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PORTUGAL: COASTAL DYNAMICS

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FIELD TRIP GUIDE

A-1

THE LITTORAL OF OPORTO REGION (NORTHWEST PORTUGAL)[1]

António Alberto Gomes; Maria Assunção Araújo; Andreia Sousa

1. Geomorphological and geological setting

One of the most common characteristics of the Portuguese littoral is the so-called "littoral platform", comprehending different altitudes and bordered from the inland by a contrasting straight relief.
The littoral platform is at around 75m (on the North, close to Ave River) till 130m (at the South) and goes down towards the sea like a staircase (Ferreira, 1983). This platform is bounded to the east by a step relief – the "marginal relief" (Araújo, 1991) and has the shape of a fault scarp related with the Porto-Coimbra-Tomar shear zone.

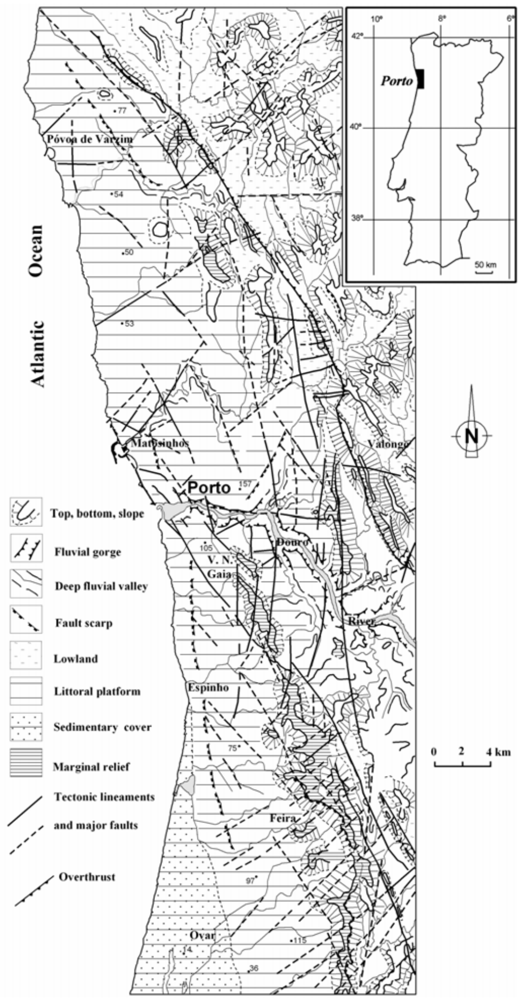

Figure 5. Geomorphological setting of Oporto region.

[1] **1st Stop** – S. Felix de Launde.

This planation surface is generally covered with several outcrops of the so-called Plio-Pleistocene deposits (Fig. 5). Till the eighties this platform has been considered as stable staircase of old marine levels, registering in a passive way the eustatic fluctuations. The rigid step easterly bordering it should be a fossil cliff. However, new studies have proved that many of these deposits have a continental origin.

Douro is the most plentiful river of the Iberian Peninsula and its unusual entrenched valley even close to its mouth, is generally understood as evidence of antecedence (Rebelo, 1975; Daveau, 1977). It seems that the river existed already before the uplift of the tectonic compartment, creating this strongly entrenched valley.

The main lithological units are (Fig. 6):

i) granitic rocks (Variscan and/or pre-Variscan), including two mica granites, medium to coarse grained, with mega crystals; biotitic granites fine to medium grained; gneisses, migmatites and gneissic granites;

ii) metasedimentary rocks (upper Proterozoic-Palaeozoic), which include schists, greywackes, quartz-phyllites and quartzites;

iii) sedimentary cover (post-Miocene), including alluvium and fluvial deposits.
The Crystalline basement, which is strongly deformed, and overthrusted metasedimentary rocks and granites are the regional geotectonic framework of Porto region (Chaminé et al. 2003a, b).

Porto–Albergaria-a-Velha shear zone (s. str.) corresponds to a major NNW-SSE dextral strike-slip fault of sigmoidal multiscale geometry, stretching from Porto to Tomar (Chaminé, 2000). The dextral faulting system is associated with transpressive kinematics triggered by the post-orogenic collapse of the structure along the ancient Porto–Coimbra–Tomar thrust planes. These processes generated a multitude of discrete ENE-WSW to NE-SW regional brittle fault systems.

2. The littoral platform

The littoral platform has been understood simply as a staircase of marine terraces facing the sea, as mentioned before. However, that idea applies only to the lower and western part of this platform. The older deposits have a fluvial origin. A step, between the marine and fluvial deposits, establishes a very sharp separation and seems to have a tectonic origin (Fig. 7).

In the fluvial deposits cluster it is possible to make a distinction between the higher and lower deposits. The first ones are related to low energy environment, probably deposited inside a littoral plain and the lower and newer deposits are much coarser and have a typical alluvial fan facies. There is a clear evidence of the existence of two phases of geomorphological development: the younger, reddish alluvial fan deposits contains, in several places whitish blocks that are remains of the older deposits. The destruction of an old sedimentary cover suggests the change of a low slope sedimentary environment into a landscape where increased slopes furnished some boulders (more than 50cm wide). It is possibly to correlate this change to a climate crisis (Ferreira, 1983), because the kaolinite, which was very abundant in the older deposits (more than 90%), is more scarce in the alluvial fan deposits.

The fluvial deposits reveals another difference: the strong iron cuirasses disappears from the older ones to the newer ones, which may represent the change from tropical climate conditions prevailing during the Miocene and lower Pliocene into more temperate ones at the end of Pliocene and during the Quaternary.

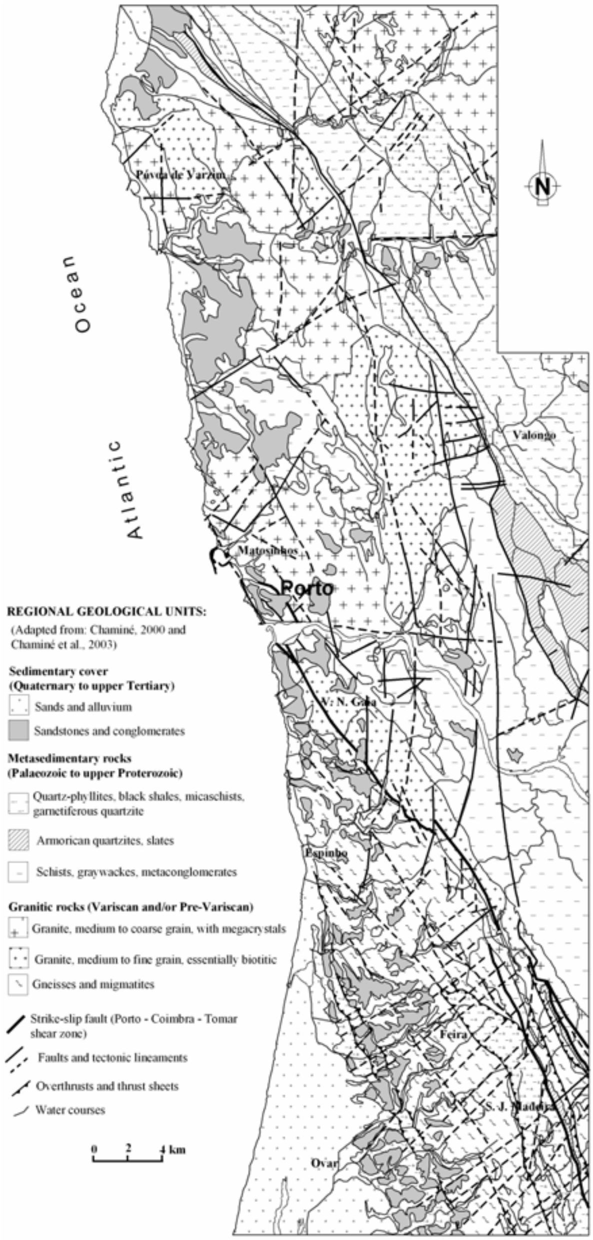

Figure 6. Geological framework of Porto region.

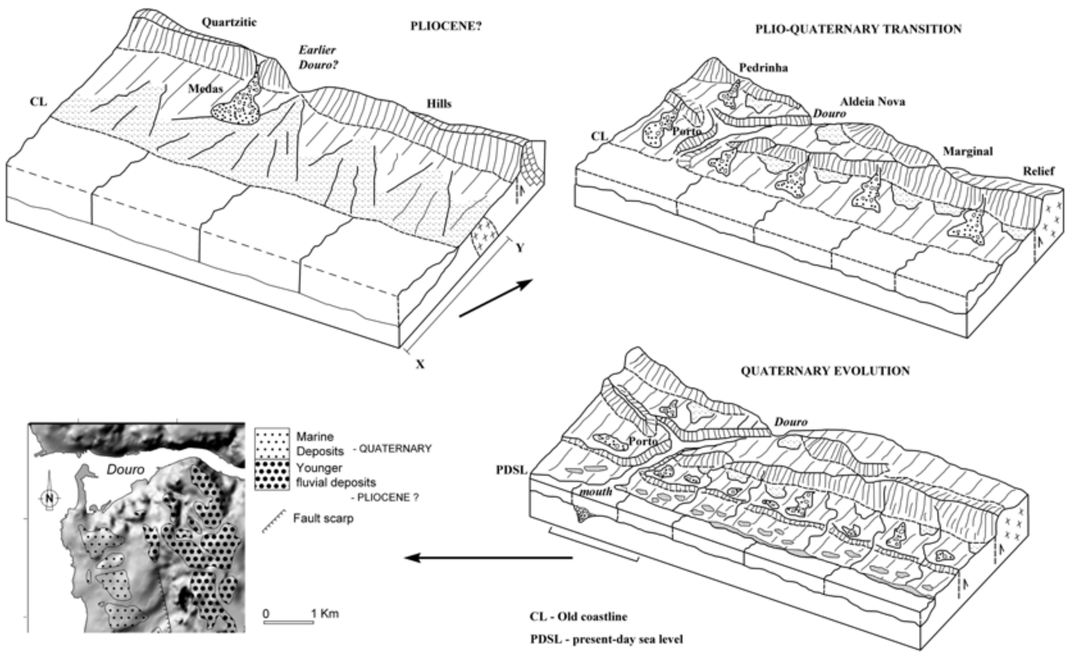

Figure 7. Geomorphological evolution of Porto littoral platform (Araújo et al, 2003).

Since the forties, Ribeiro et al (1943) highlighted that the higher fluvial deposits (Rasa de Baixo) where balanced to the east, towards marginal relief, in the opposite direction of the sea. That implies a presumption of tectonic movements acting after the deposit's formation. The creation of a marginal horst, in NNW-SSE direction, by a post-Pliocene movement on Porto-Coimbra-Tomar shear zone (marginal relief) could be the origin of the alluvial fan deposits (Araújo, 1991; Araújo et al, 2003). Those alluvial fan deposits where also affected by compressive movements, attested by several mostly inverse faults (Araújo et al., 2003).

Between fluvial and marine deposits exists a quite straight step that can reach 30m (Fig. 7). This step suggests that, during Quaternary, the western part of littoral platform must have subsided along a sub-meridian fault (Araújo et al, 2003). This process allowed marine erosion and sedimentation over the subsided tectonic compartment. This fault scarp was reworked, afterwards, by the sea during the higher marine level and may be considered a fossil cliff.

In conclusion, there were at least two phases of neotectonic movements affecting the fluvial deposits. Presumably, the most recent of these movements created also the straight slope between fluvial and marine sediments.

Douro's Estuary Dynamics[2]

António Alberto Gomes; Ana Ramos Pereira; Maria Assunção Araújo; Andreia Sousa; Francisco Veloso Gomes

The Douro River has the greatest drainage basin in Iberia (97, 682km^2), 81% in Spain and 19% in Portugal (INAG, 2003). The Douro's River average natural outflow is 22, 458hm^3 (INAG, 2001), which corresponds to a 710m^3/s average discharge.

The estuary's topography has been modelled throughout the Quaternary, especially during low sea levels. However, insufficient research has been developed on this subject. We can point out that at S. Paio bay (Fig. 8), the Upper Pleistocene thalweg was near the southern bank, deeper than 50m bellow present-day sea level (Carvalho and Rosa, 1988). Nowadays, the estuary's depth reaches -31m about 3km upstream (INAG, 2001).

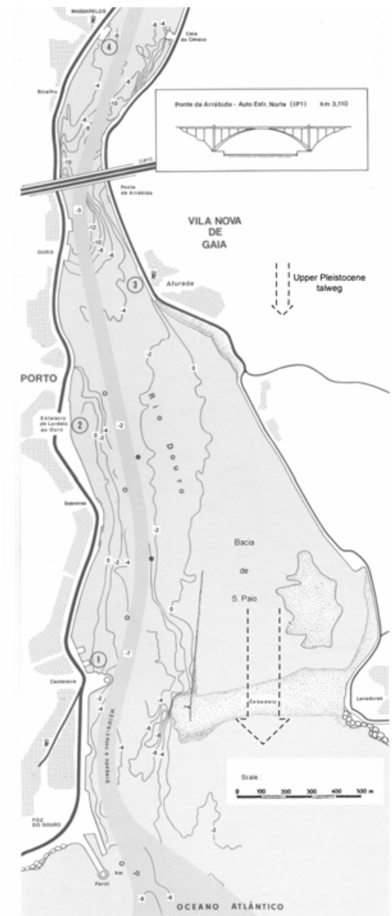

Figure 8. Estuary map showing the bathymetry and the dredge navigation channel; equidistance equal to 2m (IND, 1991)

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[2] **2nd Stop** – Vila Nova de Gaia – Cabedelo.

The estuary's width varies between 130m and 1, 310m near the Douro River's mouth. Its entrance is nowadays partially blocked by a changing sandy spit. In a mesotidal environment that reaches 4m, the estuary tidal range varies between 2.4 – 2.7m (spring tides) and 1.2 – 1.5m (neap tides). The tide could penetrate, until 1985, 37km inland, when the Crestuma dam was built. Nowadays, this dam is the new estuary boundary, which extension has been reduced to 21.6km.

During dry weather the tidal currents prevail while during floods it's the opposite. Though the entrenched valley and its irregular bottom topography are conditioning factors, the river discharge and the tidal range are the triggering ones.

The river's discharge has changed in the last half century with the construction of 36 dams in the Portuguese counterpart. The lowering of the water discharge and the velocity curves as well as the retention of sediments in the dams were not the only consequences. The reduction in the flow of solids creates a lack of sediment flowing into the estuary and offshore. This reduction is also related to sediment extraction and dredging of large amounts of sand along the river and inside the estuary (to ensure navigation security), its quantification is still unknown, but it has subtracted a very large amount of sediments. They are now missing in the long shore drift. The sediment dredging estimative in the downstream part of the river, between 1982 and 1986, was $3x10^6m^3$, almost the amount calculated for littoral drift.

The potential transport capacity of oblique waves (between 1 and 2 million m^3/yr) is now greater than the annual sediment volume supplied by the rivers (at present between 0 and 0.2 million m^3/yr). In present-day some tens or hundreds of thousands of cubic meters per year reach the long shore drift, very much depending on climate wave and fluvial discharge (Veloso-Gomes et al, 2002).

Vidinha et al (2002) highlighted the importance of the Douro River to the long shore sediment supply, mainly to the southern sandy beaches and dunes. Studying the mineralogy of the fine fraction of beach and dune sediments, these authors show the importance of this source till the Aveiro inlet, 52km down drift. According to Oliveira et al (1982), the Douro River represented 90% of the sediments drifting along the shore.

2. THE MOUTH SPIT

Cabedelo is the Portuguese name for the sandy spit that almost encloses the river mouth. It is a very changeable feature (in position and width), responding to climate wave and river discharge.

The long shore drift act mainly in the N-S direction although some singular events of SE currents can be found as a consequence of specific hydrodynamic processes (refraction and diffraction) or SW storm episodes. The wave climate has medium significant wave heights from 2 to 3m, with periods ranging from 8 to 12s and storm significant wave heights exceeding 8m (maximum wave heights up to 1.7 times the significant wave heights), with periods reaching 16 to 18s (Fig. 9). The local wave conditions are different from the offshore ones due to the effect of the bathymetry and local phenomena, especially refraction, diffraction and shoaling (Veloso-Gomes et al, 2002).

Sediments travelling S-N, near Cabedelo, can reach 1,5 millions m^3/yr (INAG, 2001) and could close the river mouth. However, the river's discharge and the tidal currents balance and special dredging keep it open.

During the December 1909 flood ($19,500 m^3/s$ and 100 year return period), Cabedelo almost disappeared but it gradually grew up, attaching itself to the southern margin in June 1910.

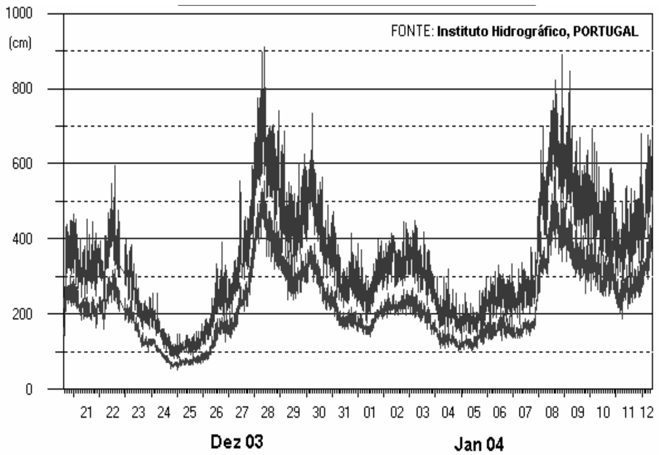

Figure 9. An example of significant and maximum wave high during a storm period at Leixões buoy (www.hidrográfico.pt).

In the nineties the wash-over of the spit, bringing oceanic waves upon S. Paio bay salt marsh got more and more frequent, even during a period with less severe floods while the spit migrates upstream (Fig. 10, 11 and 12).

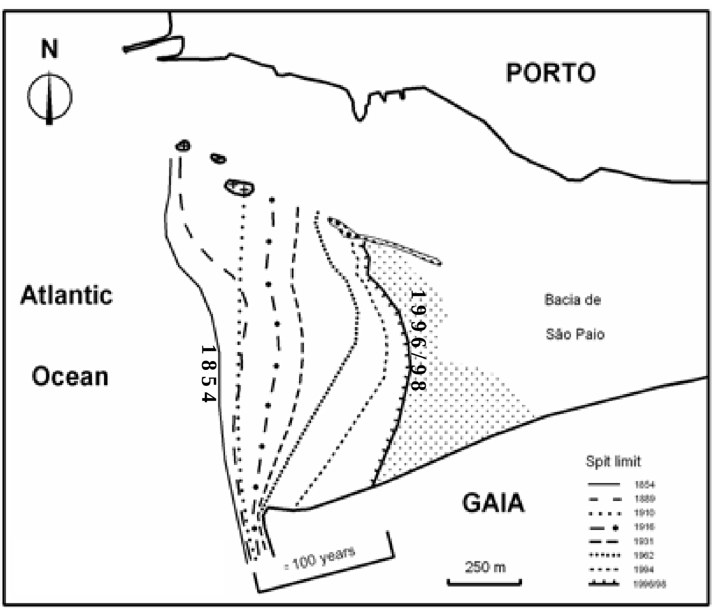

Figure 10. The retreat of the sand spit since 1854 to 1996-98. Administração do Porto Douro – Leixões (1999).

Floods can be controlled by dams only up to amounts of 7,000 a 9,000m^3/s. The extraordinary floods are the ones that go beyond +6.00m (above hydrographic zero), measured at the right margin, near D. Luiz's bridge. These floods can go over Ribeira embankment. Douro's extraordinary floods have a great water flow, a rapid propagation, a strong water level elevation and a short duration, because the drop of water level is relatively fast (IHRH, 2003).

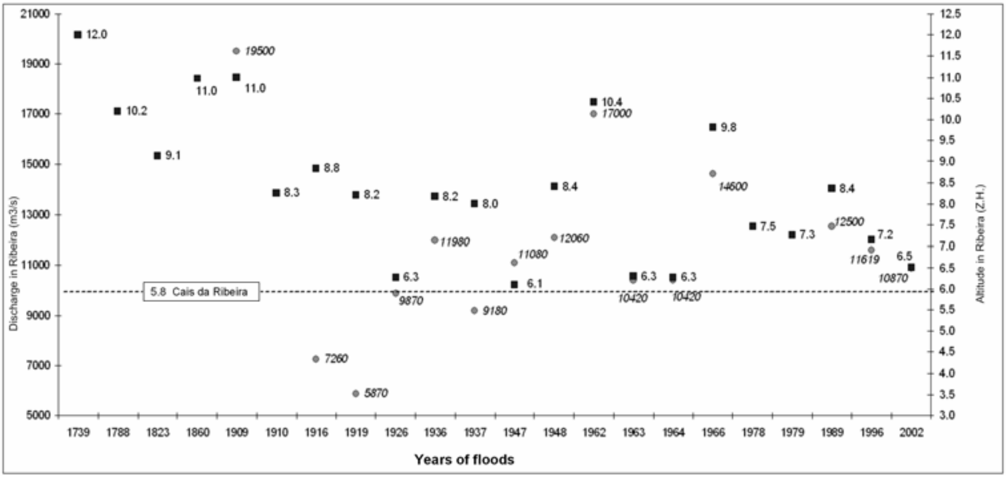

Figure 11. Extraordinaire floods in Ribeira – Porto (IHRH, 2003). The altitudes are referred to hidrographic zero (1,8m under topographic zero).

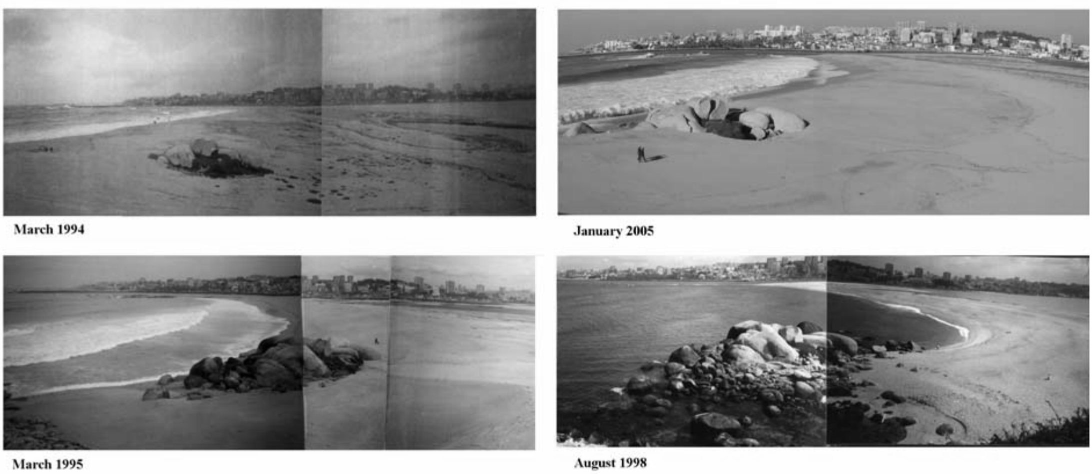

Figure 12. Panoramic views showing recent evolution of the Cabedelo sand spit.

The spit evolution tendency (thickness and upstream migration) changed during the winter 2000/2001, when a big flood occured. The triggering factors were: (i) the intense winter and spring rainfall, that was above the 1961-90 average and doubling the annual average in some areas of the drainage basin and (ii) great discharge of an upstream dam, after a quite long water river retention related to an accident with a bridge. The enormous amount of water and sediments provided the supply of the spit that grows and migrates towards the sea.

The present-day situation shows the previous tendency as no big floods have been registered since then. To stabilize the river mouth and allow safe navigation, a new project is going to be implemented during 2005 and 2006. The layout is present in figure 13.

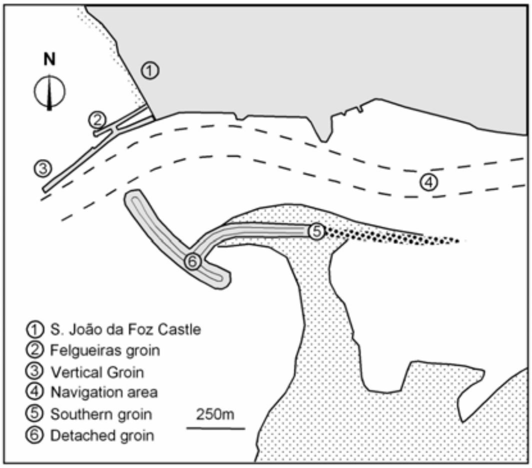

Figure 13. The new project to allow bank protection and safe navigation on the Douro´s mouth (Jornal de Notícias, 30 de Abril de 2004).

THE EVOLUTION OF THE NORTHERN END OF THE AVEIRO LAGOON SYSTEM[3]

Helena Granja

1. Geological and geomorphological setting

The Esmoriz lagoon is located south of Espinho, in a flat area, slightly sloping towards the sea. It has a smooth NNW-SSE relief corresponding to the boundary between the littoral and the Douro valley. This nearly flat surface (the littoral platform) has its greatest width at Cantanhede (20km).

Most of the littoral is covered by different dune systems and Quaternary deposits forming the northern end of the Aveiro lagoon, the border of the brackish coastal lagoons (Esmoriz and Aveiro) and of the fresh-water lagoons (more inland).

The strongly metamorphic ante-Ordovician schist-greywacke complex can be observed in two bands, separated by a NW-SE oriented porfiroid granite, inland from the littoral border.

2. Palaeoenvironmental reconstruction of the lagoon

The present-day Esmoriz lagoon is the remnant of a larger lagoon system, probably identical to the one still existing today at Aveiro (Fig. 14). Based on the description of outcrops and some cores, the

[3] **3rd Stop** – Esmoriz Lagoon.