Universidade de Coimbra

MARE

THE NAZARÉ COAST, THE SUBMARINE CANYON *and* THE GIANT WAVES - *a synthesis*

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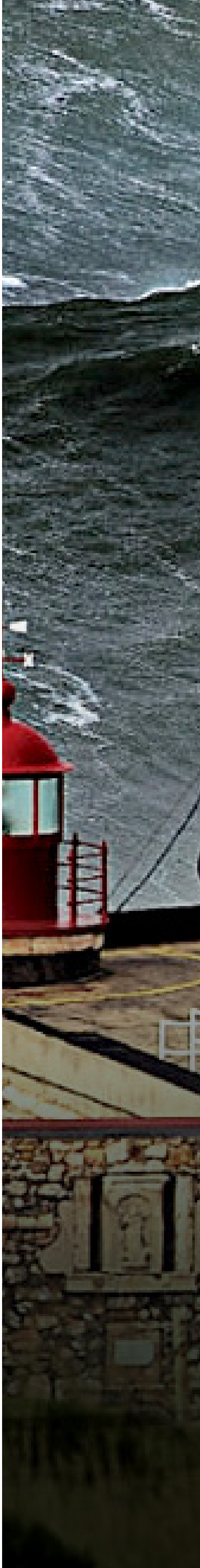


Abstract

The topic of this work is the coastal zone of Nazaré (located in central western mainland Portugal) and adjacent offshore, in particular the submarine canyon, summarizing and organizing available information in order to be used by a wide public. The physical characterization, mainly focused on the geomorphology and coastal dynamics, is based on previously published works but also on new data. The information here provided aims to help tourists not familiar with the region, namely those involved in surfing practices, in order to understand the peculiar setting and the expected waves. An explanation for the genesis of the Nazaré giant waves is also provided.

Photo taken at Nazaré promontory in November 1st, 2011 (from www.zonnorthcanion.com)

1. INTRODUCTION

1.1 OBJECTIVES

This work aims to present the general characteristics of the Nazaré canyon and adjacent beach, addressing the geomorphology and coastal dynamics.

1.2 GEOGRAPHICAL SETTING

Nazaré is a town and a municipality in the west sub-region (NUT III/Leiria District), in western central Portugal. The county is divided into three administrative areas: Nazaré, Valado dos Frades and Famalicão (Fig. 1.1). It borders the Atlantic Ocean in the west and its neighboring municipality is Alcobaça.

Nazaré town occupies an area of 82.4 km^2, which maximum length is 13 km, in the East - West and 15 km in the North - South. Nazaré hosts about two-thirds of the population of the municipality, having a little more than half of the entire area. In the last ten years the resident population has only increased by eight individuals.

The landscape is mainly characterized by areas with pinewoods associated to higher elevations and agricultural lands of lower elevations along the Alcoa's River valley and near Nazaré, dominated by irrigation (Fig. 1.2). The following landscape units can be considered:

- The Alcoa river valley, with the fertile fields of Valado dos Frades and Cela, which is occupied with arable crops on irrigated land (corn and vegetable orchards);
- The Nazaré beach develops along a flattened coastal area, north and south of the promontory;
- The Plateau of National Forest Valado de Frades develops on the north and the east of Nazaré. The urban settlement is almost non-existent and the forest cover has little biodiversity;
- The Cliff zone is represented by woods and some pine forests, alternating with small areas of bare soil;
- The sites of Pederneira and Nazaré, which were ancient seaports. At the top of the headland is located the Sítio, a relevant viewpoint.

In the past, Pederneira and Sítio were separated by pinewood but, due to the increasing urban pressure, they are now almost connected due to the various housing developments that have been made between them.

Fig. 1.1 - Geographic location of Nazaré (a sector of the 1:500,000 map of the Igeo).

Fig. 1.2 - The Nazaré region, as showed by the Google Earth (2012 image).

1.3 CLIMATE

For the climate characterization of the Nazaré municipality, the values recorded by the Aljubarrota and Leiria udometric stations were used together with Alcobaça climatological station (Câmara Municipal da Nazaré - CMN, 2011). The annual average temperature ranges from 12.5ºC to 17.5ºC. The highest values are recorded during June to September, which corresponds to the period of the year with the highest number of forest fire occurrences. In the town of Nazaré, the daily average maximum temperature never reaches 30ºC in summer and the average minimum daily temperature could reach 4ºC only in January. During summer, temperatures reach higher values but the variations in minimum temperatures during the night are not significant because the proximity to the sea.

The relative air humidity is high and ranges between 60% and 87%, according to the data from the meteorological station of Alcobaça (1978-1990). The humidity values decrease in the warm months, which makes days drier. In the rainy season the sea plays an important role as humidity increases as a result of a larger amount of evaporation.

According to the "Atlas do Ambiente", the average annual precipitation for the municipality of Nazaré is 700 - 1000 mm. The rainfall reaches its maximum during the months of January (138 mm) and December (128 mm) and the minimum during the months of July (6 mm) and August (10 mm), thus, following the trend of the Mediterranean climate where the rainfall is concentrated in the colder months of the year.

The dominant winds are from NW and SW quadrants, the latter associated with atmospheric depressions. Given its orientation E-W, the headland interferes with the winds and has a great influence on the dynamic conditions of the sea near the beach.

1.4 GEOLOGICAL SETTING

In the Nazaré region, a sedimentary record ranging in age from the Lower Jurassic to the Quaternary can be found (Figs. 1.3 and 1.4) (e.g. França & Zbyszewski, 1963; Dinis et al., 2008). The lithologies are diversified and comprise siliciclastics, marls and limestones. Volcanic rocks also occur locally and granite and metamorphic rocks outcrop at the Berlengas archipelago (at SW).

Some important tectonic faults exist in the region, namely the NE-SW trending Leiria-Caldas da Rainha structure (e.g. Dinis et al., 2012).

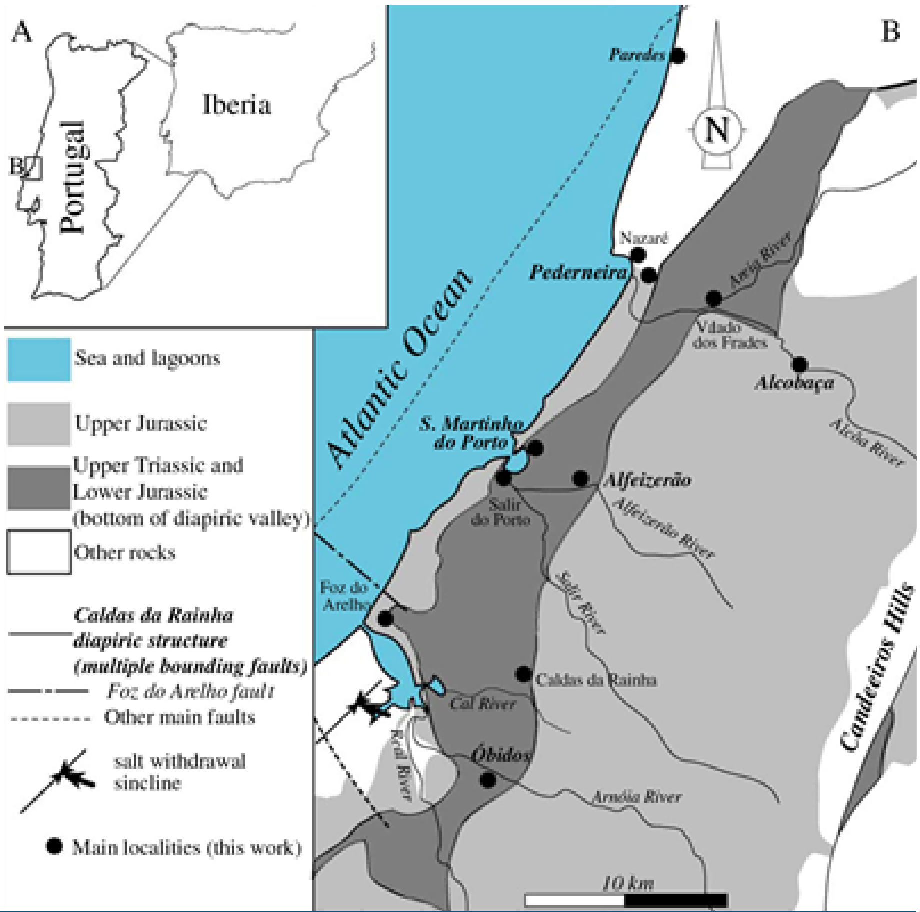


Fig. 1.3 - The onshore geology of the Nazaré region:
a: location. b: main geological units (Dinis et al., 2006).

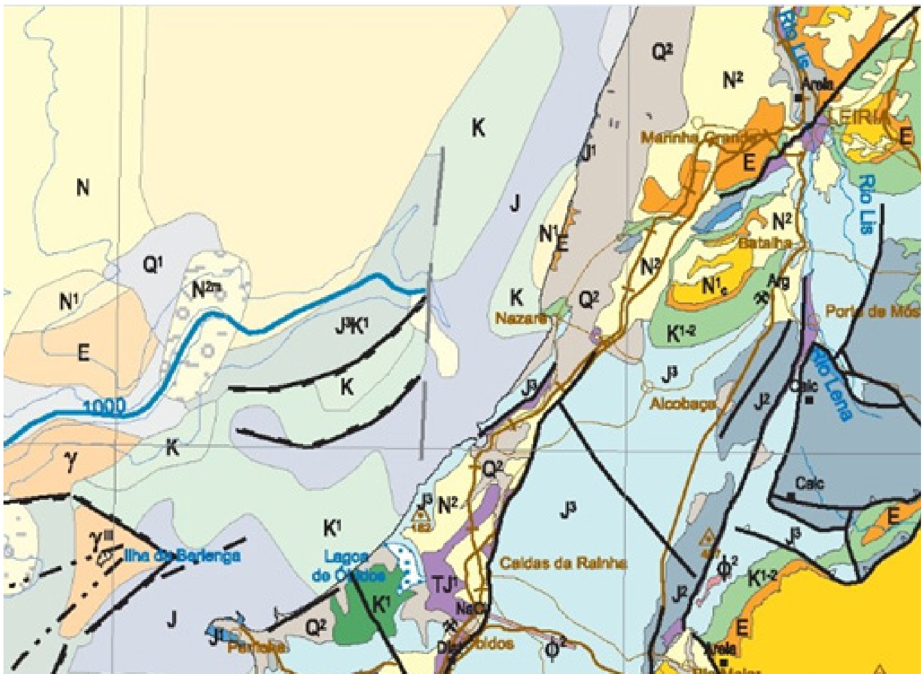


Fig. 1.4 - Geological map of the Nazaré region (a sector of the Carta geológica de Portugal, scale 1/1000000; LNEG, 2010).
j - Jurassic; k - Cretaceous; e - Eocene; n - Neogene;
q - Quaternary; faults represented in black.

This coast has sandy beaches that are straight stretches of coarse sand to pebbles, extending for several kilometers, limited by rocky headlands (Henriques, 1996; Cascalho et al., 2014). Belts of aeolian dunes border the landward edge of the beaches, resulting from sand being carried by the wind from the upper beach sector (Henriques, 1996; André et al., 2009; Ramos, 2014). In particular, the presence of hard Cretaceous limestones explains the presence of the Nazaré headland. In the south, the sea cliffs are cut on Upper Jurassic siliciclastics but up north of the headland the cliffs are cut on softer Eocene sandstones.

Some of the sands that, moved by littoral drift, could reach the Nazaré canyon are transported to deeper marine environments (Oliveira et al., 2007, 2011, 2014), but the majority could surpass towards south the Nazaré headland (Duarte et al., 2014) (Fig. 1.5).

The adjacent continental platform has outcrops of the rocky basement or a cover of sands and sandy gravels. Sediments recovered from the canyon consist mostly of terrigenous mud and, locally, sands of presumed turbiditic origin (e.g. Stigter et al., 2007; Arzola et al., 2008; Lastras et al., 2009; Martín et al., 2011; Ramalho et al., 2014). The current dynamics records demonstrate the presence of moderately strong tidal currents in the upper and middle canyon, directed predominantly along the canyon axis and typically alternating in up and down – canyon direction with a semi-diurnal frequency. Submarine canyons are referred as active conduits for transport of particulate matter to the deep sea. In this case, the sedimentary material derived from the near-shore, (predominantly silt and clay) is transported down the canyon and delivered at the abyssal plain. Turbidity currents strong enough to transport sand down the canyon are rare, occurring only on centennial or longer timescale.

Fig. 1.5 -The Nazaré coast, as provided by satellite Landsat 5 TM image, 1994 (Edisat). along the shore, the light blue band indicates the sand movements, by littoral drift, that surpass towards south the Nazaré headland.

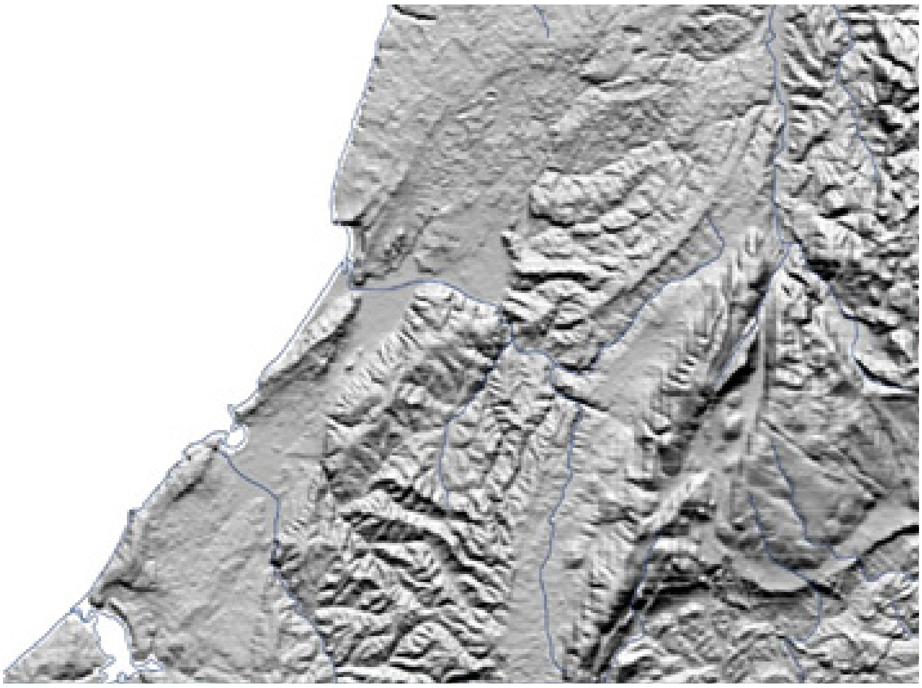


Fig. 1.6 - Digital elevation model (DEM; based on STRM data) of the Nazaré region onshore, with a 5x vertical exaggeration.

1.5 GEOMORPHOLOGICAL SETTING

The onshore of Nazaré is essentially a region of low relief (Figs. 1.6 and 1.7). The altitude varies from sea-level to about 180 m, reached in the town of Raposos (at SE), but about 50% of the county has less than 60 m of altitude.

The alluvial plain of Nazaré occupies the northern end of the SW-NE elongated depression (Figs. 1.7 and 1.8). Usually the limit of this depression corresponds to faults, probably resulting from the intense late Cenozoic compression. The alluvial plain has continuity to Ponte das Barcas, to the south towards Famalicão and Valado de Frades, and ending at the east near the villages of Casalinho, Maiorga and Fervença, located about 8 km from the sea (Henriques et al., 2006). The alluvial plain is crossed by two small rivers, Alcoa and Areia, with torrential regime.

The Pederneira Lagoon (Figs. 1.7 and 1.8) is nowadays an extensive flat area known as valley of the Cela/Valado dos Frades and Maiorga, flanked to the west by the hill of Serra da Pescaria and to the east by the Bárrio hills.

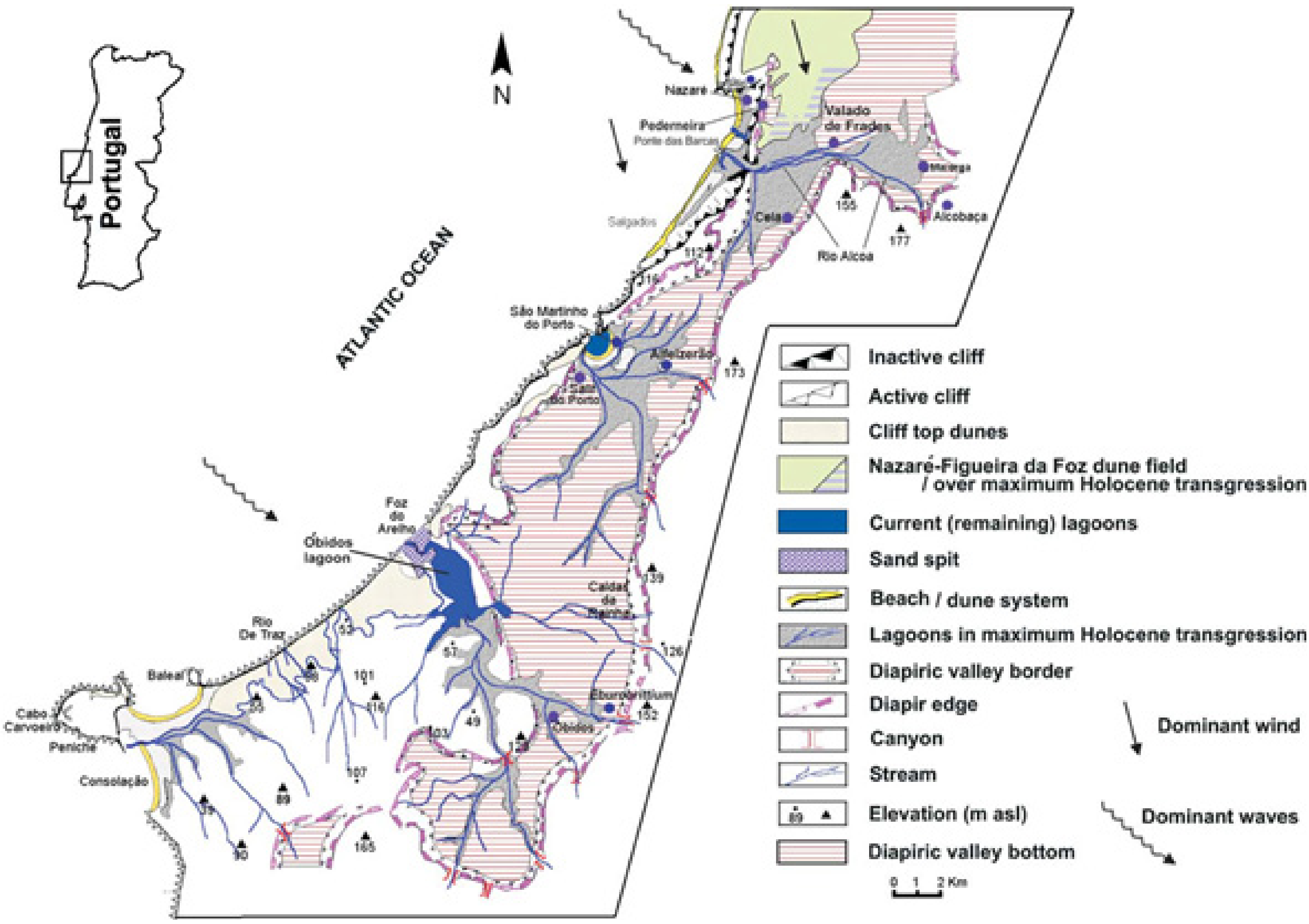


Fig. 1.7 - Geomorphological map of the coastal area between Nazaré and Peniche, including the Caldas da Rainha diapir valley (masl - metres above sea level) (Dinis et al., 2006).

The headland divides the littoral into two beaches: in the north, the Praia do Norte; in the south, the Praia da Nazaré – facing the Nazaré Bay (Fig. 1.9). This latter is divided by the mouth of the Alcoa River (Fig. 1.8): in the north, the Praia de Banhos; in the south, the Praia dos Salgados.

In the continuity with the Nazaré headland, but separated from it by a few meters, there is a stack of trapezoidal shape, large and steep (the stone of Guilhim), and another much smaller (the stone of Leme) (Fig. 1.10).

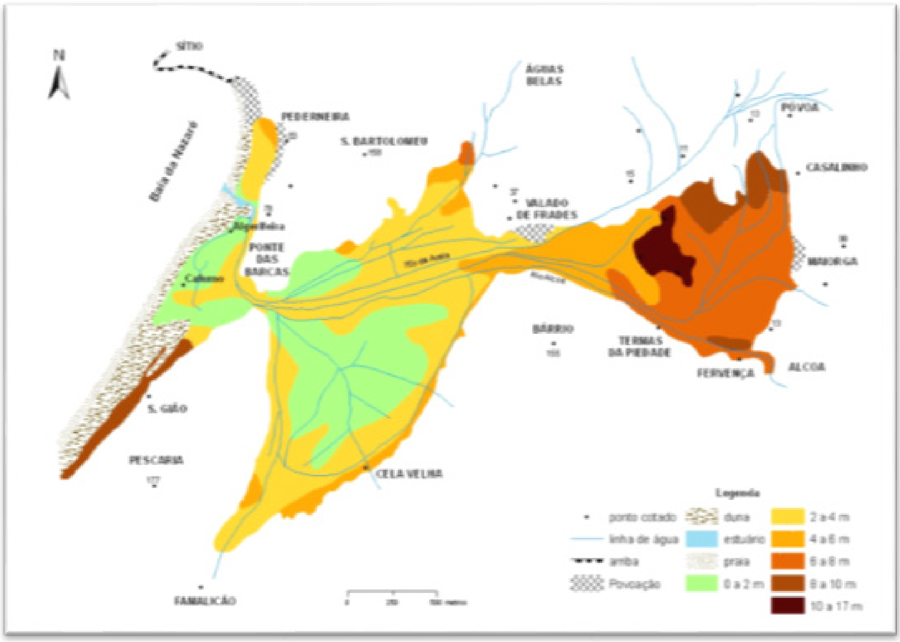


Fig. 1.8 - Morphological sketch of the aluvial plain of Nazaré (made from 1:2000 topographic plants, 1974 and 1977) (Henriques et al., 2006).

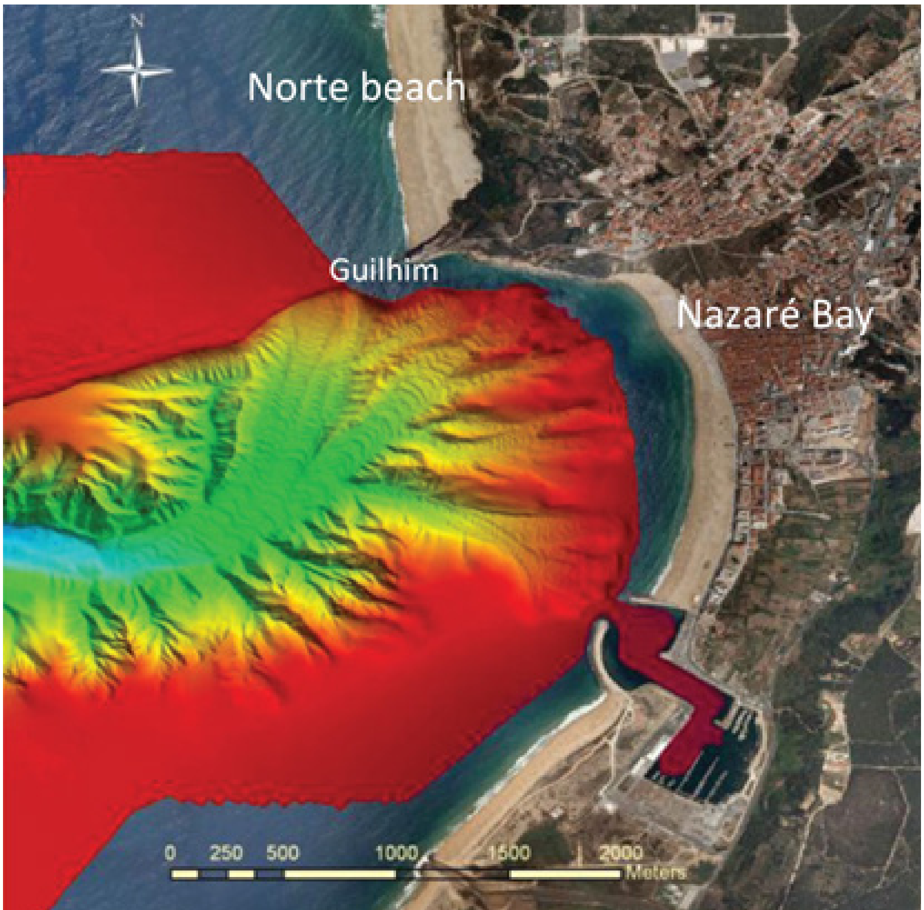


Fig. 1.9 - Praia do Norte, Nazaré canyon head and Nazaré bay (Duarte et al., 2014).

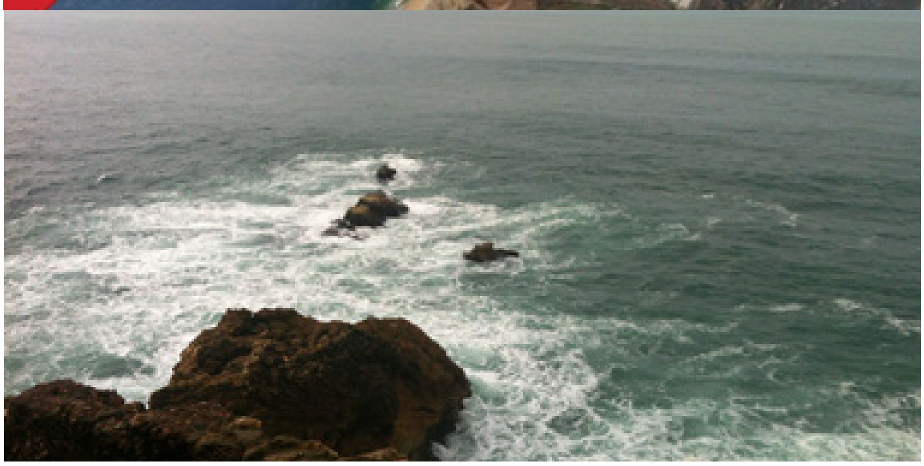


Fig. 1.10 -The Pedra do Guilhim, a large stack located near the Nazaré headland (author: Maria Margarida Gouveia; January 21, 2015).

The relationship between the formation of the promontory and the Nazaré submarine canyon has wide acceptance. It is the largest submarine canyon in Europe and is one of the largest canyons in the world. It is located 100 km north of Lisbon, with a direction ENE-WSW in the upper part and E-W in the middle and lower part (Fig. 1.11).

It cuts across the continental shelf almost to the beach which morphology and geographical location allows it to capture (and eventually redistribute) the particles derived from the continent (littoral drift and rivers input). This canyon has been reported in the literature as the major active sediment conduit to the abyssal plain (Oliveira et al., 2007 in Silva et al. 2013). The canyon head is located very near the shore and reaches 20 m in depth and few meters in distance from the beach. Distally this large submarine valley leads to the Iberian Abyssal Plain, some 210 km from the coast at a water depth of 5000 m (Figs. 1.12 and 1.13).

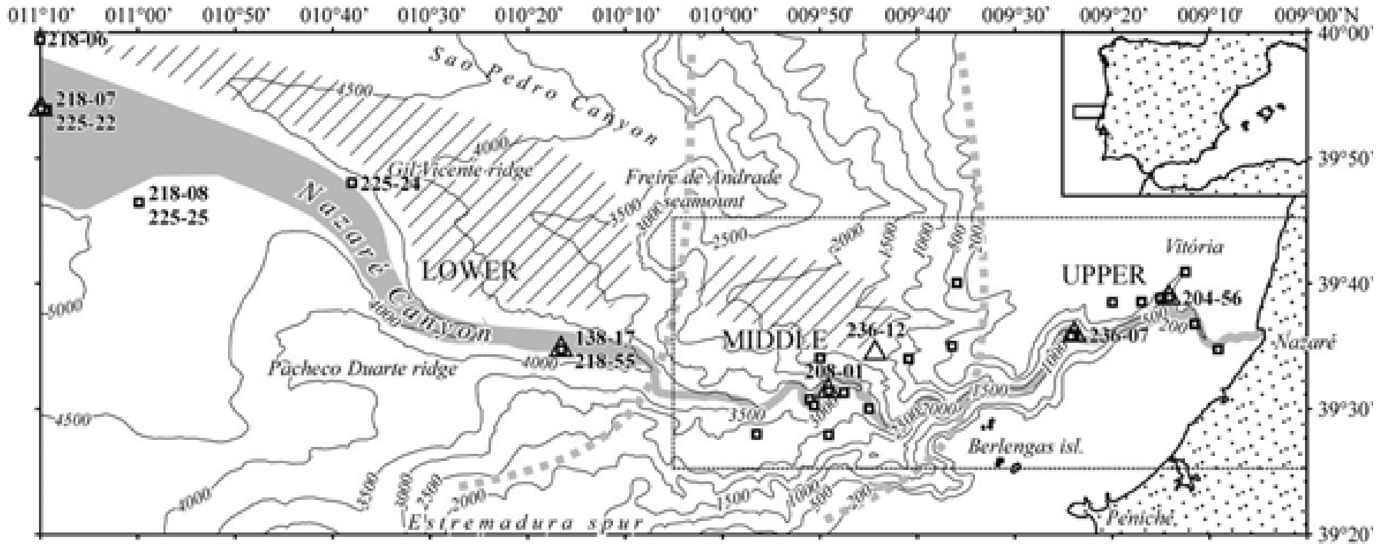


Fig. 1.11 - Schematic map of the Nazaré canyon area (Stigter et al., 2007).

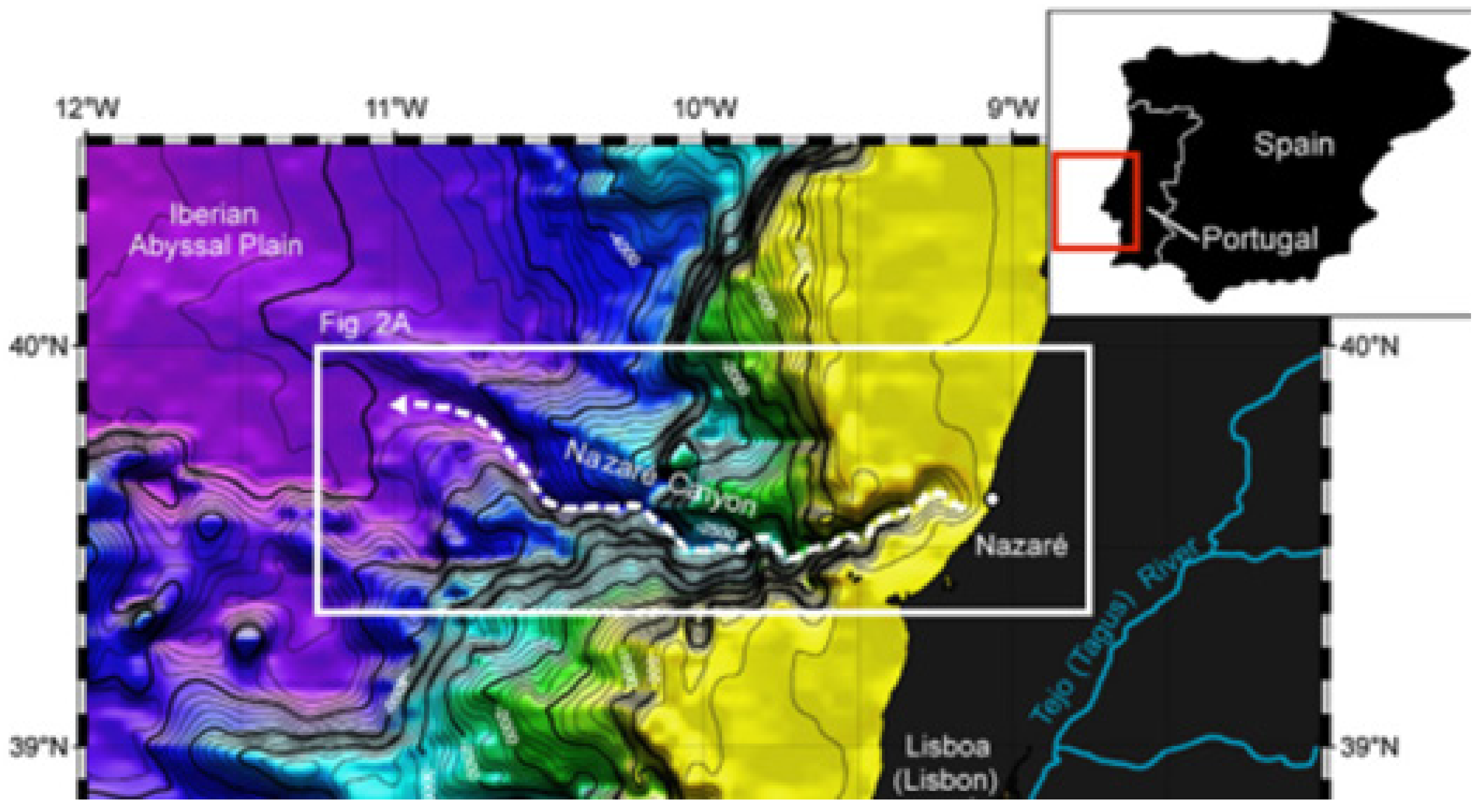


Fig. 1.12 - Bathymetry map of the west iberian margin showing the location of Nazaré canyon (Arzola et al., 2008).

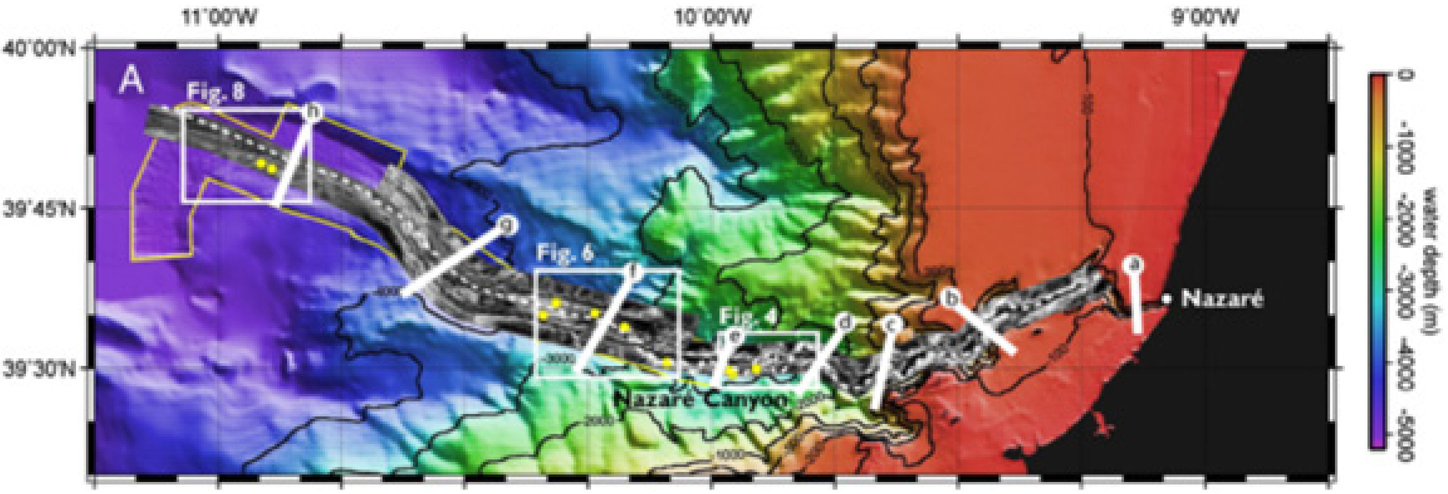


Fig. 1.13 - Extent of side scan sonar coverage of Nazaré canyon. Contours are 100 m, 200 m, 500 m, 1000 m than every 1000 m; a-h represents strike profiles and dashed white lines represents dip profiles (adapted from Arzola et al., 2008).

The radioisotope fluxes determined in the lower part of Nazaré canyon by Van Weering et al. (2002) suggest rapid accumulation of sediments in the upper and middle part of the canyon, from where it is episodically flushed into the Iberian Abyssal Plain. This explains the terrigenous signature of the sediments, particularly around the canyon's head. These terrigenous particles were derived from the erosion of beaches and cliffs, and transported by the dominant north-south littoral drift into the canyon with a possible contribution from northern rivers, Mondego and Douro, respectively (Guerreiro et al., 2009).

The initiation of sediment wave topography is due to heterogeneous deposition from sediment gravity currents flowing over discrete obstacles on the seafloor. The basal coarse-grained bed load layer 'feels' the topography; consequently this lower portion of the flow accelerates and bypasses sediment across the downslope-facing flanks, and decelerates and deposits sediment on the upslope-facing flanks of the waves. In contrast, the fine-grained suspended load is thicker and less affected by topography, so deposits a drape of roughly equal thickness over both flanks. The result is a sequence of interbedded sand-mud turbidites on the upslope-facing flanks, and mud-dominated turbidites on the downslope-facing flanks, shown clearly in the Nazaré Canyon mouth (Arzola et al., 2008; Lastras et al., 2009).

1.6 ANTHROPIC INTERVENTIONS IN THE VICINITY OF NAZARÉ

Several man-made features are present in the vicinity of Nazaré (Fig. 1.14): the jetties of harbor, the artificial mouth of the Alcoa River and the seawall located between the Marginal Avenue and the inner edge of the Praia dos Banhos.

The construction of Nazaré harbor was finished in 1983 and is very important for the fishing activity, leading to the economic development of Nazaré. Besides the fishing activity, recreational boating has known a notable importance in the last two decades.

The progressive silting of the Alcoa River estuary caused, in 2003, the flooding of agricultural land along its margins. During high tide, a large amount of sand was deposited at the river mouth. The river evidenced some displacement towards the south (Fidalgo, 2013).

1.7 THE PICTURESQUE VILLAGE OF NAZARÉ

The picturesque village of Nazaré was for centuries the main sanctuary of the Marian cult in Portugal, having an enormous importance in the touristic development of this village. According to Fidalgo (2013), the development of this urban nucleus resulted from two migration processes. One, during the 16th century (1542), coeval with the silting of the harbor of Paredes, that led to the migration of the population to various locations of the Portuguese coast, of which the Pederneira (a name given by the existence on the site of a round pine tree, with the size of "five spans of flint "(described by Father António Carvalho da Costa in Fidalgo, 2013). The second migration, that profoundly changed the social, geographical and economic habits of the people of this coastal area has presumably occurred during the second half of the 18th century: the migration from the fishing community of Ílhavo to Lavos, Gala, Cova, Buarcos, Matosinhos, Peniche, Nazaré and São Martinho do Porto, among others, formed important new fishing colonies.

Fig. 1.15 - Representation of the miracle experienced by Fuas Roupinho, at the hermitage da memória (sítio da Nazaré) (adapted from www.turistaprofissional.com).

The famous traditional festival of Nazaré takes place in September and lasts for three days, with fireworks, bullFighting and performances in the town theatre.

The image of Senhora da Nazaré, whose chapel was built in 1370 by King Fernando was, for a long time, considered as one of the most miraculous images of all Christianity. The first hermitage was built by Fuas Roupinho, from Porto de Mós, during King Afonso Henriques reign. At that time, the image was placed between two rocks on a place called The Memory (Ortigão, 1876).

Fig. 1.16 - Old photo of the fishing activities at the Nazaré beach (unknown author and date).

The first miracle, that caused the devotion of D. Fuas and the construction of this hermitage, happened in September 14th of 1182, when he was hunting on a foggy day. When chasing a deer, he almost fell off a cliff into the sea. The running horse that he was riding only stopped when Fuas shouted for help to "Nossa Senhora da Nazaré ", (our Lady of Nazaré), (Fig. 1.15). The legend says that the horseshoes were carved in the limestone forever.

Fig. 1.17 - Old photo of the fishing activities at the Nazaré beach (unknown author and date).

After the construction of the hermitage in honor of "Nossa Senhora da Nazaré", many miracles were recorded in a book where the stories were authenticated by the witnesses' signatures. From a copy of this book, a work has been published in 1628 called, "Antiga Imagem Sagrada de Nossa Senhora da Nazaré", (Ancient Sacred Image of our Lady of Nazaré), by Manuel de Brito Alão (Ortigão, 1876).

The first buildings in Nazaré should have been made in the northern area, sheltered by the headland and developed in parallel streets leading to the sea. The Nazaré, Praia de Banhos, developed significantly during the 14th century, was supported by the fishing activities and tourism.

"In the 17th and 18th centuries, the monks of Alcobaça tried to legally obtain the temporal jurisdiction over the site of Nazaré and the territory donated by D. Fuas Roupinho, but these attempts have failed. Both remained under the administration of the Confraria de Nossa Senhora da Nazaré, supposedly constituted in the 15th century by the men and women of Pederneira village and placed under royal protection, in the early 17th century" (CLASNZR, 2014). According to Frei Manoel de Figueiredo (Fidalgo, 2013), in 1780 fifty-eight houses in areas next to the sea along the promontory of Nazaré were listed, where the fishermen kept their gear.

Until the seventies of the last century, fishing activities (Figs. 1.16 and 1.17) represented about two-thirds of the economy of Nazaré.

The seasonality of these activities, coinciding with the annual fishing rhythms - a great bustle in the summer and almost inactivity during the winter months - was always felt by the local population as their major weakness: the Nazarenes always lived this duality between the abundance during the summer and the times of hunger during the winter (Trindade, 2008).

At the end of the 19th century, during the summer, the Praia de Banhos (Bathing beach), (immediately south of the headland) received a bather population that was larger than the population of Sítio da Pederneira (Figs. 1.18, 1.19 and 1.20).

Fig. 1.18 - Old photo of the Nazaré beach during summer, the later called Praia de Banhos (unknown author and date);
www.google.pt/search?q=imagens+antigas+da+nazare&rlz

Fig. 1.19 - Old photo of the Praia de Banhos during summer (unknown author and date);
www.google.pt/search?q=imagens+antigas+da+nazare&rlz

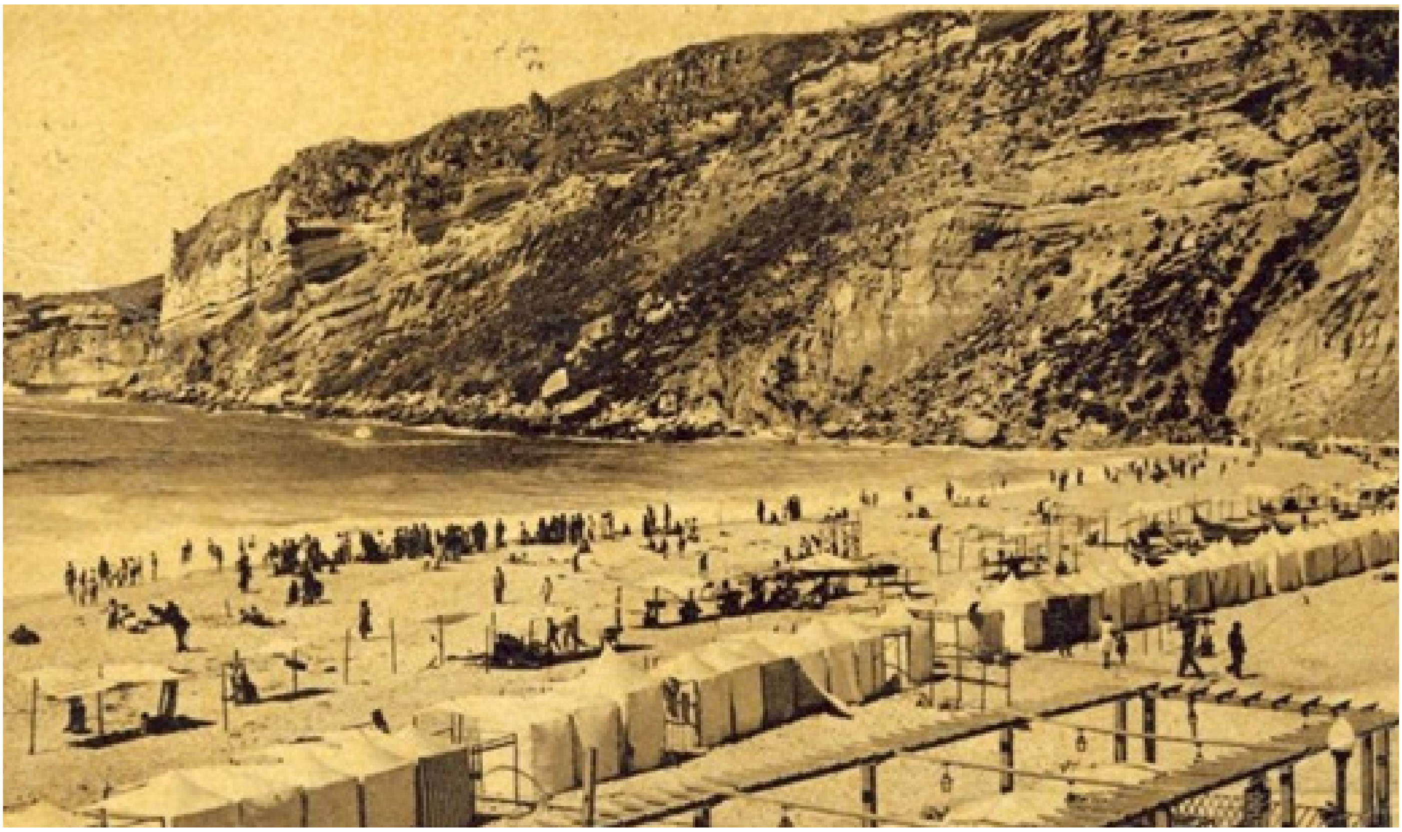


Fig. 1.20 - Old photo of the Nazaré headland and southern beach during summer, the later called Praia de Banhos (unknown author and date); www.google.pt/search?q=imagens+antigas+da+nazare&rlz

The designation of Village to Nazaré was attributed to the urban area of the Praia da Nazaré and the Sítio da Nazaré, by order of the Ministry of Interior, on the 28th February of 1957 (Figs. 1.21 and 1.22).

Nazaré represented the struggle for survival and the union of the fishing community had a common goal: the sea (Fidalgo, 2013). The decline of the importance of fishing activities for the local economy in the past thirty years has accentuated this dependence of summer economic activity (Trindade, 2007).
Since 1983, with the inauguration of the harbor, boats and fishermen left the beach. The organization of the social life of the fishermen was based on a family structure formed by almost matrilineal lineages. When men married they abandoned their families of origin and were integrated into their wives families.

After a few generations this generated a large concentration of families in neighbourhoods or streets, linked by the maternal side, which allowed people to help each other in any tragic situation.
This very particular social organization has been disappearing and the typical fishermen houses have been occupied by shops, and also by the type of life of future generations, not facing fishing as a professional activity to follow. Today it is tourism that occupies most of the population and is supported in activities like hotels, trade and restaurants. In order to reinvest in the image of Nazaré and its fishing tradition in the 90s of last century, the Xávega art was recreated (Trindade, 2008). The Xávega art is a traditional fishing technique, dominant in the Portuguese central coast (Nunes, 2006 in Delicado et al., 2012) and practiced in Portugal since the 18th century. This technique consists of dragging "on edge" as vessels launch their fishing nets and make the "siege" to the fish. The fishing net is then pulled from the beach, once with the help of oxen, currently using tractors. Today it is a show enjoyed by tourists and persists in this area.

Apart from this aspect of the fishing culture, during Easter an ethnographic group has been responsible for organizing an exhibition where the costumes, the house, the tavern, the work with the fishing nets, the popular games and the recreation of scenes of everyday life can be seen by tourists. The peculiar habits of the fishing community that lived by the sea, made Nazaré beach, since the mid-fifties, one of the most popular touristic destinations of Portugal (Fig. 1.23).

Fig. 1.21 - Old photo of the Nazaré village (unknown author and date).

Fig. 1.22 - Old photo of the Nazaré village (unknown author and date); www.fotos.sapo.pt/rjoalmeida/fotos/?uid=muyithnzou9vgtdsvj7l&aid=73

Fig. 1.23 - Panoramic view of Nazaré, from the Sítio, beach exposed during low tide (author: Pedro P. Cunha; July 2004).

2.

LITTORAL MORPHODYNAMIC AGENTS

2.1 WINDS

Between April and October, the weather situation that influences the Iberian Peninsula corresponds to the joint action of the Azores anticyclone, centered on its most northerly position, and a thermal depression located on the peninsula. The resulting atmospheric circulation of the joint action of these two action centers determines a northern wind along the western Portuguese coast, often reinforced during the afternoon due to a caving depression (e.g. POEM, 2005).

2.2 TIDES

The western Portuguese coast is affected by a mesotidal regime, with semi-diurnal tides and small diurnal inequality. At Nazaré coastal reach, the tidal range has a minimum of 0.9 m and a maximum of 3.8 m.

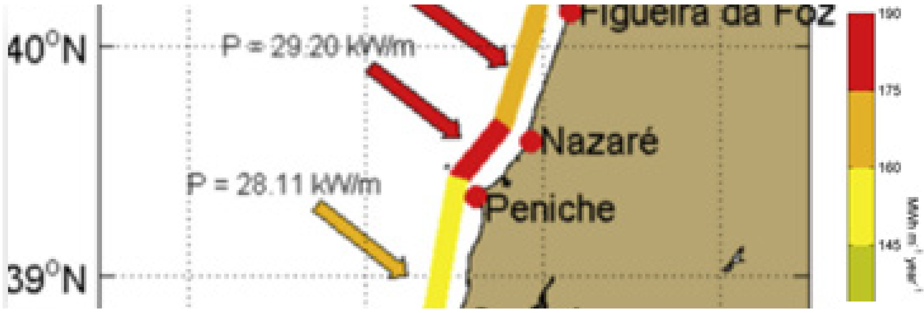


Fig. 2.1 - Relationship between the coastline orientation and the available wave energy to the coastline (adapted from Mota & Pinto, 2014).

2.3 WAVES

The western Portuguese coast is well exposed to the North Atlantic wave regime, characterized by a predominant swell from the NW quadrant and a wider directional spread (SW to N) of other waves, generally less energetic. The offshore incident wave regime is characterized by an average significant wave height (Hs) of 2-2.5 m, wave periods of 9-11 s corresponding to WNW to NNW swell (Andrade et al., 2002; Dodet et al. (2010) in Bosnic et al., 2014).
The offshore dominant wave direction and the orientation of the coastline is determinant for the resulting nearshore total available wave energy (Fig. 2.1). The effect of refraction on the wave field as it propagates into shallower waters is significantly higher in the sections least orientated with the annual average wave direction, leading to a higher energy reduction along those coastal areas. The NW dominant offshore wave direction clearly benefits the perpendicularly oriented Peniche - Nazaré reach, which shows only 11% reduction in wave power density relatively to the offshore value, thus becoming the near shore area with higher wave energy resource (Mota & Pinto, 2014).

The nearshore wave propagation in this area is significantly disturbed by the complex morphology of the Nazaré canyon head (Fig. 2.2), which interferes with the net southward longshore sediment transport (e.g. Dias et al. (2002) in Silva et al., 2013). The Nazaré headland shelters the embayment at south, inducing a less energetic wave regime at the Praia da Nazaré (in particularly the Praia de Banhos); here, the sea currents are weak and do not exceed 0.2 m/s (Bosnic et al., 2014). The beach located at north of the headland, called Praia do Norte, has a more energetic swell (Fig. 2.3) and very active dynamics, both in terms of curling and longshore drift of sediment. The Praia do Norte is immediately located northwards of the submarine canyon where the changes in the wave refraction pattern are related to the progressively smaller wave breaking angles northward from the headland (Silva et al., 2013); at this beach, the water current velocity varies mostly from 0.3 up to 0.7 m/s.

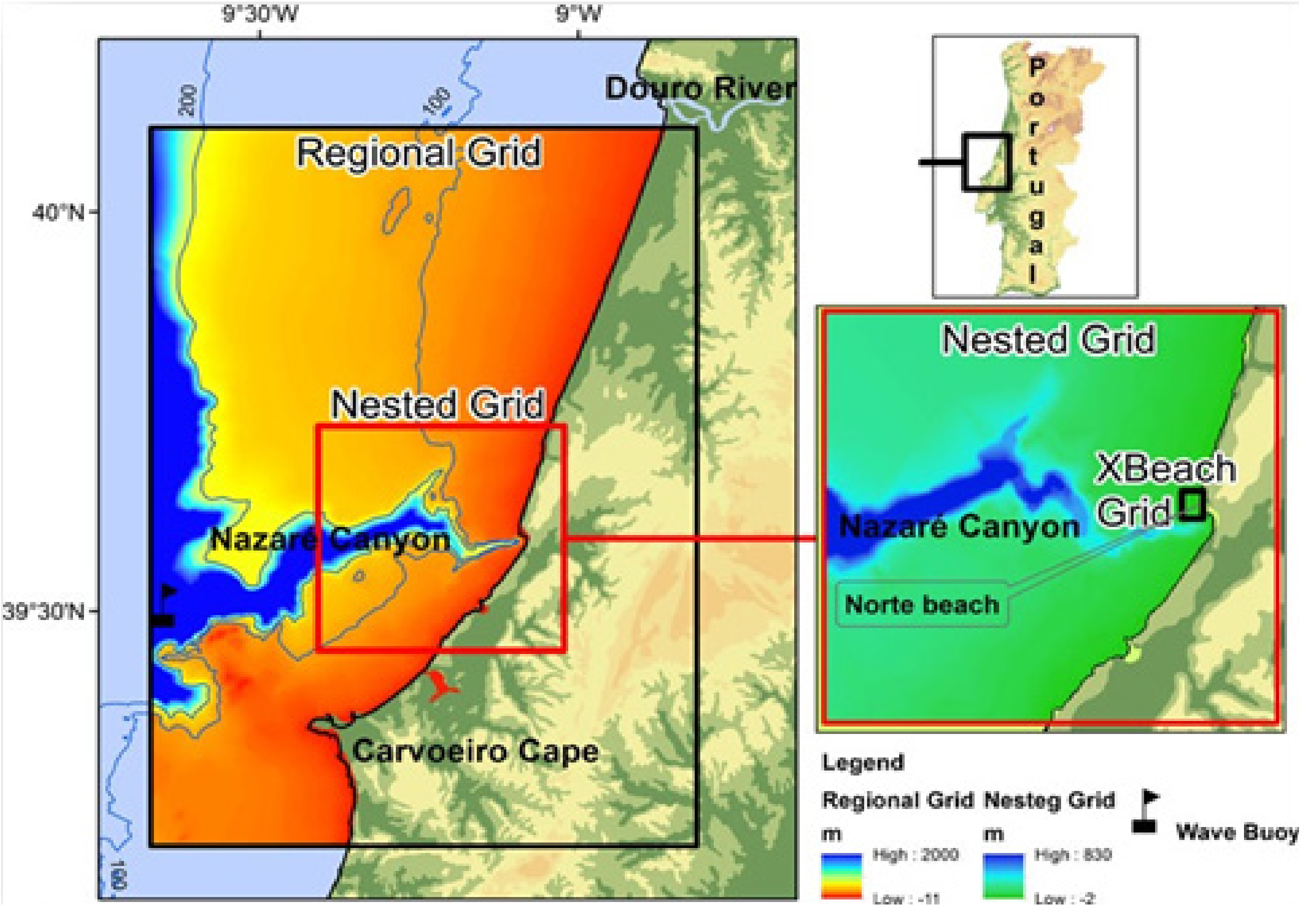


Fig. 2.2 - Praia do Norte location and spatial coverage of the bathymetric grids used in the morphodynamic modelling (Silva et al., 2013).

Attending to his "V" transversal geometry, E-W orientation, low longitudinal slope (10 - 20%) and canyon's head deeply carved on the coast line, the Nazaré submarine canyon is a typical gouf-type canyon (Guerreiro et al., 2009). It is 230 km long and 5 km below sea level at its deepest part. It is big enough to hold a considerable volume of water and any swell is funneled all the way along the narrow canyon to the Praia do Norte and adjacent headland.

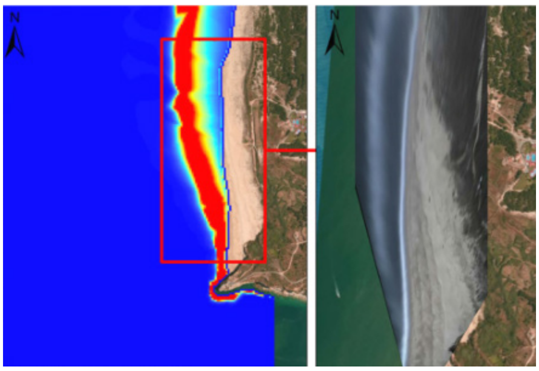


Fig. 2.3 - Wave dissipation model of the Praia do Norte (Silva et al., 2013).

According to the Instituto Hidrográfico (Cardoso, 2013; written communication), the arrival of a strong swell, from the west/northwest quadrants, results in:

1 - The refraction of the wave, due to the difference in depth between the continental shelf and the submarine canyon. This effect leads to a change in direction over the canyon (where the waves travel faster).

2 - Overtopping a topographic barrier (steep vertical variation). The abrupt depth reduction leads to a shoaling effect on the wave (reduction of wave length and increase of wave height). This effect occurs gradually with the approach of a wave to the shore.

3 - Positive interference between the wave travelling from the canyon and the wave propagating across the northern continental shelf. This effect promotes a new increase of wave height at the point of intersection of the two wavefronts.

4 - Littoral drift. The wave propagation promotes a current, flowing along the beach with a northernly direction, which deflects offshore near the cape, acting as a topographic barrier. This current is enhanced by the water pile-up in the cove. The current, flowing with an opposite direction to the wave propagation intercepts the wavefronts, leading to an additional increase of the shoaling effect.The combined effect of these processes significantly increases the wave height, which can reach much higher values than those observed offshore. These waves break when their height is approximately equal to the local water depth. The results are spectacular, with giant waves breaking on the cliffs of the headland (Figs. 2.4, 2.5 and 2.6).

Fig. 2.4 - Strong waves at the Praia da Nazaré (Praia de Banhos);
www.google.pt/url?sa=i&rct=j&q=&esrc=s&source=images&cd=&cad=rja&uact=8&ved=0cacqjrw&url=http%3a%2f%2f
www.surfguru.com.br%2fnoticias%2f2013%2f10%2fscooby-e-maya-tentam-superar-onda-gigante-de-Mcnamara-em-Portugal.html&ei=9hjkvlk2iswtu7

Fig. 2.5 - Giant wave reaching the Nazaré headland;
www.almasurf.com/arquivos/image/2012/529041_409111969172415_1437498536_nbrunoaleixo.jpg

Fig. 2.6 - Giant wave breaking at the Nazaré headland (author: Bruno Aleixo);
www.noticiasaominuto.com/desporto/171169/Mcnamara-partilha-foto-impressionante-da-nazare#.uvxnuvl_uvm

According to Quaresma (2006), under the project "EUROSTRATAFORM", whose objectives included the specific study of submarine canyons and their role in sediment dynamics of European continental shelves, the data obtained revealed also the propagation of internal waves of large amplitude, forcing pulses of strong currents.

The higuest ocean waves along the whole the Portuguese shore occur, more frequently at the Praia do Norte. The submarine canyon of Nazaré plays a decisive role in the local movement of water and sediments, but can also generate giant waves.

During winter, big storms in the North Atlantic Ocean generate swells that reach the western Iberian margin. Severe stormy waves are frequent in the western Portuguese coast. As an example, on January 21, 2013 the Portuguese Hydrographic Institute registered waves 19 m high and winds of 107 km/hour offshore of Nazaré, typical values of severe storms. At November 1, 2011, Garrett McNamara surfed one gigantic wave generated by an intense storm at the near Ireland offshore. This achievement promoted Nazaré to the world. This site is now a "magnet" for surfers searching for extreme wave conditions (Figs. 2.7 and 2.8).

Fig. 2.7 - Surfing with extreme wave conditions at Praia do Norte;
www.google.pturl?sa=i&rct=j&q=&esrc=s&source=images&cd=&cad=rja&uact=8&ved=0cacqjrw&url=http%3a%2f%2fsicnoticias.sapo.pt%2fdesporto%2f2014-02-02-ondas-gigantes-e-Mcnamaraatrairamcentenas-de-curiosos-a-nazare&ei=knjkvitccoasufavg_ge&bvm=bv.85970519,dd24&psig=afqjcnf08hgjbo3c8jri2gcecxf6pdyiow&ust=1424345435280804

Fig. 2.8 - Surfing with extreme wave conditions at Praia do Norte;
www.regiaodanazare.com/getjournalnewsthumb.ashx?fb=8292

Usually, when the large open-ocean swells approach the coast they start to slow down by interaction with the ocean bottom. However, at Nazaré offshore the ocean swells get focused in the submarine canyon that points to the coast and do not lose energy until they reach the near shore. As the waves emerge at the canyon head, they reach very shallow bottom and became suddenly very high.

The results of the Siam project (first integrated assessment of climate-driven impacts and adaptation measures at a country-scale) suggested that storminess along the Portuguese margin may increase by the end of the 21st century. This increase comes out as markedly seasonal, with extreme events. This modification could increase 15-25% the present day erosions rates (Andrade et al., 2006).

3. THE EVOLUTION OF THE NAZARÉ COAST

3.1 EVOLUTION DURING THE LAST 18 KYRS

By 18 kyrs BP (Before Present), at the Last Glacial Maximum (LGM), the landscape of western Iberia was significantly different from today (Fig. 3.1A). The glacial ice caps were quite expanded, covering part of the North Atlantic, Northern Europe (at about the latitude 50ºN) and half of North America (reaching latitude 40º N). Due to the accumulation of ice at continental glaciers and mountain glaciers, in Portugal the sea level was between 120 to 140 m below the present sea level (Dias, 1985, 1987). Because of this low sea level, the paleo-coastline was located near the edge of the continental shelf, several kilometers from the present coastline (Dias, 2004). At that time, the polar front was located at the latitude of northern Portugal (e.g. McIntyre, 1973), and the temperature of water near the coast reached values below 4ºC (e.g. McIntyre et al., 1976; Molina-Cruz & Thiede, 1978). Near the Portuguese coast, icebergs experienced an accelerated melting (e.g. Guillien, 1962). On land, there was a strong contrast between the cold environment along the Atlantic coast, with abundant snow, strong winds and high cloudiness. In the rest of the Iberian Peninsula, the rainy seasons were much more durable than currently, experiencing the highest rainfall in autumn and spring (Daveau, 1980 in Dias, 2004). The modern vestibular reaches of rivers, corresponded to very deep valleys, were undergoing an intense erosive fluvial incision.

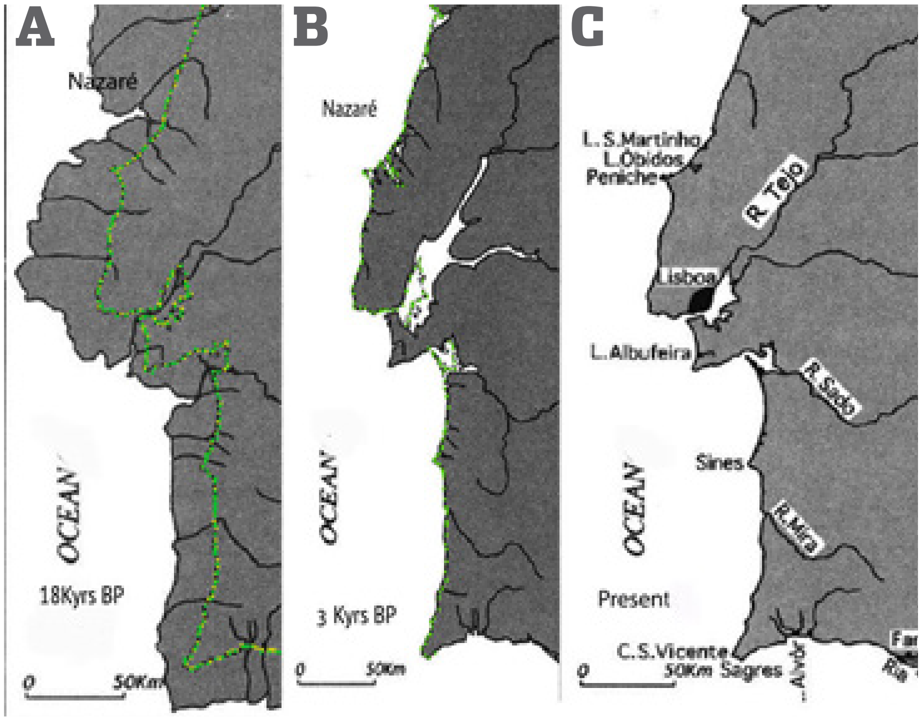


Fig. 3.1 - Presumed Portuguese coastline at ca. 18 kyrs BP (A), 3 kyrs BP (B) and in the Present (C) (adapted from Dias, 2004).

In the Portuguese platform, the relative sea level seem to have risen at a moderate rhythm until about 16 kyrs BP, reaching a level ca. 100 m below the present sea level.
Until about 13 kyrs BP a stabilization period was experienced. The rapid sea level rise that occurred between 13 kys and 11 kyrs BP flooded a significant part of the fluvial valleys.
At 11 kyrs BP, in the Iberian Peninsula the climatic conditions were warm, due to an interglacial period. After that, climate changed to glacial conditions and the sea level lowered to 60 m below the present level (Dias, 1987). The sedimentation of Pederneira lagoon began when the sea level reached the mouth of the Alcôa river (-30 m at 8000-9000 yrs BP) recording events since the early Neolithic and the Atlantic climatic period (Dinis & Tavares, 2009). For two millenniums the sea level rise was very fast but decreased between 5 kyrs and 3 kyrs BP, reaching approximately the present level (Fig. 3.1B). During the high-stand sediments were mainly deposited in estuarine or lagoon environments (Figs. 3.2 and 3.3).

3.2 HISTORIC EVOLUTION OF THE COAST

During historical times, the Portuguese coastal setting has undergone profound changes (Figs 3.1C, 3.4, 3.5, 3.6 and 3.7). Whether as a result of natural forcing, either due to the human activities (deforestations and brush clearing, agriculture, etc.), the fact is that intense sediment supply to the coast was reached. It seems that before the start of our era, the main estuaries became almost filled and begin to export to the coast large amounts of sediment.

At the time of Roman occupation, in the area surrounding the lagoon of Pederneira, the sea water reached far in the interior of the estuaries. Figure 3.6 shows a picture from 1592, representing the Pederneira village and the Fort at the headland (Fidalgo, 2013). During the seventeenth century, the Pederneira lagoon could have been navigable but only with small boats.

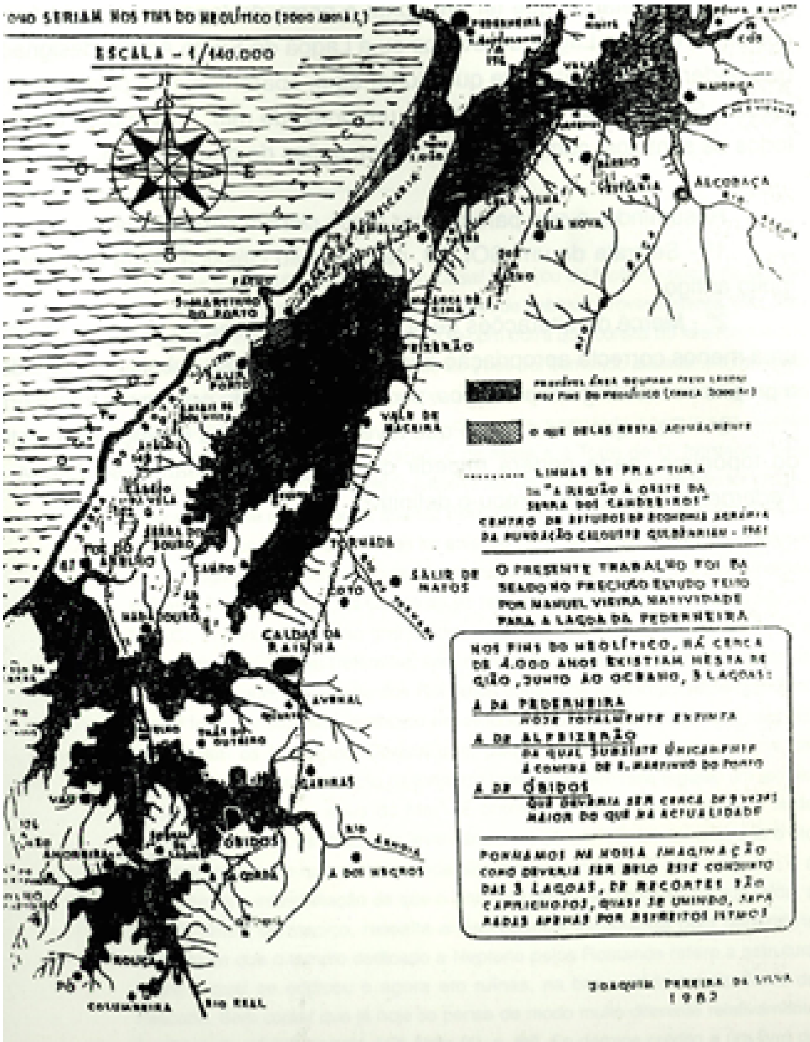


Fig. 3.2 - Map of lagoons of Pederneira, Alfeizerão and Óbidos at 2000 yrs B.C. (author: Joaquim Pereira Da Silva; date: 1982).

Fig. 3.3 – Map of the lagoons of Pederneira and Alfeizerão during the Neolithic period (10000 – 3000 B.C.) (adapted from Weinholtz (1967-1978) in Monteiro, 1995).

Fig. 3.4 - The Oldest map of Portugal (author: Fernando Alvaro Sêco; date: 1560).

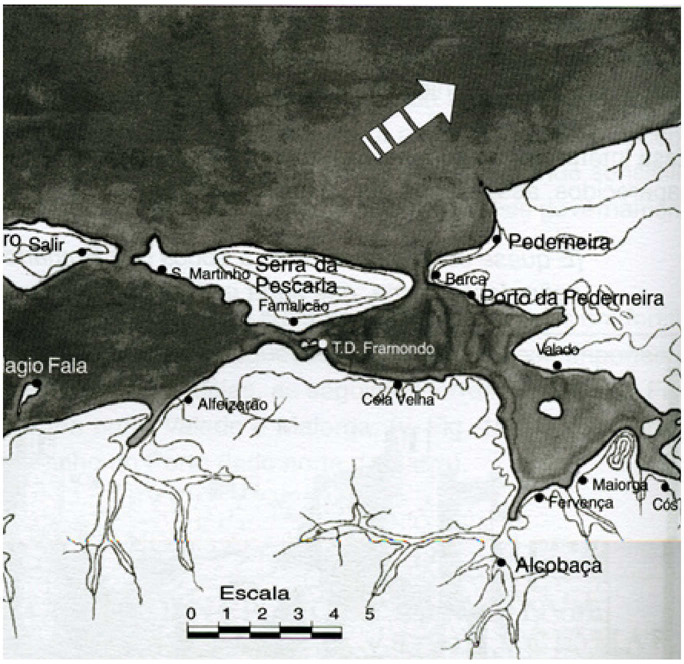


Fig. 3.5 – Palaeogeographic reconstruction of the lagoons of Pederneira and Alfeizerão in the beginning of the 16th century (adapted from Weinholt (1967-1978) in Monteiro, 1995).

Fig. 3.7 - Map of província da Estremadura (date: 1846).

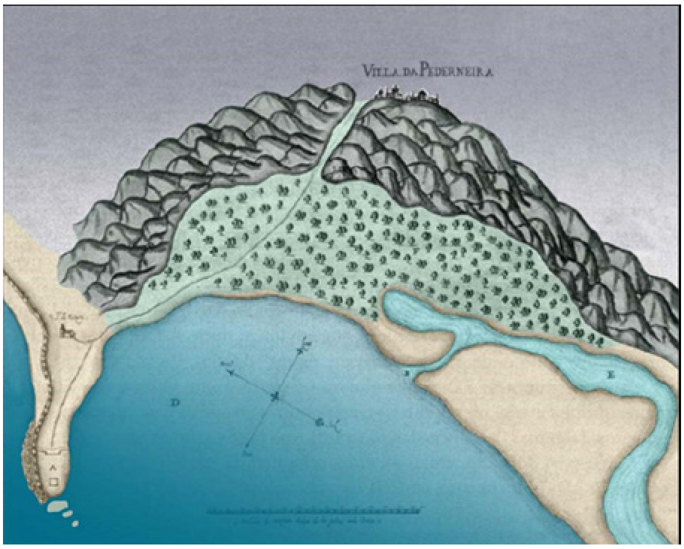


Fig. 3.6 - Plan of Pederneira village, 1592 (Fidalgo, 2013); the Pederneira lagoon is already almost filed with sediments.

The Pederneira lagoon became fully filled, mainly fed by large areas of loose ground and intensive agriculture and deforestation in the Alcôa drainage basin, within a geological structure favorable to clastic transport (Dinis & Tavares, 2009).

During the twentieth century, many human activities dramatically reduced the sediment supply to the coast (Dias, 2004) leading to relevant changes in physiography (Figs. 3.8, 3.9, 3.10, 3.11 and 3.12).

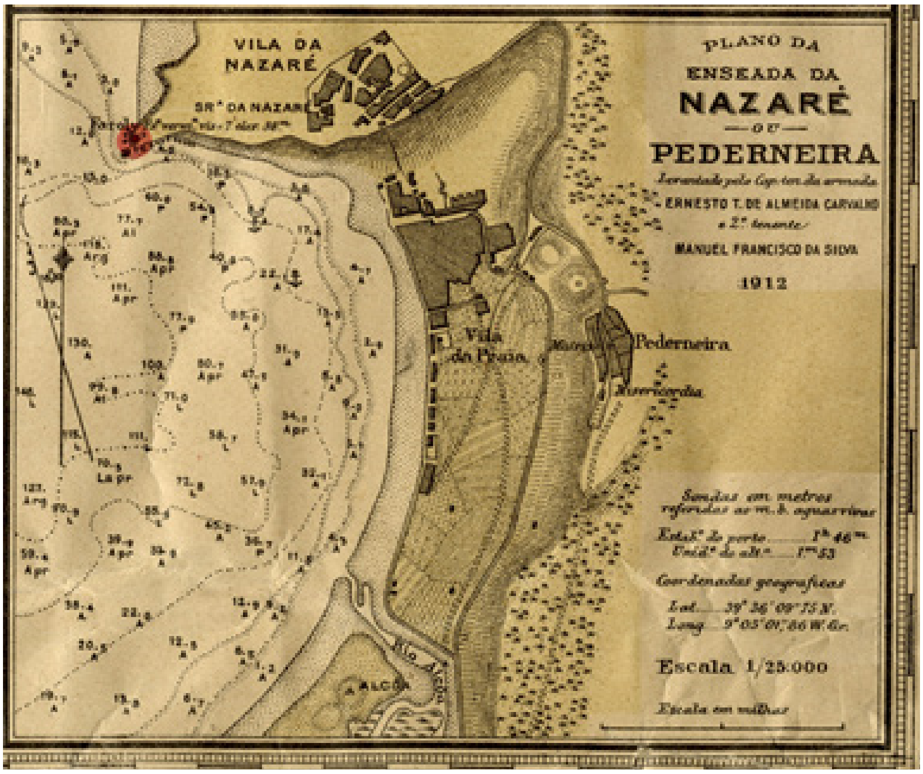
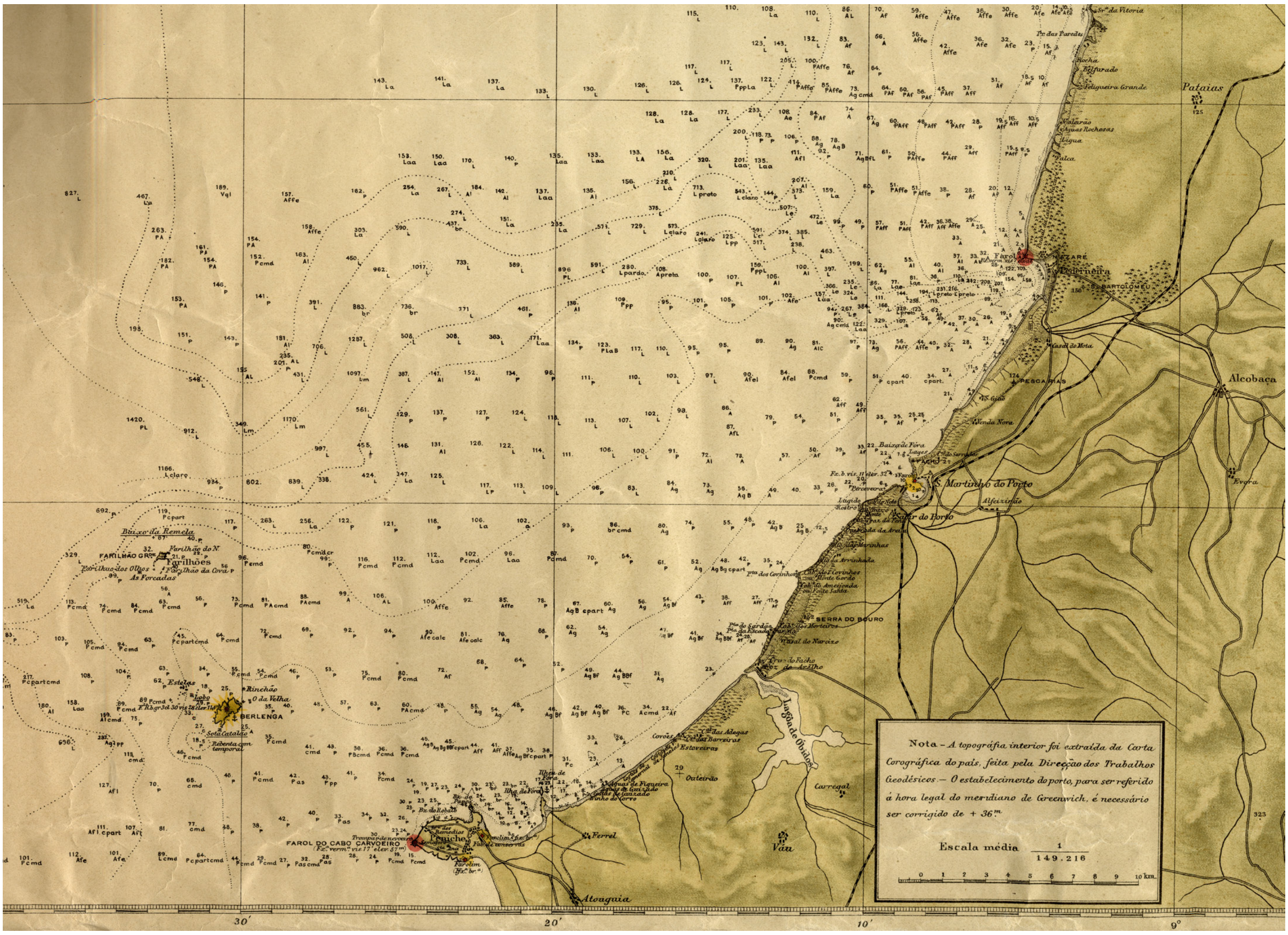


Fig. 3.8 - Plan of Nazaré at 1:25 000 scale (author: Manuel Francisco da Silva; date:1912).

Fig. 3.9 - Map of central Portuguese coast with bathymetry offshore and topography onshore, 1:150 000 scale (date: 1915).



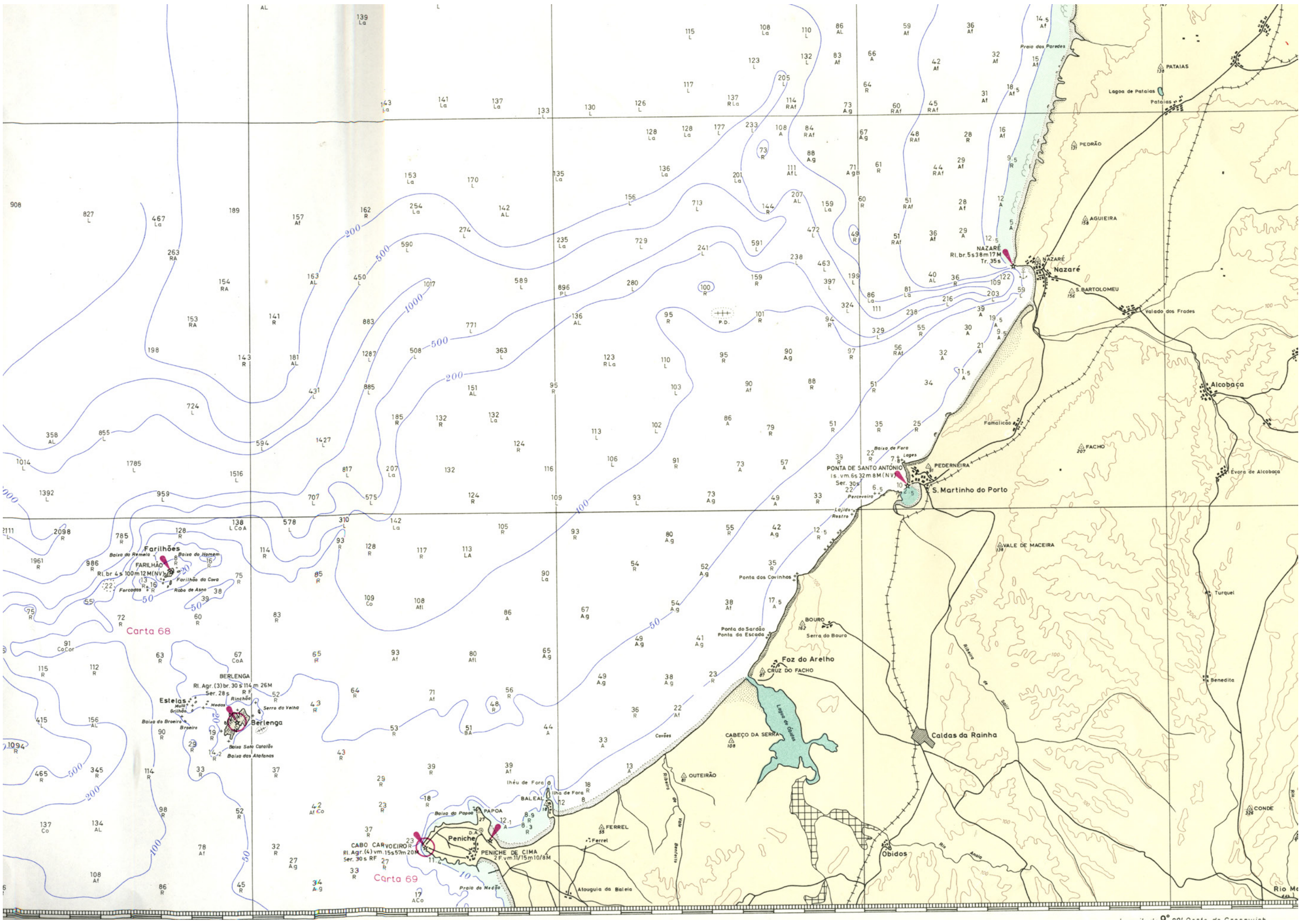


Fig. 3.10 - Map of central Portuguese coast with an offshore bathymetry; 1:150 000 scale (date:1912).

"The shoreline is often considered as an indicator of short and long-term coastline changes that are central to defining the coastal hazard zone. Despite its common usage, the shoreline has been given several definitions based on different approaches: physical, geological, biological, or coastal engineering.

Boak & Turner (2005) describe a wide variety of shoreline definitions. Depending on the definition, the shoreline position can vary up to hundreds of meters. The choice of the period over which the waterline is averaged to determine the shoreline will also cause some differences between shoreline definitions"(Almar et al., 2012).

Fig. 3.11 - Topographic map of the central Portuguese coast; 306-b, 1:25000 scale (date: 1942).

Fig. 3.12 - Topographic map of the central Portuguese coast, 306-b, 1:25000 scale (date: 2003).

3.3 EVOLUTION OF THE COASTLINE DURING 1958-2014 BY ANALYSIS OF AERIAL PHOTOS AND IMAGES

Understanding the behavior of beach morphological response to meteorological and oceanographic forcing ranges is an important key for integrated coastline management. Beaches are one of the most mutable environments in the world. Analysis of aerial photos is one of the methods used by geomorphologists and Earth scientist to establish reference scenarios and to quantify morphological changes, like shoreline position or aeolian dune configuration, for example. This requires baseline data, diagnostic indicators and related measurements (Carapuço et al., 2014).

The establishment of monitoring programs in sandy shores can be considered as a starting point to understand present-day shoreline evolution. Topo-bathymetric data acquired along several years, and the respective DEMs, can provide accurate information for shoreline evolution. Usually the best indicators are the shoreline position and the limit beach-aeolian dunes.

The recent evolution of the coastline performed in this coastal stretch, was based on dated aerial photos coverages of 1958, 1991, 2002, and satellite digital images (Google Earth) of 2006, 2008, 2009 and 2014, respectively. Geo-processing tools such as ArcGIS software were used.

Praia da Nazaré is considered as a beach-dune system, because its inner boundary is established by active aeolian dunes. The Praia de Banhos is located between the cliff of Sítio and the harbor. The inner edge of this beach is made by the retaining wall of the avenue and not by dunes (Fig. 3.13) and is, therefore, included in the beach system with an upper limit shore face (Henriques, 1996).

This analysis reveals that between 1958 and 2014, both north and south of the promontory, the active aeolian dunes moved toward the beach (Fig. 3.14).

The evolution of shoreline, expressed by changes in the limit beach face – berm (Fig. 3.15) documents a trend for progradation, in contrast to other beaches of the western coast of Portugal.

Fig. 3.13 - Photo of praia de Banhos, in Nazaré (author: Margarida Porto Gouveia; january 20, 2015).

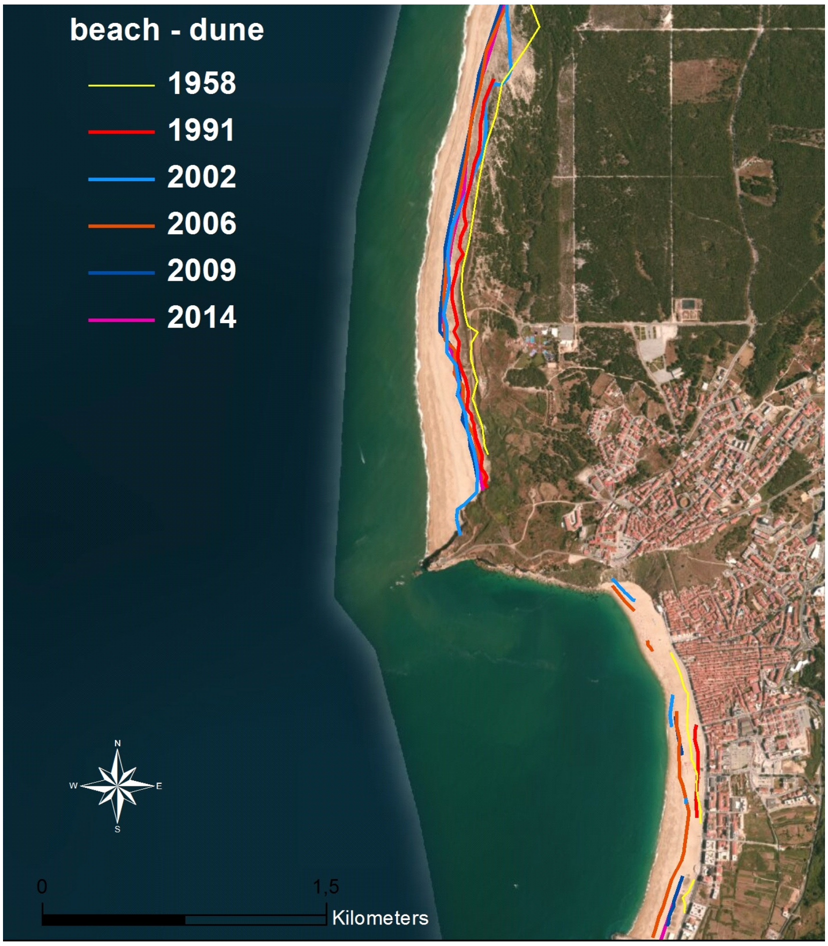


Fig. 3.14 - Evolution of the limit beach – aeolian dunes during the period 1958 to 2014 (source of the image used for plotting: 2014 Google Earth).

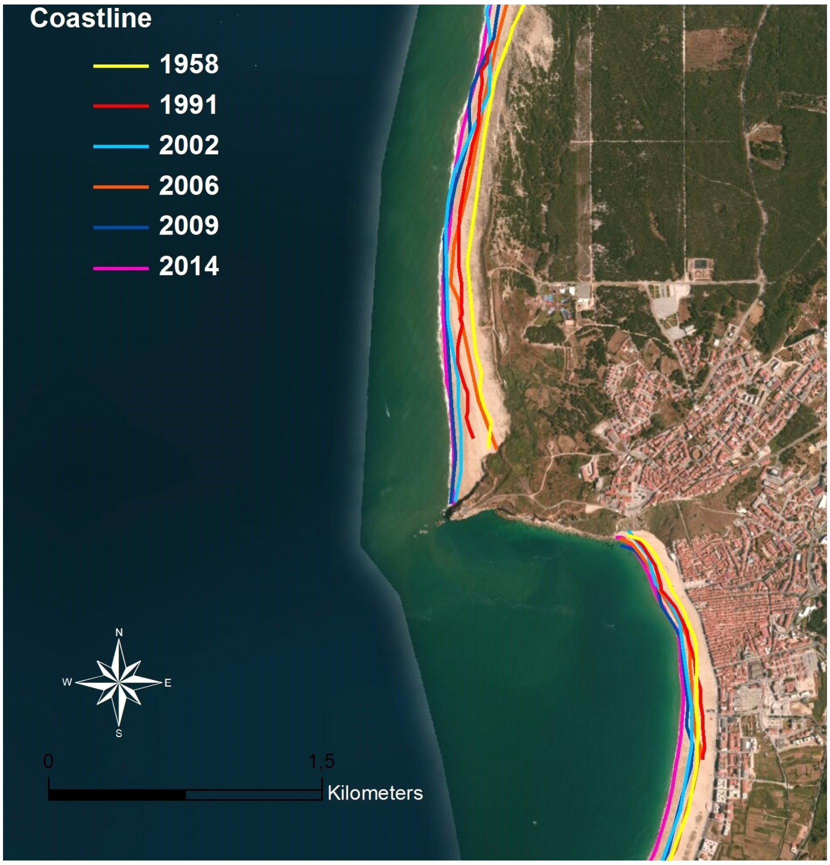
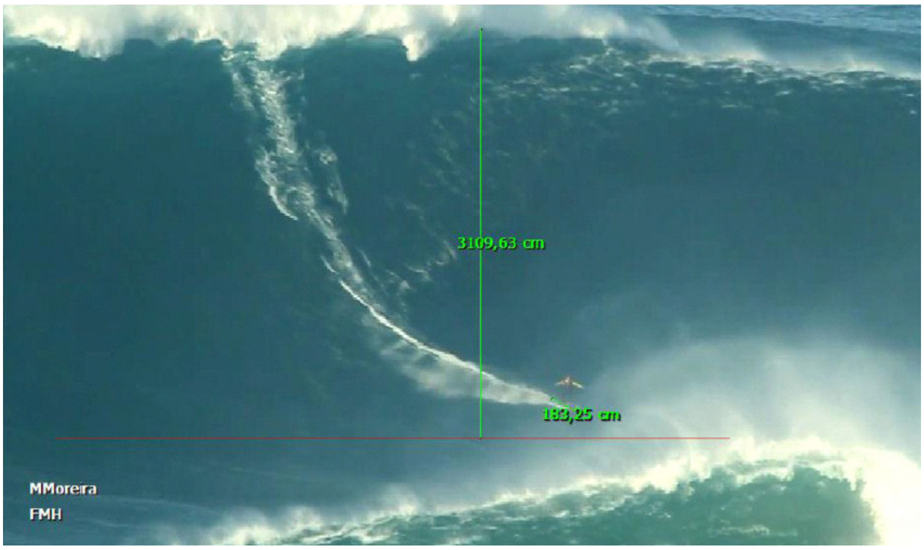


Fig. 3.15 - Evolution of the Nazaré shoreline during the period 1958 to 2014 (source of the image used for plotting: 2014 Google Earth).

In 2010, the municipal company "Nazaré Qualifica" invited the U.S.A. surfer Garrett McNamara, one of the world's best big wave riders, to develop a three-year project titled North Canyon. Throughout this project, this athlete hit successive world records in the size of waves, showing the city of Nazaré and Portugal to the world. Also other Portuguese athletes successfully challenged the waves of Nazaré canyon.

On November 1st, 2011, G. McNamara, surfed a giant wave that later achieved the Guinness World Record for the largest wave surfed and wons the Billabong XXL Award for the biggest wave (Nazaré Qualifica (2013); in Ferreira, 2013). "The largest wave successfully surfed had a face estimated at 23.77 meters (78 feet) in height", writes the famous book (in surfertoday.com, February, 2nd, 2015). However, the previous estimated height for this wave was 31 m (Fig. 4.1).

Fig. 4.1- First estimate of the height for the wave that Garrett McNamara surfed on November 1st , 2011 (source: sicnoticias.sapo.pt, seen in February14th, 2014).



4.

SURFING PRACTICES IN NAZARÉ

On January 28th, 2013, Garrett McNamara surfed a higher wave than the record hit in 2011, reaching ca. 34 meters (Fig. 4.2). This wave received a major highlight of the international press, including international newspapers by The Times (Fig. 4.3), El Pais and CNN television network (Lusa, 2013). On the same day at Nazaré, Antonio Silva and Ramon Laureano also surfed a wave of over 25 meters (SurfTotal [ST], 2013).

Fig. 4.2- Measurement of the wave surfed by Garrett McNamara on January 28th, 2013 (34 m) (source: sicnoticias.sapo.pt).

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Surf's up and up as daredevil crests a record wave

Garrett McNamara, from Hawaii, rides a 100ft wave yesterday in Nazaré, Portugal. The surfer said he had wanted to stay in bed after a fall the day before. News, page 5

Assad blamed after scores of bodies are found in river

Martin Fletcher

Scores of corpses were pulled from a river in Aleppo yesterday after the worst massacre that Syria's war-ravaged second city has suffered.

The bloodied, mud-caked bodies of between 60 and 80 young men, some mere teenagers, were fished from the Quiq River in a contested district controlled at present by the rebels. Video footage posted on the internet showed that most had been bound by the wrists, then killed with a point-blank shot to the head. Their identification cards had been removed.

The opposition accused the regime of slaughtering the men because they were Sunni Muslims. The Government's soldiers and Shabiha militia have carried out similar massacres in

A regime that is getting away with mass murder

Leading article, page 2: World, page 29

Fig. 4.3 - News about the Nazaré giant waves in The Times;

www.dn.pt/inicio/tv/interior.aspx?content_id=3023617&seccao=media

Another historical day at Praia do Norte, Nazaré was on October 24th 2013, in which surfers like Garrett McNamara, Carlos Burle, Sylvio Mancusi, Rodrigo Koxa, Maya Gabeira, Felipe "Gordo" Cesarano, Hugo Vau, Eric Rebiere, Pedro Scooby and Andrew Cotton were present.

Images of surf experts as Hugo Vau, Andrew Cotton, Kealii Mamala, Tom Butler, Sebastian Steudner or Rodrigo Koxa, surfing the giant waves of Praia do Norte, returned to run the world, over the weekend of November, 29th and 30th, 2014 although the Nazaré canyon has not generated anything close to the size of the largest wave ever ridden.

During 2014, worldwide surfers challenged the limits at Praia do Norte. Despite some fears, the sea conditions allowed the capture of memorable images (Figs. 4.4. and 4.5).

The North Canyon Project - exploration program of big waves, for surfing and stand up paddle, and promotion of Nazaré - remains high, "with great movement on social networks, many followers in Praia do Norte, and guaranteed impact inside and outside the country," according to the news in Diário de Notícias of December 4th , 2014.

Fig.4.4 - Garrett McNamara surfing in Praia do Norte at November 18th, 2014.

www.facebook.com/163839373642847photos/a.203403679686416.61249.163839373642847/999298920096884/?type=1&theater."

Fig. 4.5 - Garrett McNamara surfing in Praia do Norte at November 19th, 2014;
www.facebook.com/163839373642847/photos/a.203403679686416.61249.163839373642847/1000777359949040/?type=1&theater

All these achievements supported by the increasing number of surf schools and camps, makes Portugal a required spot for a significant number of domestic and foreign tourists coming from Europe and all over the world during all the seasons (Ferreira, 2013).

According to António D'Orey, a Portuguese surfer, Nazaré is not only known by the giant waves that have long been mediated lately but also for the quality of their current waves. The big-wave surfing is considered different from the usual surf (e.g. which is practiced in Supertubos championship in Peniche) (D'Orey interview, 2015). The Portuguese mainland is always the place where the waves are larger and even in days of small waves many surfers can be found there. It is also one of the first places in western Portugal to receive a new curling NW. For example, a new swell reaches the Praia do Norte in the morning but the Sintra coast only in the afternoon; it also makes someone want to go there to spend the day to take full advantage of certain waves. At the Praia do Norte, the waves usually display a triangle or wedge geometry.

A wave, when approaching the beach, could interfere with another wave coming sideways, promoting the sudden swelling of the waves in contact. The blistering burst area progressively enlarge laterally. This allows the surfer to be in the right position (in the highest part of the wave before it bursts) to choose whether to go right or left. Another important factor in the quality of the wave is the fact that as it swells fast when it bursts, it forms a very predictable tube, searched by surfers. Regarding the Nazaré giant waves, what makes it a unique place is precisely the brutal wave swelling when two waves of different directions clash transforming a 5 m wave into a 15 m wave. The Jet Ski just has to put the surfer at the point where the wave is higher and then the surfer chooses to go right or left where the wave rapidly loses strength and height.

Although Garret McNamara surfed big waves in various parts of the world, we can recognize in Nazaré some similarities with the seas of Mexico and Hawaii. G. McNamara has no doubts in regard to Praia Norte : "a unique place in the world where the waves have a lot of personality and are very special." "In fact", he said, "all in Nazaré is special" and therefore, he returns, year after year to compete, but also to "share with the greatest number of people" the adventures of giant wave surfing that in the last year have contributed to attract thousands of people to Nazaré (In: Público and Lusa on January 21st, 2013).

The Nazaré gigant waves revealed to be an excellent trigger for the transfer of scientific knowledge in a language comprehensible for all types of public (Carapuço et al., 2014).

ACKNOWLEDGEMENTS

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