

The Use of the GPS in the Identification of Fossil Shore Platforms and its Tectonic Deformation: an Example from the Northern Portuguese Coast.

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ABSTRACT

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Since more than 20 years we have the strong impression that recent tectonics may be active in the northern coastal zone of Portugal. This assumption is compatible with several recent studies on this matter. However, to prove the incidence of recent tectonics, we must find unequivocal deformation marks on the geomorphologic surfaces and on the Pleistocene deposits. Moreover, the deformed surfaces/deposits must be dated. This poses several difficulties as the marine deposits could not be dated by TL and OSL is quite problematic due to the small thickness of the beds and its iron cemented character. In order to overcome these issues, the study of Quaternary sedimentary deposits of the coastal zone of Porto was based upon a very detailed fieldwork and the accurate altitude definition with a GPS (Leica SR20). The use of a static reference to correct the data obtained with the mobile receptor (rover) allowed us to obtain a good precision on the altitude of significant geomorphologic points. This procedure allowed us to characterize the several marine platforms along this coastline and perform some detailed profiles of rock outcrops emerging from sand beaches. Studying the geomorphologic development of present day platforms and its relationship with tidal levels, it was possible to identify some rare tiny platform remains standing above actual platforms (possible Flandrian) and also the more frequent and generally deposit bearing Eemien platform. This work suggests that the last interglacial marine deposits have suffered some tectonic disturbance as they appear at quite different altitudes along this coastal zone. Furthermore, its altitude accompanies the general trend of geomorphologic features: the higher coastal sectors generally bearing higher coastal deposits and higher fossil platforms.

ADDITIONAL INDEX WORDS: *shore platforms, last interglacial, neotectonics, Porto, Northern Portugal, Vila Chã beach*

INTRODUCTION

There are much more studies about sand beaches than about rocky coasts, whose studies are a bit neglected (STEPHENSON, 2000). This happens partly because its slow evolution is hardly compatible with model use and experimentation (SUNAMURA, 1992). In the last years, the studies were more frequent: see TRENHAILE, (1997, 2005), STEPHENSON (2000), KENNEDY and DICKSON, (2006), TRENHAILE. and KANYAYA, (2007), NEVES, (2004), BLANCO CHAO *et al.*, (2007). Most of the studies focusing on the erosion processes generally explain the development of shore platforms cut into sedimentary rocks, whose evolution is relatively fast. The crystalline bedrock of the northern Portuguese coastal zone is a difficult field work for finding rapid changes and measuring rock degradation. On the other hand, rock resistance allows the preservation of relict forms (shore platforms and notches), sometimes conserving old Eemien deposits. These forms and deposits are key information for assessing ancient sea levels and evaluating possible land movements from relative sea-level evolution.

The total studied area lies between Rio Ave mouth and Espinho (fig. 1), and it corresponds to the coastal area surrounding Porto

city. It is a structurally heterogeneous area (ARAÚJO *et al.*, 2003). Several studies, including very recent ones confirm the existence of neotectonic movements acting upon the geomorphologic surfaces and late Cenozoic deposits (GOMES *et al.*, 2007; GOMES, 2008). Its situation as a borderland between different structural regions and terranes can explain part of these movements. The possible emergence of a collision zone between North Atlantic sea floor and Iberian plate could reactivate some late variscan strike slip faults (CABRAL, 1995; RIBEIRO, 2002; DE VICENTE *et al.*, 2008).

This borderland tectonic situation provides a higher tectonic activity than should be expected from a passive margin. Most probably it also has disturbed the eustatic marine platforms that can be assigned to at least 3 levels (ARAÚJO, 1991).

The crystalline Precambrian and Paleozoic rocks are frequently covered with beach sands. However, locally, a seasonal beach erosion reveals rock outcrops buried under the sand beaches. These outcrops generally correspond to notches and shore platforms.

The old ideas about a stable and rigid staircase of “raised beaches” (TEIXEIRA, 1979) have been already completely

overcome (ARAÚJO, 1991, GRANJA, 1990, ARAÚJO *et al.*, 2005). Meanwhile, the emergence of new technologies such as the GPS allowed us to improve data collection and precision.

We have tried to apply this new technology to solve an old problem: the precise amount of deformation between old marine platforms. In order to understand this deformation, a good knowledge of the recent platforms morphology and the way they evolve was our first priority.

Shore platforms result from the retreat of marine cliffs (TRENHAILE, 1997). They can appear in 2 different shapes: almost horizontal platforms and ramped platforms (SUNAMURA, 1992, TRENHAILE, 1997). Its development is very much related with the tidal range, rock resistance, cliffs height and wave exposition (TRENHAILE, 1997).

The erosion capacity of the sea is also dependant on the time the sea stays at each different level. According to TRENHAILE (1997) "the level of greatest wave erosion on a rock coast must therefore be associated with the elevation most frequently occupied by the water surface". In fact, at the South coast of England, Wright reported "that alongshore variations in the altitude of the cliff-platform junction generally accord with those in tidal range" (SUNAMURA (1992).

In semi-diurnal tides, the tidal duration is highest at mean high water neaps and at mean low water neaps (PUGH, 1987).

The nearest tidal station to the studied area is Leixões. The general prediction tidal data for 2008 at Leixões is presented at table 1.

Table 1: Tidal altitude predictions at Leixões (Instituto Hidrográfico). HTL: High Tide Level, LTL: Low Tide Level, CD: Chart Datum.

	Relative to CD	Relative to msl
Max HTL	3,76	+1,76
Mean HTL	3,07	+1,07
Mean LTL	0,93	-1,07
Min LTL	0,28	-1,72

The data at table 1 is referred to Chart Datum (PUGH, 1987, the so called "Hydrographical Zero" in Portuguese tidal data), which, in this station, lies 2m below mean sea level (msl). In the right column the data is referred to msl.

Although it is impossible for us, for the time being, to calculate the tidal duration at each level (TRENHAILE and KANYAYA, 2007), in Galicia, the highest tide duration happens at mean neap high tide level and at mean neap low tide level (BLANCO CHAO *et al.*, 2007). Our field work showed that the shore platforms development coincides quite well with the altitudes between the mean LTL and a bit higher than the mean HTL. At Leixões they are, respectively 1,07 below msl and 1,07m above msl (Table 1).

It is sometimes possible to define at the connection with the sea cliff, a notch which can be quite impressive at resistant rock (granites, gneisses and migmatites) (fig. 1-B and C). These shore platforms can develop in several ways, depending very much on their rock material. Our field knowledge in this crystalline Precambrian and Paleozoic basement suggests that the class 2 shore platform as defined by SUNAMURA (1992) is the most common. These platforms are formed by 2 stretches: a ramp, close to the notch and then, a gentler dipping surface till mean LWL (ANDRADE *et al.*, 2002, TRENHAILE and KANYAYA, 2007).

Shore platform elevation is not constant, depending very much on wave exposition and rock resistance and structure. Generally

shore platforms are quite exiguous – the most extended we found inside a coastal area about 40km long appears at Lavadores beach and had a measured extension of 47m. In general, the shore platforms we find on a crystalline bedrock are narrow and sometimes quite irregular. Besides that, most of them are buried under beach sands and they are only occasionally visible.

For this paper we focused in Vila Chã beach (fig. 1-A), a small fishing harbor 17km north of Douro mouth, where rock outcrops are quite frequent and extended. Its geological background is made of very interesting migmatites and gneisses, cut by pegmatite's dikes (TEIXEIRA, 1968). It corresponds to a high grade metamorphic belt related to the alkaline granites intrusion (RIBEIRO *et al.*, 1979).

Beyond its geologic interest and beauty (TEIXEIRA, 1968), as they are quite resistant, the rock outcrops preserved the marks of old marine still stands and, at the same time, they present unequivocal marks of tectonics affecting the shore platforms (fig. 1-A). So, in this particular place, in a quite small area (about 630m long), it is possible to discuss the staircase model for shore platforms and how tectonics may affect it.

Our principal goal is to identify the different platforms present at the studied area and understand its staircase system and its variations along a short stretch of Northern Portuguese coastline.

METHODOLOGY

In order to a better definition of actual marine platforms to provide information to compare with the fossil ones and identify its possible tectonic disturbance, we have used a Leica SR20 GPS system.

It is composed by 2 GPS receptors. One of them must be in a static mode as long as possible and it is connected to an antenna mounted on a tripod. The height of the antenna basis must be carefully measured. The other receptor (rover) is connected to an antenna generally mounted on a 2m pole and it is moving in the field (kinematic mode). It can calculate accurate positions for points, lines and areas in a WGS84 coordinate system, convertible to a local, Portuguese coordinate system (Hayford-Gauss Dt73).

After returning from the field, the static receiver data are processed against a reference GPS station (whose precise coordinates are known) to provide an accurate position of the static GPS. Afterwards, this static GPS data is used as a reference to correct the rover points. The static GPS must be as near as possible to the rover, so they can catch the same signals from the satellites. The presented data were obtained using a static GPS always less than 1000m away from the rover. The position of each point was obtained after a 30-60 seconds of rover stationing. The error range of this processing is less than 14cm (according to precise leveling marks).

In an area presumably affected by recent tectonics (ARAÚJO, 1991), the methodology should comprise dating techniques. However, as discussed in MARTINS and CUNHA (2006) and ALONSO and PAGÈS, (2007), most of the deposits are not suitable for TL and OSL dating techniques. So far we only got an indirect age of a marine deposit at S. Paio beach, about 1 km to the South of Vila Chã. There, an aeolian sand overlying a solifluidal and a marine deposit was TL dated 84±18/-12 ka BP (Nick Debenham, Quaternary TL Surveys, UK, see ARAÚJO and GOMES, 2004). The marine deposit appears between +5,1 and +5,9 m above msl and it fossilizes an old shore platform at the same altitude range (between 5,92m and 5,43m).

Similar deposits overlying old shore platforms were found in several places along the studied coastline. Its altitude can be variable, due to probable neotectonic movements (ARAÚJO, *in press*).

In stable areas, the Eemien interglacial deposits, corresponding, approximately to OIS 5e, (SHACKLETON *et al.*, 2003) seem to be around 2m (above msl) as assumed by ZAZO *et al.*, (2003) for the calculations of rates of vertical movement. Consequently, at stable areas, the Eemien deposits and platforms should stay slightly above the present ones. However, at uplifting areas, its altitude can be significantly higher reaching 7-9m (Lavadores and S. Paio beaches, ARAÚJO, *in press*).

Moreover, most authors consider that sea level did not reach the present elevation during the high stands corresponding to OIS 5c and 5a (DUMAS *et al.*, 2005). So, the former shore platforms and deposits (OIS 5e) were preserved. During OIS 4, 3 and 2, climatic conditions and sea level were quite variable (DUMAS, 2005) and produced terrestrial deposits that covered Eemien old beaches and platforms (BLANCO CHAO *et al.*, 2007). Late Glacial Maximum sea

level reached 120m below the actual level (DIAS *et al.*, 1997). Then, there was a rapid sea level rise (Flandrian transgression) and sea level attained a position, similar or slightly higher than the actual one, around 6000 years BP. At this new high stand the sea began to erode previous deposits (last interglacial and last glacial deposits), carving a new shore platform, which altitude, at Vila Chã fishing harbor is slightly lower than Eemien platform. Of course, the slight cooling in the middle of the Eemien can also be responsible for a lower sea level and this intermediate platform may be eventually assigned to events older than the Flandrian transgression. However, at Vila Chã, the freshness and sharpness of the notch (fig. 1-C) points out to an age younger than last interglacial.

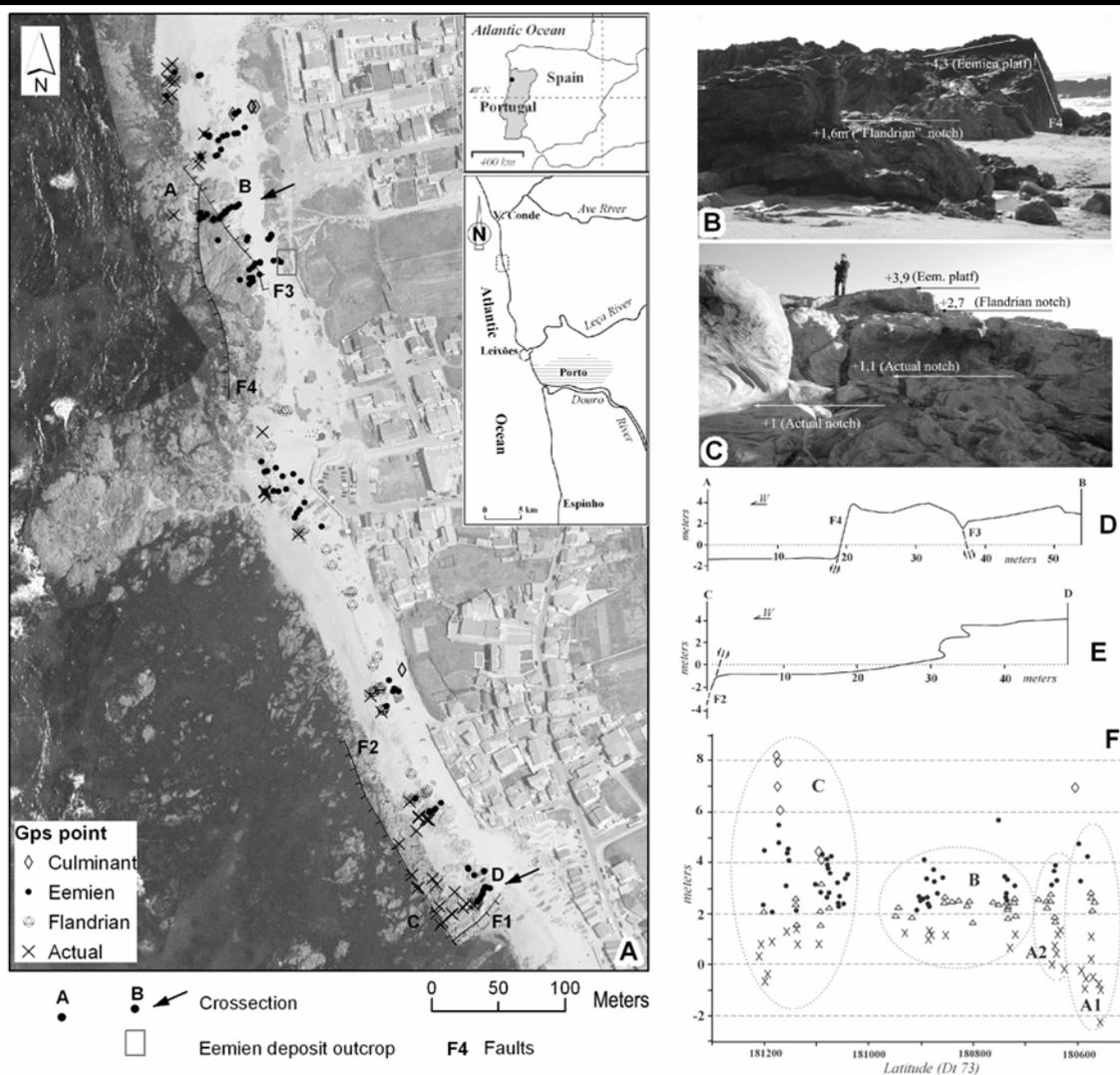


Figure 1-A: Aerial photo of Vila Chã beach. Probable faults: markers at lower blocks.
 Figure 1-B: View to the South showing the area represented in profile 1-D.
 Figure 1-C: View to the East at Vila Chã fishing harbor: 3 different platforms are visible.
 Figure 1-D: W-E profile (A-B cross section). Faults F3 and F4 are clearly visible.
 Figure 1-E: WSW-ENE profile (C-D cross section). Corresponding to fig. 1-C.
 Figure 1-F: The point altitude variation. See discussion in the text.

In a “normal”, stable situation, this “Flandrian” platform is very difficult to distinguish from the actual shore platform. However, when vertical movements are present, the Eemien platform can be higher than +5m and the possible Flandrian platform is imbedded into this older platform and stays slightly above actual platform. We think this is the case presented in Vila Chã beach (fig. 1-C). To validate this hypothesis a differential GPS was used to get precise altitude data for the relevant rock platform points. Almost all the rock outcrops visible over this area at 26/12/2008 and 12/01/2009 where referenced with the GPS. We looked mostly for meaningful points (highest and lowest point in a stretch, inflexion points).

RESULTS AND ANALYSIS

At fig. 1-F we have plotted the points position determined by the GPS against the latitude data (Hayford-Gauss Dt73 coordinate system).

As the coastal stretch we focused on is exactly N23°W, it means that latitude data don't represent the exact distance between each point, but it can be used quite approximately for an easy representation of altitude variation along the coastline.

At the Vila Chã fishing harbor a ENE-WSW fault (F1, fig. 1-A) delimit a “raised” block where it was possible to identify a “Flandrian” notch above the actual shore platform (fig. 1-C, profile 1-E). In this particular place 3 marine levels are clearly distinguishable. At the C-D cross section it is also possible to identify a scarp (F2) ca 1m high which development suggests strongly a neotectonic displacement.

Traveling to the north, as the uplifting of the surface disappears, the Eemien platform goes down. The Eemien marine deposit, covered, as usual, by the solifluidal würmian formation, appears at an altitude ca 4,16 above msl (fig. 1-A). This outcrop certifies that the underlying platform is certainly Eemien. Profile 1-D shows the underlying platform development in a WSW direction. In this profile we can see that the visible remains from this platform go down till 2,3 m and then, suddenly, we have an uplift in the rock outcrops defining a surface culminating at 4,3m, that seems to be the same Eemien platform, uplifted by a fault (F3). Just after this culminating point, the surface goes down till -1,2m. This N-S scarp is around 5m high and corresponds to a quite obvious fault (F4, Fig. 1-A).

Fig. 1-F shows a longitudinal profile along the studied stretch. The projection of the points altitude against their latitude shows 3 different areas:

A1 - At the south, near the harbor notch it is possible to identify 3 marine platforms: The Eemien, the possible Flandrian and the actual one. It is possible to define an adjacent less uplifted area (A2) where the “Flandrian” platform is less obvious.

B - To the north (B area) it is almost impossible to separate the Eemien platform from a lower, “Flandrian” one. Considering that, in the apparently uplifted A1 area, the “Flandrian” notch appears at +2,7m, we considered all the points above +2,7m as “Eemien”.

The other points, at lower altitudes, correspond to a probable degradation of the Eemien platform converted into a gentle dipping ramp where only the actual notches around +1m above msl are identifiable.

The type B situation is the most common considering all the studied coastal area (ca 40 km long, from Rio Ave mouth till Espinho).

C - The C area is surrounded by clear faults (F3, F4, fig. 1-A and fig. 1-D) affecting the rock outcrop development and the altitudes of the observed points. In this case, the prevalent faults are sub-parallel to the coastline main direction. As a result, the geomorphologic arrangement is quite different than at A1 area.

Some points above 5,5 m may represent the down wearing of platform remains older than the Eemien (identified in the fig. 1-A and 1-F as culminant points).

Shore platforms have a variable width. KENNEDY and DICKSON (2006) refers a variation in width from 20 to 80m in relatively soft rocks (marine sandstones and mudstones). The abundance of fractures diminishes the rock resistance and allows a faster down wearing and the carving of lower platforms. Besides that, significant changes in elevation can occur over distances of a few hundred meters depending on wave exposition (KENNEDY 2006). The irregularities in the topographic development of these surfaces are the norm. However, a systematic field recognition has proved that, into the studied area, the actual platforms appear generally between the mean high tide level and mean low tide level (fig. 1-F).

A. TRENHAILE model (2001) has been applied to Galician area (BLANCO CHAO *et al.*, 2007), ca 70km to the north of Vila Chã beach. It is generally assumed that Galician coastline is more stable than surrounding areas (Northern Portugal, Cantabrian coastline (ALONSO and PAGÈS, 2007; BLANCO CHAO *et al.*, 2007). As we found several neotectonic evidences along this coastal area, a model that implies a tectonic stability and the reutilization of ancient shore platforms, as assumed in Galician coast, cannot be applied in our case. Beyond that, ancient platforms are clearly visible on this littoral area and, most of the time, they are higher than present sea level, postulating some tectonic uplift and the consequent staircase development of shore platforms.

CONCLUSIONS

The detailed field work and the precision topography of significant points in shore platforms development allowed us to distinguish the actual platform, generally ranging between mean low tide and mean high tide level (ca -1 and +1 relative to msl) and the older and higher shore platforms assignable to Eemien and hypothetically to Flandrian transgression. A clear differentiation between these 3 levels depends very much on rock resistance and its ability to preserve old geomorphologic features, but also on the existence of some uplift which is the ultimate and most important cause of this staircase development.

The type B situation (fig. 1-F) is the most common considering all the studied coastal area (ca 40 km long, from Rio Ave mouth till Espinho). However, in some special conditions (resistant bedrock, probable uplift), a younger platform carved under the Eemien one can be preserved (figs. 1-C and 1-E). We think may be this can be used as a criteria for identifying recent uplifting areas.

The altitude of these old shore platforms can help in this investigation, but cannot be the only criteria. At each place we must perform a detailed field work and GPS point localization, trying to get the best tide and the best outcrop exposition (during Winter or closely after stormy weather).

It was possible to identify several faults (fig. 1-A) that have a clear relevance on topographic development of the shore platforms and therefore seem to be an evidence of recent tectonics.

Because of the aggressiveness of littoral weathering, and also because of wave attack during storms and high spring tides, old shore platforms continue to evolve (BLANCO CHAO *et al.*, 2007). So, unless they are fossilized under marine deposits that attest a good conservation, their altitudes may be underestimated relatively to its coeval sea level.

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WEB SITE

INSTITUTO HIDROGRÁFICO: Leixões Tidal data prediction:
<http://www.hidrografico.pt/previsao-mares.php>

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