff retreat, as was already indicated, and provokes the instabilization of the rest of the slope. Often, these sea storms occur along with heavy rainfall, capable of trigger off the mass movements on the slope. Therefore, there is a convergence of situations that causes an intense activity of the marine and sub-aerial processes. In these circumstances, the retreat of the whole of the coastal slope reaches higher magnitude, either by the waves action, or by events of big mass movements, whose deposits are carried away by the sea, increasing the slope instability. The coastal system of Castelejo, remain in this phase since the end of the 70's till 1986.

Figure 5 - Scheme of the sea storms phase at Castelejo



There is another phase, a calm phase, without sea storms events significant to the coastal dynamic. In this phase the shore platform is covered by sand (fig. 6). The fine sands are selected by the wind and carried away to build climbing dunes, fossilizing the cliff that was cut in the previous phase. As was also recognized for other places in the world by Sunamura (1992), the beach then begin to act as a defence against the swash current that rarely reaches the cliff base.

Figure 6 - Scheme of the calm phase at Castelejo



On the other hand the covering of the cliffs by the climbing dunes acts like a shield, and consequently the cliff erosion is much reduced. However, we must stress that in the coastal slope sectors where there is a propitious geological structure, even in this calm phase, the evolution by sub-aerial processes with high frequency and low magnitude rockfalls still persists leading to he creation of the coluvio-aeolian deposits already referred. In Castelejo, a calm phase has begun in 1987, and ten years later still remains.

This example points out the influence of the wave climate on the evolution of the coastal systems. The research on the wave climate of the past two decades that is being carried out for the Portuguese coast will surely help to state exactly its influence in the dynamic of the described cycle. It is hoped that the human pressure do not increases in this area, because as it is, Castelejo is an excellent place to study the interaction of the natural processes of landforms evolution.

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