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Relative Sea Level, Diastrophism and Coastal Erosion: the Case of Espinho (Portuguese NW coast)

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Abstract

The plotting of relative sea level for several stations belonging to the Iberian Peninsula shows different trends. These trends seem to be related with the diastrophism affecting more intensely the Northern and Southern façade of the Peninsula. The marine terraces (Pleistocene) at the North of Espinho (NW coast of Portugal) and the würmian/holocene deposits at the South of this city show opposite tectonic trends that seems to define a tectonic depression corresponding approximately to the localisation of Esmoriz lagoon. At Espinho, coastal erosion began in the middle of nineteen century. We think that the contemporary rising of sea level that began after the end of Little Ice Age, together with a possible subsiding trend, may be responsible for the severe erosion endured by this area.

1. INTRODUCTION

The understanding of coastal dynamics lies, ultimately, on the relationship between relative sea level and sediment supply to the coastline.

Relative sea level depends on several kinds of data that can be resumed in the simple diagram of R. Paskoff (1985).

Eustatic variations have a global character. On the contrary, the movements that take place in the continent are spatially localised. Generally, land movements have a slower rate than the eustatic variations. However, they must not be neglected, as eustatic variations can be reduced or amplified by the land movements, which have a much bigger duration in time. So, the net sea level variations must be understood as a resultant of the interference between sea-level changes and land movements. That's why we must always speak about "relative sea-level". Obviously this resultant can be different in adjacent areas if its diastrophism has a different rate or a different sense.

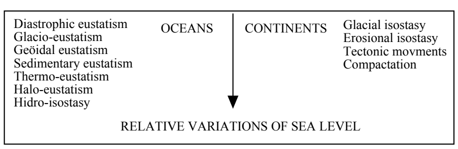

Figure 1: Phenomena interfering with long time variation of sea level (R. Paskoff, 1985)

2. SOME DATA AND ITS DISCUSSION

The permanent service for mean sea level (PSMSL) presents the data of more than 1000 sea level stations. The complete data set can be found at:

http://www.pol.ac.uk/psmsl/psmsl_individual_stations.html

Figure 2: Localisation of the stations discussed in the text

This data allows us to plot the recent sea level variations for 31 places within the Iberian Peninsula. The length of the series varies greatly. Only 20 stations have series of, at least, 10 years. So, the study of its variation is not equally reliable for all the 31 stations. That's why we only present the ones that seem more reliable. The chosen stations are localised in figure 2.

Within these 20 stations, we can see different kinds of relative sea-level plots: in most of the cases, the relative sea level is rising. However, sometimes, like in the case of Santander, the 2 stations (Santander I and Santander II, figures 3 and 4) have opposite trends, even if they are geographically quite close (only 2' of distance in longitude).

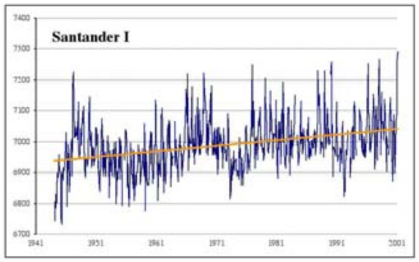

Figure 3: Monthly sea level variations at Santander I (1944-2000)

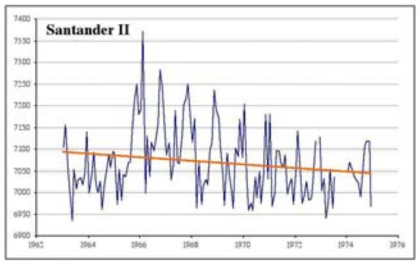

Figure 4: Monthly sea level variations at Santander II (1963-1974)

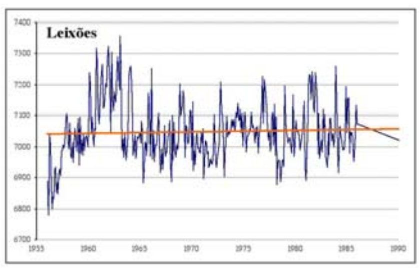

Figure 5: Monthly sea level variations at Leixões (1956-1985)

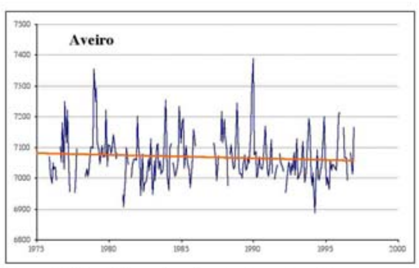

Figure 6: Monthly sea level variations at Aveiro (1975-1996)

To the South of the Peninsula, at Cádiz, we find again 2 stations quite closely situated (Cádiz II and Cádiz III) with opposite trends.

Most of the plots we made for the Portuguese coast show some sea-level rise. However, at Aveiro, there is a slight trend to a sea level drop.

Cascais has the longer series of the Iberian Peninsula (95 years) and one of the longest in Europe. Another long series correspond to Lagos (63 years), at Algarve.

At figure 11 (at the end of the paper) we plotted the trends of all the PSMSL stations in the Iberian Peninsula. Of course, the reliability of sea-level curves depends very much on the length of the series. That's why we also plot the number of years used to calculate the trends.

We can see that most of the stations have a positive trend. This means that at those stations the sea level is going up. However, the amount of sea level rise can be quite different from one place to another. And there are also some stations where the sea level is descending.

At figure 12 we can see the global sea level rise that took place after the end of Little Ice Age. The subsequent climate warming is the main cause of a slight a sea level of about 12 cm in 140 years (according to Mörner, 1973). This should mean a "global" trend of about 1mm/year.

Recent data is slightly higher. According to J. M. A. Dias (1990), the global sea level rise should be around 1,5mm/year.

Of course, the sea level variations that are clearly out of this "medium" range may be assigned to other phenomena (see figure 1).

The figure 11 shows that the trends at the western coast of Iberian Peninsula have a low variation.

However, when we approach the Northern and Southern coast, we have stronger variations and several cases of dropping sea level. We think that the only explication for this phenomena is the tectonic background of this areas, which represent the newer orogenic belts (Pirinéus at the North, Béticas at the SE coast) or the collision front between Eurasia and Africa (Southern coast west of Gibraltar).

3. TECTONIC BACKGROUND OF THE LITTORAL PLATFORM NEAR PORTO

We have made some attempts to analyse the distribution of marine terraces in the area between Vila do Conde and Espinho (fig. 13; Araújo, 1991, 1997, 2000 and 2001). Based on sedimentological criteria, we ranged the marine deposits in 3 different levels (the referred altitudes were find at Lavadores, where our staircase model has been defined):

- Level I (the highest, around 30m and the oldest); level II (between 18-15m); level III (from 10m till 5m; Araújo, 1991).

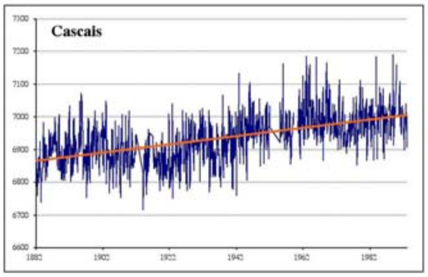

Figure 7: Monthly sea level variation for Cascais (1882-1992)

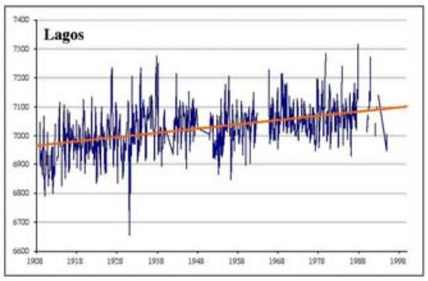

Figure 8: Monthly sea level variation for Lagos (1909-1985)

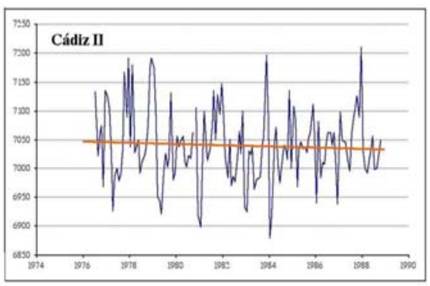

Figure 9: Monthly sea level variation for Cádiz II (1976-1988)

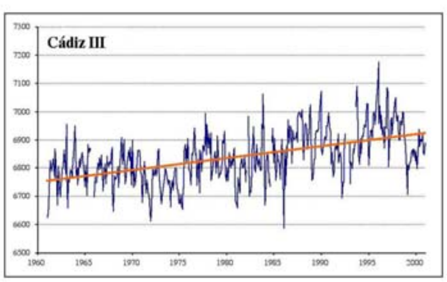

Figure 10: Monthly sea level variation for Cádiz III (1961-2000)

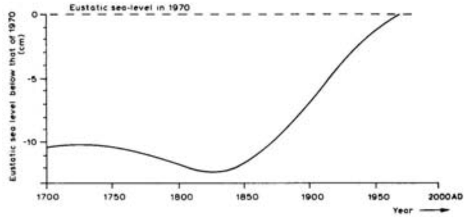

Figure 12: Eustatic sea level changes during the past 250 years (after Mörner, 1973).

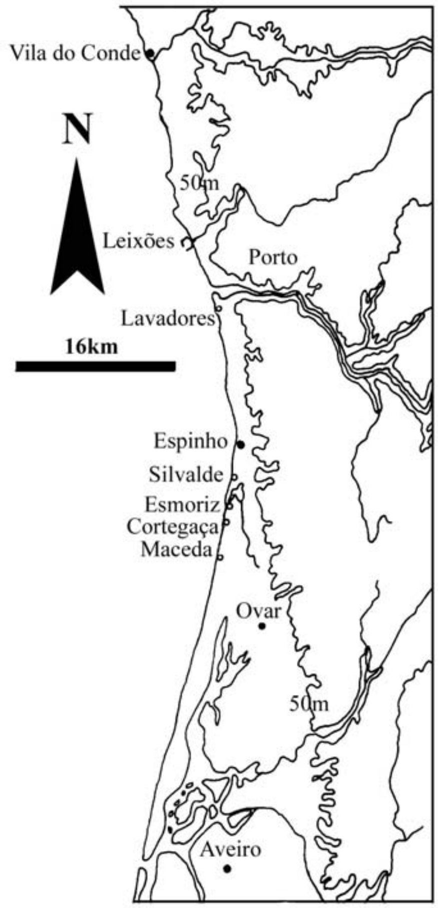

Figure 13: Localisation of studied area

The trendlines for marine deposits (fig. 14) show they have lower altitudes at the South of the studied area (in the direction of Espinho).

These general trends don't mean a regular subsidence: the height variation of marine terraces along the coastline is quite irregular and seems to define a puzzle of small blocks which may undergo different tectonic movements.

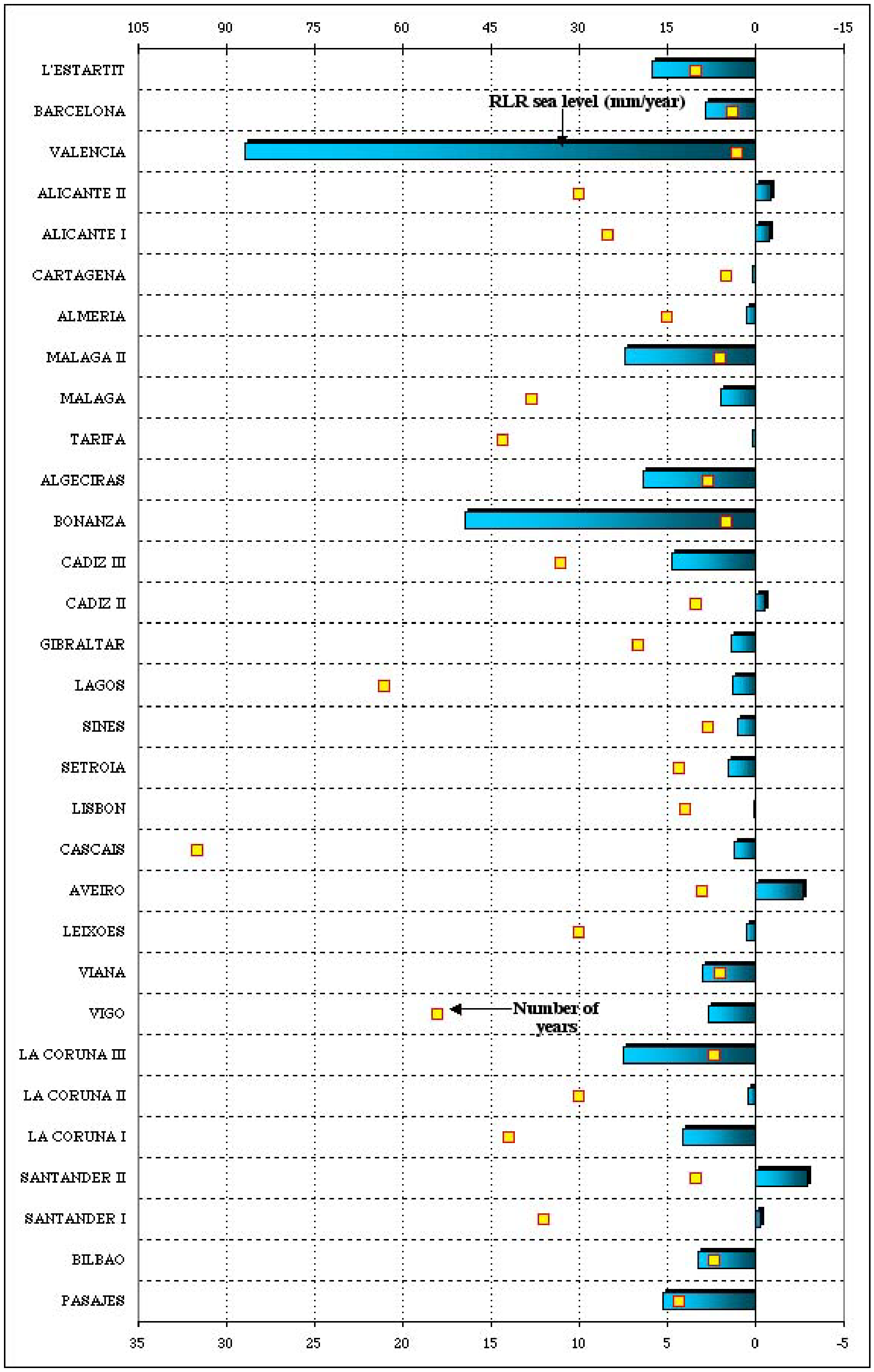

Figure 11: The trends of sea level variation at the Iberian Peninsula (data from Permanent Service for Mean Sea level: PSMSL).

4. POSSIBLE NEOTECTONICS AT THE SOUTH OF ESPINHO.

The area to the South of Espinho is a low area, covered with several dune systems.

The retreat of the coastline has carved cliffs upon the dune systems, allowing us to see the fini-pleistocene and holocene deposits that lay beneath recent sand dunes and beaches.

Since 1986 (Araújo, 1986) these deposits have been monitored and the first ideas we had about them have been reviewed (Araújo, 1991).

After that, several papers have been produced on this subject (Carvalho & Granja, 1995, Granja, & Groot, 1996, Granja *et. al*., 1999).

At Esmoriz, very close to its breakwater and because of the beach erosion due to its construction, we could see (around 1980), an aeolian sandstone with an irregular surface, forming ridges and grooves (fig.15), covered by a black layer of peat. This deposit appeared around mean sea level and, to our knowledge, was never seen again.

This sandstone with the curious ridges and grooves is quite conspicuous in that area and it appears 1,75km to the South, at Cortegaça beach as a part (Bsh, spodic horizon) of a podzolic soil.

The aeolian sandstone is about 1,5m thick. On the top of it we found some pieces of coal, for which we obtained a datation of 5885±75 BP (Niedersächsisches Landesamt für Bodenforschung, Hannover).

Beneath it there is a greenish-gray silty layer for which, at the same Hannover lab, we obtained a datation of 13810±380 BP. These silty layers are recurrent. Recently (May 2002), at Maceda beach, we count 4 of these layers (fig. 16). They seem to be the remain of ponds installed in the troughs between dune ridges, and probably each one represent a moment of a wetter climate during Würm and Tardiglaciar.

At Cortegaça and Maceda beaches the spodic horizon that appeared at mean sea level near Esmoriz lagoon (fig. 15) was considerably higher (respectively 5m and 7m: fig. 17).

Figure 17 represents the difference in altitudes of the brown spodic horizon and the lower greenish layer from Esmoriz beach till S. Pedro de Maceda beach.

On the contrary of the dipping to the South trend we assumed for the marine pleistocene deposits at the North of Espinho, the spodic horizon and the lower greenish layer seem to have a North dipping trend.

So, it seems that the depressed character of the area between Espinho and Esmoriz may have something to do with this tectonic trends.

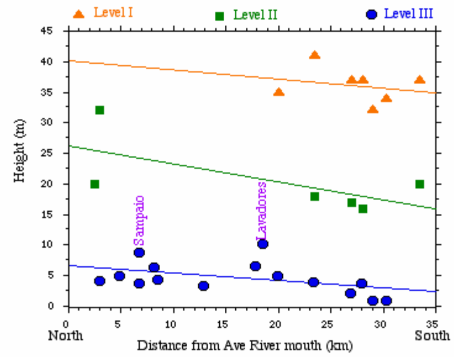

Figure 14: The height of marine deposits outcrops and its evolution along the studied coastline

5. SOME CONCLUSIONS: POSSIBLE CAUSES OF COASTLINE EROSION AT ESPINHO

Espinho has suffered from severe erosion since 1869 (Ferreira Diniz, 1909). The occidental part of the city of Espinho was destroyed around 1909 (fig. 18).

The construction of Leixões harbour began in 1884. The fundamental issues are two large “L” shaped breakwaters. The Northern breakwater is 1.579m long. The Southern breakwater is 1.147m long. They were ready at February 1895 (APDL site: http://www.apdl.pt).

So, at 1889 when a part of the city of Espinho was already destroyed (figure 18) Leixões breakwaters were not ready yet.

A contemporary testimony (Ferreira Diniz, 1909) concludes that the cause for the erosion at Espinho can not be the building of Leixões harbour because the coastal retreat began before that its construction was ready.

The same conclusion can be see at G. Soares de Carvalho (1999), where much older “sea invasions” are referred to have happened at 1834, 1869, 1871 and 1874.

For the 1889 “sea invasion” we don’t know if the breakwaters were enough long at that time to produce a serious influence on littoral drift, which is prevalent from the North. But we can imagine that, as Leixões stays at the North of Douro mouth, its breakwaters will stop the sand coming from the Northern (and less important rivers, Mota-Oliveira, 1990) and its influence is not much relevant at Espinho sedimentary budget. The hypothesis (G. Soares de Carvalho (1999) of an inversion of littoral drift at the area of Leixões harbour (from the general direction North to South to South-North) goes in the same direction.

But even if there is some influence of Leixões harbour to the Espinho erosion, the non-coincidence of dates seems quite impressing.

That brings we back to the Mörner curve for sea level evolution. Apparently, the lowest point of sea level was reached at 1830. Than, the sea level began to rise, slowly but continuously.

According to Brunn principle (Paskoff, 1985) for each mm of sea level rise the coastal variation in the horizontal direction will be 100 times bigger.

According to the same principle, the rate assumed in the Mörner curve (around 1mm/year) should produce a coastal retreat of 10cm/year.

Even if it is a slow rate, the cumulative effect from 1830 to 2000 (170 years) could mean 170m of coastal erosion, and this is already meaningful. This issue is surely responsible for some of the coastal retreat that happens at 70% of the coastlines in the world (Bird, 1993).

However, the sea level rise is only one of the causes of beach erosion. According to A. Dias (1990) sea level rise is responsible for only 10% of the beach erosion problem.

Other reasons can be pointed out:

- The sedimentary deficit of the rivers, due to dam construction (the sand supply to the coast by the Douro river is actually only 20% of its "natural" conditions (Mota-Oliveira, 1990);
- The impact of coastal constructions (the breakwaters of Leixões, for instance);
- Another interesting idea pointed out by Paskoff (1985) and G. Soares de Carvalho (1999) is the hypothesis that because of the end of flandriana transgression the sediment supply to the coastline has been slowed down. This, together with the other referred facts, could create a sedimentary deficit and the consequent coastal erosion.

Now we must come back to the tectonic trends we inferred from the distribution of marine terraces and the heights of podzolic soils.

If those trends are confirmed, the area between Espinho and Esmoriz corresponds to a tectonic depression. This could explain why we have a small lagoon in Esmoriz (fig. 13).

This could also explain why the coastal erosion began <u>before the construction of the breakwaters at Leixões</u>: the small rising of sea level that began after the end of Little Ice Age, acting upon soft pleistocene and holocene deposits was increased by a possible subsidence of Espinho-Esmoriz area.

Although no movement is objectively referred at that area in Neotectonic map of Portugal (Ribeiro and Cabral, 1988), there is a "lineament" that can be prolonged from Gerês Mountain till the area of Ovar. Like the other strike-slip faults of NNE direction, this one is probably an active fault, with neotectonic movement.

Another meaningful lineament of NNE-WSW direction crosses the coastline just where its direction changes from NNW to NNE, precisely at the place of Espinho.

Figure 15: The aeolian sandstone covered by peat at Esmoriz

Figure 16: At Maceda beach the Bhs horizon appears at about 7m above msl (mean sea level).

As we have seen before (figs 3-10) the land movements <u>does have some influence on relative sea level variation.</u> May be this is the reason why coastal erosion has been so fast and devastating at Espinho.

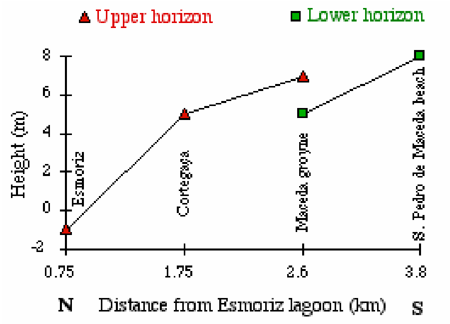

Figure 17: Height variation of podzolic soils and lagunar deposits between Esmoriz and Maceda beaches

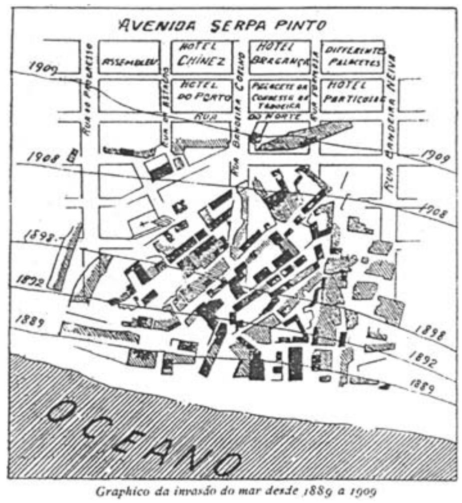

Figure 18: The sea invasion at Espinho from 1889 till 1909 (After Ferreira Diniz, 1909).

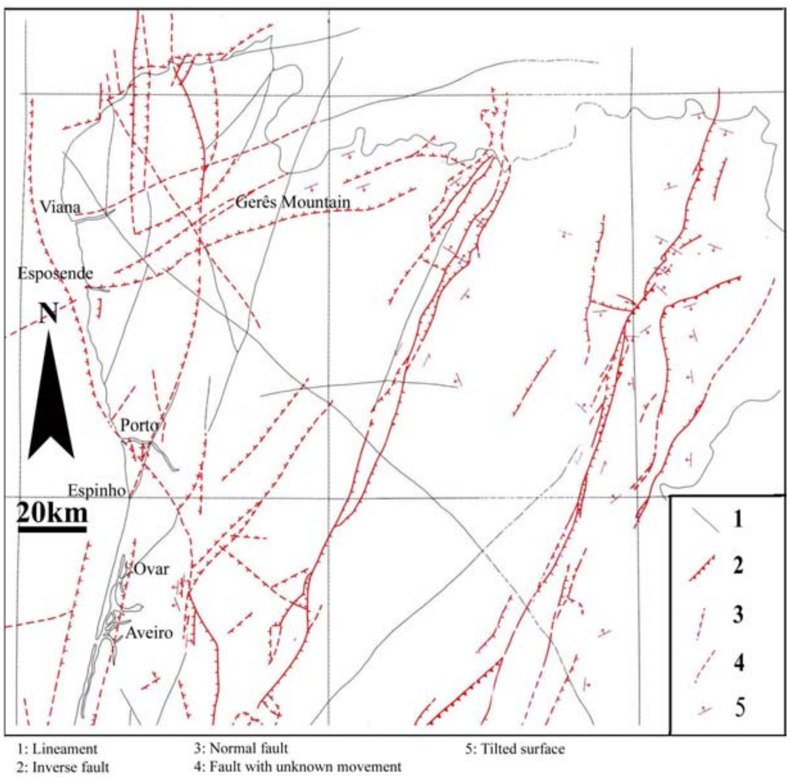

Figure 19: Fragment of the Neotectonic map of Portugal (after Cabral & Ribeiro, 1988)

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