CHAOTIC DISTRIBUTION OF RAVINES IN THE ARRABIDA REGION:IMPLICATION FOR RECENT TECTONICS

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ABSTRACT: The Arrabida mountain, in the center of Portugal, is a marginal relief on a passive margin. It has been uplifted since the Tortonian and a planation surface is now 110m above sea level. During the same time span, coastal erosion has been active and the former coastline was some 5 km more to the South. Uplift and coastal retreat, during various phases of sea level mobility may be correlated . As the base level changes, the geometry of ravines has to change also. A D.E.M. was realised and, after the execution of some mathematical morphology routines, a model for ravine evolution was tested. This model implies that the evolution of ravine incision is non linear and chaotic, at least at a meso scale level. Field work, performed from 1990 to 1994, with the help of the Luso French commission for marine Geosciences, has proven effective for calculating present day rate of retreat, and producing some evidences (but not quantified) for neotectonics. Any attempt to extrapolate in a linear way from present day measurements into the past are in total contradiction with geological data. So we are, once more, confronted with a non linear evolution. This paper is an attemp to correlate the chaotic evolution of the drainage system with the non linear evolution of the coastal retreat. Main forcing factors are eustatism, tectonics, as expected. The important point is that their respective role is scale dependant. Though sea level has changed a lot, the most efficient forcing factor is the steepness of the slope system. In this very peculiar way, this part of the continental passive margin is behaving like a very active slope system.

INTRODUCTION

This paper aims to link field work evidences of coastal retreat with a model of land form evolution. The Arrabida mountain, on the Portuguese passive margin is a spectacular land form, with high cliffs (over 300m) made of limestone and silty limestones. It is a wide anticline, overthrust to the South. It displays traces of ancient sea levels, with abrasion platforms, and is eroded by a complicated pattern of coastal ravines which continue under the sea. Field work has provided a lot of data about present rate of retreat and passed sea level have carved notches and platform that may provide some information about passed rates of retreat. In the first part of this paper a model is established for the ravine pattern. Then it is compared with measured retreat rates and a global model for coastal evolution is presented. This work is part of the DISEPLA program directed to understand the global input of land material to the Portuguese shelf.

A MODEL FOR A CHAOTIC EVOLUTION OF MESO SCALE RAVINES

The region of the Arrabida Mountain has been digitized (with Autocad) in order to produce a DEM. The pixel is 30*30m wide and the vertical resolution of the DEM is one meter. The algorythm used for interpolation was taken after Depraetere (1990) and relies on a cubic function.

1) Definition of land forms with mathematical morphology

On the DEM the land forms may be easily recognised by visual examination. Though, they cannot be quantified that way. A tool has to be found, in order to transform the

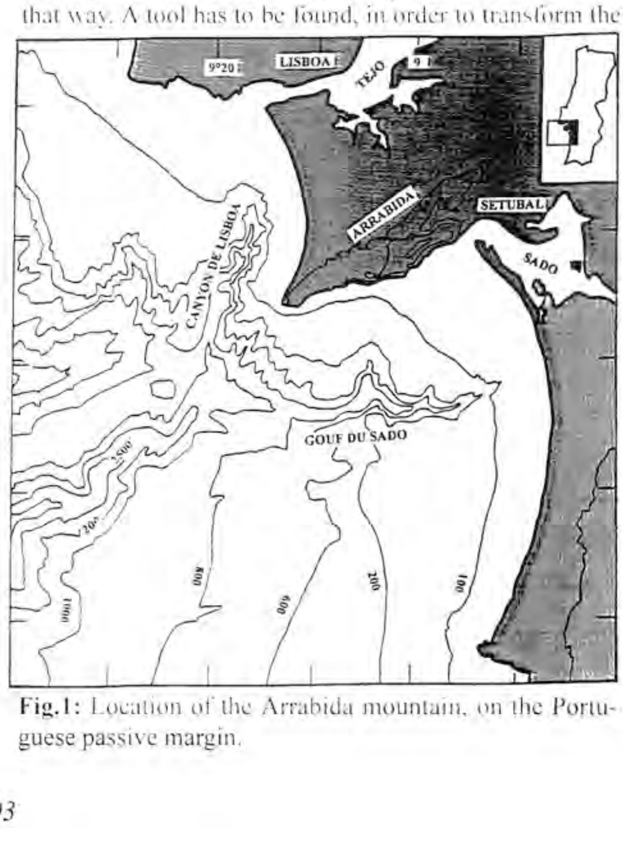

Fig.1: Location of the Arrabida mountain, on the Portuguese passive margin.

pixels into landforms, which are a combination of pixels. Mathematical morphology (Serra, 1982, Schmitt and Mattioli, 1994) was designed in order to describe forms, and not only pixels. It has been used in geomorphology (Regnauld and Thomas, 1990; Callot, 1993) and the basis of the method (combination of erosions and dilatations) is not described again here. The structuring element (*B*) varies from 3*3 to 9*9 pixels and four different files were produced for the extraction of hollows and four more for the extraction of crests.

The variation in the size of the structuring element gives an opportunity to describe the land forms at different scales of analysis. The relative incision (which is designed by «*i*») of a relief changes according to the size of *B*. A possible way of approaching the importance of scale induced variability is to plot the relative incision «*i*» against the surface of *B*, structuring element. This gives the two graphs of figure 2. Obviously, there is no correlation between the value of «i» and the growth of *B*. This exclude any possibility for a fractal relief.

From field evidences, this could be foreseen (thought out of qualitative arguments). It is supected, also from field evidences, that a discontinuous model may be quite more efficient to explain the localisation of the ravines on the Arrabida slope.

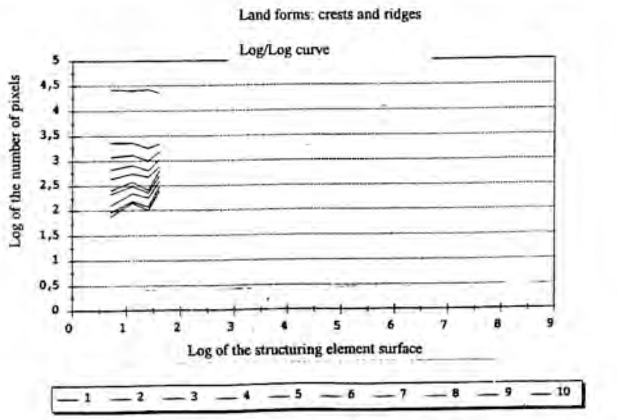

Fig. 2: Relations between the size of the structuring element B and the relative incision i. As the variation of these two elements are not corelated, the land forms are not fractal.

2) A chaotic model

Many different model for a chaotic distribution of land forms are known. Some are qualitative, such as the one used by Phillips, (1993). Others are quantitative, after the works of Bergé (et al, 1992, et al, 1988) and Turcotte (1992) has proposed a simple equation for chaotic behavior in earth sciences. This one, which is called the logistic map, is used in our work.

$$f(x=1)= af(x)\,(1-f(x))$$

In this case we assume that f(x) is the value of relative incision, «i». For a given *B*, we think that «i» varies from a low value (low incision) into a higher value (the relative incision increases throught time), as erosive effects are cumulating their effects. The parameter «a» would then represent all the erosive actions, together with slope gradient. For each value of *B* we can try to see if the evolution from «i» to «i+1» is described by this model. This would produce figure 3, where «i» is on the X axis and «a» on the Y axis.

According to a chaotic model a very small variation in «a» (ie: in initial conditions, of erosive power) would produce a very high amount of differences in the resulting value of f(x+1). The figures on the Y axis have been multiplied by -1000. So, in fact, the variations of «a» have to be read as 1000 times smaller than indicated. The different curves are representing different *B*.

If we assume that a ravine is evolving from a little stream into a wide canyon, this graphs shows obvious thresholds, related to the depth of the relative incision. From 1 to 2 meters of incision, the values for «a» are quite different, and the model is not efficient. From 2 to 5 (or 7m) of incisions, all the values of «a» are quite similar, thought they produce an increase in «i». The model works quite well. When incision is greater than 5 or 7, the model is no more a good one.

This is interpreted as an effect of scale related threshold. On the Arrabida slope, made of limestones mainly, there are many local forms (micro scale) as dolines, karstic features, small landslide, rock falls. They create low hollows, half a meter deep; or one meter for the bigger ones. They are distributed at random and cannot be discribed by a chaotic model. At meso scale level, there are ravines, which, in the beginning, start as the reunion of different rockfalls, one under the other, or close to the other. So, randomly located micro scale landforms may produce some meso scale ravines. These ravine do shift from one direction to an other, when their previous course is obstructed by boulders, or by a new rockfall. Their evolution is, thus, possibly chaotic, for they always change, but always end into the sea (the direct slope system acting as a strange attractor). The model says that this possibility is well supported by the distribution of the relative incision. At a macro scale level (here we consider incisions deeper than 7m) the course of the ravine is no longer changing. In fact few ravines do arrive to this stage of incision, and the only ones which can achieve this are the ones which are located on a fault line. Their distribution is no more chaotic, but follows a very determinist geometric pattern.

This discontinuous and chaotic model for meso scale landforms should produce a discontinuous discharge of sediment from the slope into the sea, and, probably, a discountinuous variation of the rate of retreat of the coastline.

A NON LINEAR RELATION BETWEEN MICRO, MESO AND MACRO SCALES.

The Arrabida is a coastal relief the geological history of which is well known. It has been extensively studied for the last four years, because it was elected as a protected site by the portuguese government. Funds have been obtained from the Luso-French Commission for marine Geosciences, with the help of IFREMER, JNICT, Ministry

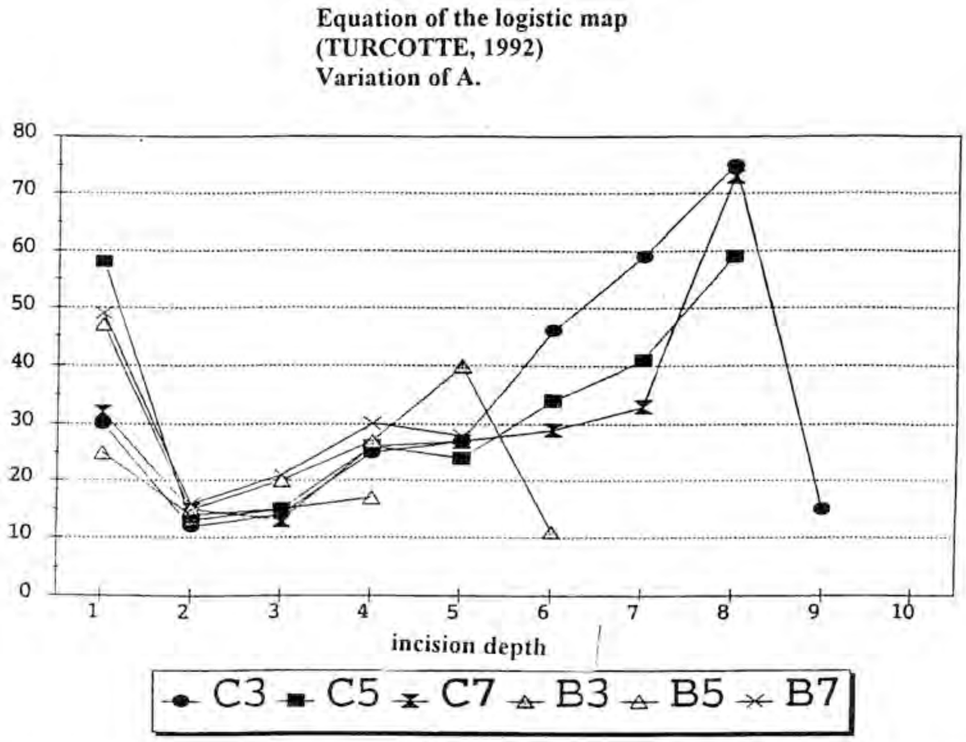

Fig. 3: Variation of the parameter «a» according to that of «i», in the logistic map equation of Turcotte (1992)

for Foreign Affairs and Universities in Lisboa and Rennes. During the previous years, offshore oceanographic caimpaign had produce many sismic profiles (Coppier and Mougenot, 1982; Mougenot 1989). So, different geomorphological indicators are well dated and are used to build a history of the evolution of the mountain.

1) Field work evidences

The Arrabida was a planation surface situated at sea level until the middle of Miocene, when uplift (mainly during the Tortonian) begun to create a series of coastal cliffs. This former coastline was some 5 km offshore, and has retreated since. A wide gap in knowledge extends untill some paleo shore lines are found and dated of the Eemian, at a present height of 20m. A 80 000 years old shore line (with a wave cut abrasion platform) is at +7m. Some submarine sea level have been observed at -21 and -12m, but they are not dated acurately. A submarine sea level at -7m is much more extended and is correlated with an estimated (but debatable) 5000BP stand (Erlides, 1992).

All these sea stands display erosional features. They can provide information about the amount of material that was removed from the cliffs at this stage. From the Tortonian the average rate of retreat would be 0,7mm/year, according to Odin (1994) chronology. An average rate, from the Eemian would give the figure of 5mm/year. For the middle of Holocene, only for the short stay at -7, the retreat rate would be 10mm/year. All these figures may be compared with present day measurements. The cliffs in Arrabida do retreat nowdays but at a very slow rate, with an average of 1mm/year. In some wave exposed locations 3 to 6 mm may occur. Rates such as 10mm are not observed today in Arrabida, but they are frequently calculated in the same type of limestone cliffs on the Northern Extremadura coast, which is directly exposed to atlantic swell whereas Arrabida is more a sheltered area.

2) A representation for a discontinuous evolution

The retreat rates may be represented on a graph where the X axis is time (logarithmic scale) and Y axis is the mm/year. This is figure 4. Time starts at Tortonian (beginning of the uplift of the Arrabida) and finishes today. The average rate of retreat from then to now is represented by a straight line. If the retreat rates were regular, all observed figures should be on this line. Obviously, they are above: if they were extrapolated they would induce a very high rate for the è millions years period. the Arrabida coastline would have been situated south of Sines, which is not supported by any field evidences.

Thought, the high rates of retreat of the Holocene have to be compensated by some other low rates of retreat. In fact, if we had more data, the retreat would be represented by a very sinuous line, alternatively above and under the average rate. This an other evidence of a very vareiable rate of erosion. It may be linked with many factors, one of them being the pattern of subaerial drainage (which is chaotic) and the other being the relative sea level.

A POSSIBLE MODEL FOR SCALAR INTEGRATION

A model is proposed in order to describe how this chaotic pattern of drainage may be correlated with sea level changes in order to produce this higly variable rate of erosion.

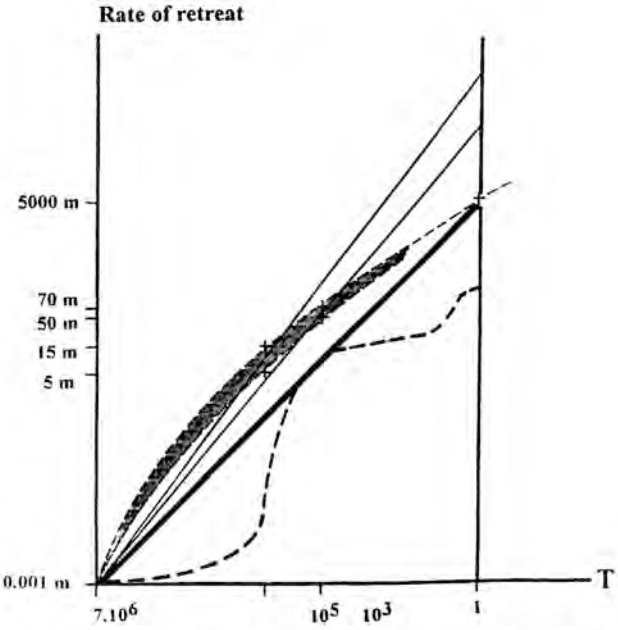

Fig.4: Variation of retreat rate of the coastline with time.

1) The requirements of the field works

Field work in this region has given a lot of qualitative informations about coastal erosion. The results show that different type of ravines are present, and they concern both the subaerial and the submarine part of the slope. On the subaerial part we have three main types of ravines, from the isolated rockfall and its trace on the slope to the well organised ravine with tributaries. They all arrive to the coast line where some of the material is removed by longshore drift, some stays on the beach and one part is moving on the submarine slope. There, three different ways may also be used, one with a rocky, gently sloping abrasion platform, one with gullies and one with a feature less slope.

Figure 5 present a conceptual model of the slope system. The main agent for erosion is not the sea, because Arrabida is a sheltered part of the Portuguese coast line. Erosion is mainly due to the abrasive power of sediment fluxes, flowing from the top of the slope down to the sea floor. The main source for these fluxes is the subaerial part of the slope: so, as the sea level rises, this source is reduced.

2) Construction and application of the model

The mathematical model is intended to be as simple as possible. It is expressed by this equation

$$T = 1/a\ (QSM + QSA2) + D$$

T is the total amount of eroded material; a is the relative sea level, measured from the base of the submarine slope; QSM is the submarine erosion provoqued by sediment fluxes on the submarine slope, QSA2 is the part of

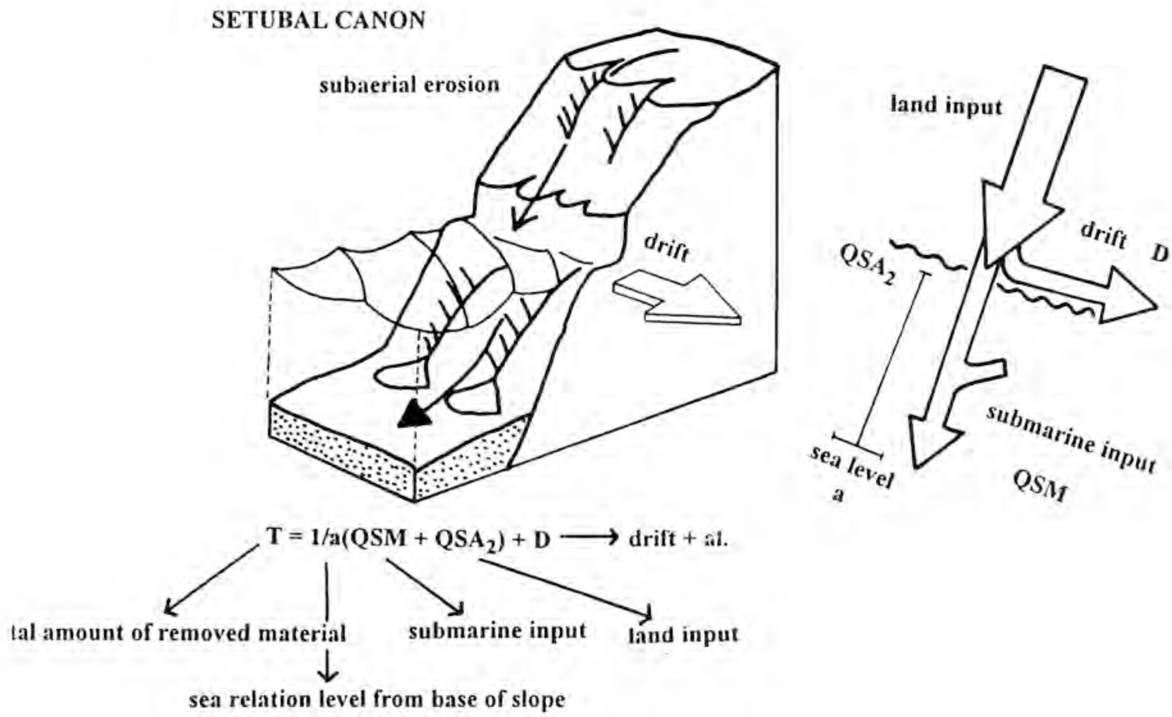

Fig. 5: Field works evidences for the sediment input and output may be summarized into this conceptual model. material is removed from the emmersed slope by the drainage pattern. One part of it (less than 15%) is removed by longshore drift. The main part goes under the sea, eroding submarine ravines. So, the main erosive agent is the abrasive power of rock falls, slope debris and ravines that are active in both parts of the Arrabida : subaerial and submarine. If the subaerial input is reduced, then the whole system is slowed. For this reason our model is regulated by the 1/a parameter, whith «a» being the relative sea level, measured from the base of the submarine slope. This «a» is , from a qualitative point of view, linked with the one in figure 3. So, there is no quantified relation.

the subaerial fluxes that goes into the sea and D is the part which is stored on beaches, removed by coastal drift. So QSA2 and D are, together, the eroded amount from the subaerial part of the slope, QSM is the eroded part from the submarine area. All these quantities are supposed to be instantaneous measurements, cumulated over a one year period.

This model may be tested and compared to field work According to the chaotic model of ravine drainage, we can assume that QSA2+D (noted as Q) varies between the higher and the lower limit of the model $f(x=1)= af(x)\ (1-f(x))$.It will give a volume of sediment as it may be linked with the average width of the ravines. The following table presents, for each sea level («a») three quantities which are the higher, the mean and the lower possible figures. The duration of the sea stands is taken after Erlides, 1992.

Fig. 6: Application of the model to field works data. The model is giving higher figures, but they are compatible with the field data. Highest rates of erosion are probably uncommon.

Application of the model to field data

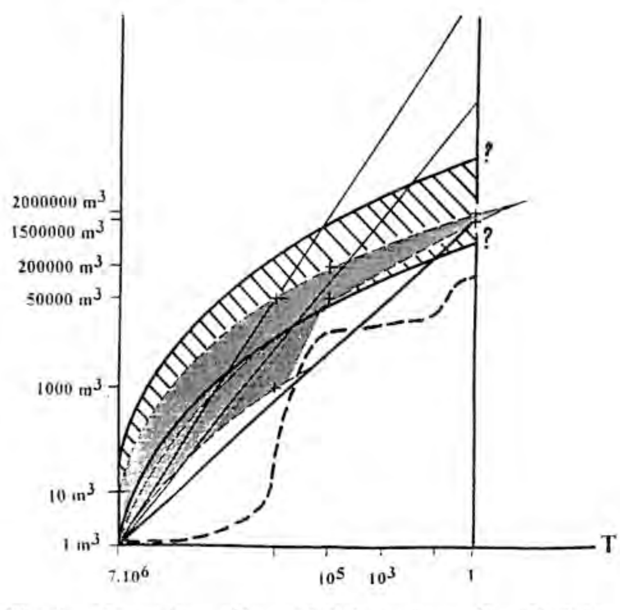

Fig. 6 - shows how this model fits quite well with field data. The calculated values are a little higher than expected: we interpret this as an evidence for the scarcity of high erosion rates, which are possible but uncommon.

CONCLUSION

A scale controlled evolution of land forms is clearly exposed by this model. Figure 7 displays its main elements. The main forcing factor for coastal retreat is «a», that is the relative sea level. Obviously this is an integration of tectonic uplift and of sea level changes. It is considered as a first order, macro scale forcing factor. The drainage pattern (that could be fractal in other places, but is here chaotic) is a meso scale process, which is considered as a second order forcing factor. The coastal erosion (stricto sensu) is not very efficient and varies according to the exact location of the coast. It may be exposed or sheltered, and is mainly sheltered in this area. We consider it as a micro scale, third order forcing factor. This allows to compare our model with others (Brunsden and Lin, 1994), as it relies on a very common approach of passive margins evolution: uplift, denudation and sea level.

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sea level	Q . high	Q mean	Q low	Duration	Q total(h)	Q total(m)	Q total (l)
+20	79	42	2.05	20 000	1580000	840000	40000
+7	92	51	2.28	10 000	920000	510000	22800
0	115	60	2.5	2000	230000	120000	5000
-7	146	75	2.8	1000	146000	75000	2800

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$$T = 1/a(QSM + QSA_2) + D$$

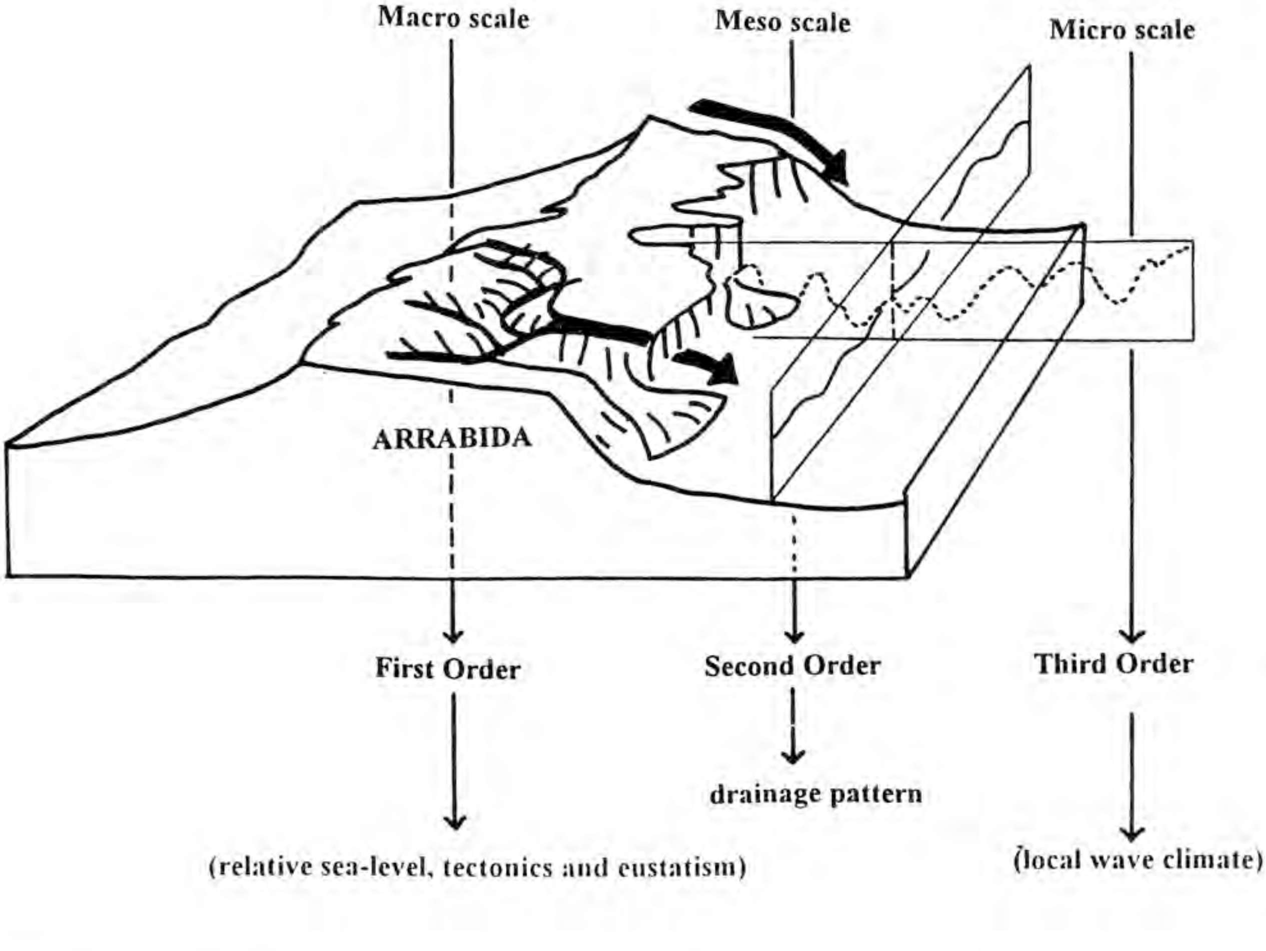

Fig. 7: A schematic diagram of coastal evolution forcing factors on the Arrabida shore line. Relative sea level (ie tectonics and eustatism) is the macro scale first order forcing factor. Drainage pattern, as a meso scale process is a second order factor whereas local wave climate varies at a micro scale and comes third. Any tectonic change would, then, be much more efficient that a climatic change to explain the evolution of land forms. This is probably linked with the present evolution of the Portuguese passive margin towards a stage of higher activity (Cabral, 1993).