

**II CENTRAL & NORTH ATLANTIC CONJUGATE
MARGINS CONFERENCE**

LISBON 2010

FIELD-TRIP GUIDEBOOK

LUSITANIAN BASIN (Portugal)

25th – 28th September 2010

Edited by:

RUI PENA DOS REIS & NUNO PIMENTEL

Impressão: Impressões e Soluções, Laboratório de imagem, LDA.

Design Gráfico: Claudia Magno

Lisboa, Setembro 2010

Tiragem: 300 ex.

ISBN: 978 – 989 – 96923 – 3 - 6

Copyright © 2010 Rui Pena dos Reis & Nuno Pimentel

ORGANIZED BY:

- **Rui Pena dos Reis & Nuno Pimentel**

SPONSORED BY

PARTEX
OIL AND GAS

Table of Contents

FOREWORD	2
INTRODUCTION	3
DAY 1	8
STOP 1A – CABO MONDEGO NORTH.....	9
STOP 1B – CABO MONDEGO SOUTH	16
STOP 1C - BOTÃO	18
STOP 1D – COIMBRA	20
DAY 2	24
STOP 2A – PEDROGÃO.....	25
STOP 2B – VALE FURADO	28
STOP 2C – NAZARÉ	31
STOP 2D – SÃO MARTINHO DO PORTO	35
DAY 3	38
STOP 3A– PENICHE	39
STOP 3B – BALEAL	44
STOP 3C – PAIMOGO	47
STOP 3D – SANTA CRUZ.....	49
DAY 4	52
STOP 4A – CASCAIS.....	53
REFERENCES	56

FOREWORD

Lusitanian Basin Fieldtrip

“Discovering Lusitania– new winds for an old basin”

This guidebook has been produced to support a 3.5 days fieldtrip, promoted within the scope of the II Central & North Atlantic Conjugate Margins Conference. The aim of this book is to provide the participants with the main information needed to approach and understand the several outcrops we'll be seeing and their meaning in the basin's evolution. It is not our intention to be exhaustive in quoting and synthesizing all the published information about each outcrop. We will only refer the key-papers, referenced at the end of the book, where you will be able to find all the data you may be interested in.

For each stop, we tried to reduce the extent of written text to a minimum, highlighting its “main focus”, “geological framework” and “observations”, with some key interpretations. Much more will be said and explained during the fieldtrip, including answers to specific questions, debate of technical details and scientific discussions about the basin's evolution. That's the aim of a fieldtrip, after all!

Besides basic written information, we tried to assemble a group of photos and diagrams, to illustrate the main aspects to be observed. We invite you to use those figures to think and discuss, and introduce on them all the information you wish. These images, and most of all, the ideas you will bring in your memory, will be your main personal asset after this field-trip!

The fieldtrip has been designed to give an overview of the main evolutionary steps of this long-lived basin, since its Later Triassic start until its late Cretaceous inversion. This entire story is well documented in large-scale outcrops, from which we had to select just a few of them. Our main criteria were the significance of the geological object, the exposure quality and the proximity to access and accommodation infra-structures. Most of the selected outcrops are along coastal cliffs, allowing us to know beautiful settings and to feel the close presence of the Atlantic Ocean, whose opening ultimately brought us all here together.

We sincerely hope you enjoy this field-trip, wishing that these new places, observations and ideas will bring you back one day, with new winds to sail...

NUNO PIMENTEL & RUI PENA DOS REIS

INTRODUCTION

The Lusitanian Basin was initiated during a late Triassic rifting phase and belongs to a family of periatlantic basins (e.g. Jeanne d'Arc Basin, Scotian Basin). It is located on the Portuguese part of the western Iberian margin (Fig. 1). The basin is nearly 130 km wide and about 340 km long; its onshore area totals over 23 000 km². It is located between Hercynian basement rocks; namely, in the east the Iberian Meseta and to the west a marginal horst system (the Berlenga and Farilhões islands are emerged parts of this system).

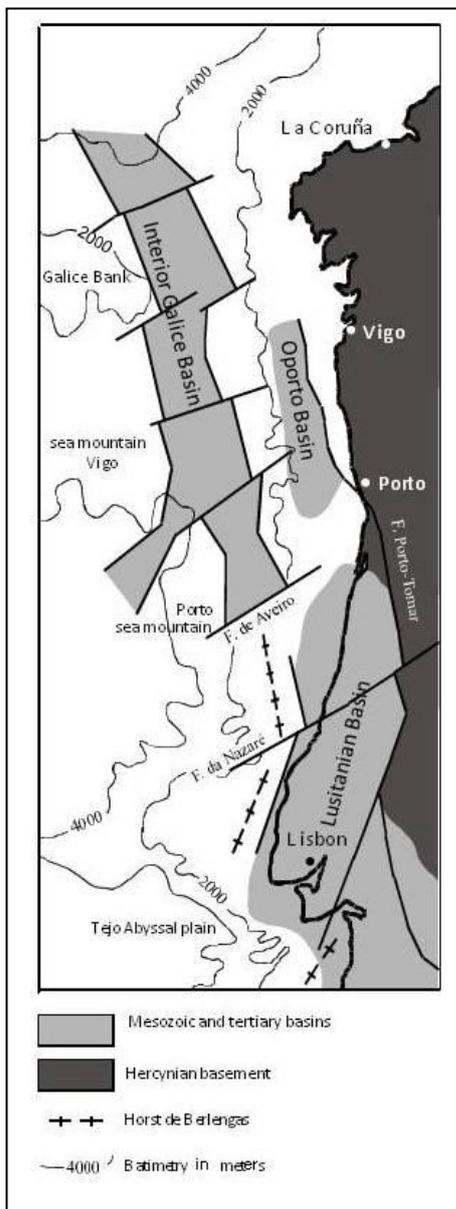


Fig. 1 - Mesozoic basins on the West Iberian Margins, showing the position of the Lusitanian Basin and other related basins.

It connects southwards with the Alentejo and the Algarve Basins and northwards, via a basement ridge, to the Oporto (or Galicia) Basin bounded by the Porto and Vigo seamounts and by the Galicia bank.

The axis of maximum subsidence, which occurred mainly during the Jurassic, follows a general NNE-SSW structural orientation.

In the Mesozoic sedimentary record of the Lusitanian Basin, five great stages of infill are identified. They are represented by the following sequences, limited by unconformities: UBS1) upper Triassic - Callovian; UBS2) Oxfordian - Berriasian; UBS3) Valanginian - lower Aptian; UBS4) upper Aptian - lower Campanian; UBS5) upper Campanian – Maastrichtian (Wilson *et al.*, 1989, Cunha & Pena dos Reis, 1993).

During the Mesozoic and part of the Cenozoic, the structures with a NE-SW and NNE-SSW direction had a mainly extensional behavior. But after the end of the Cretaceous and mainly during the tertiary Betic orogeny, the western rim of the Iberian Plate suffered a compressive deformation that led to a progressive inversion of the central axis of the basin, uplifting and bringing to the surface the thick layers deposited during the Mesozoic.

The Lusitanian Basin's evolution may be divided into 4 main geodynamic steps: i) a first west-tethyeen rifting; ii) a second atlantic-oriented rifting; iii) a three-stepped north-atlantic break-up; iv) the tectonic inversion of the basin and uplift of most of the areas.

- **The first rifting episode (Late Triassic)**

The first rifting episode began during the Late Triassic (Fig. 2 and 3), leading to the definition of a system of submeridian grabens and half-grabens, bounded westwards by the Galice bank-Berlengas trend. The sedimentary record includes coarse alluvial fan and fluvial deposits, followed by lacustrine and coastal sandstones, distally covered by evaporites.

A transgressive dolomitic limestone unit marks the beginning of a thick sag phase, composed of ramp marls and marly limestones, lower and middle Jurassic in age.

- **The second rifting episode (Late Jurassic-Early Cretaceous)**

From the middle Oxfordian to the early Aptian, a second rifting phase occurred. The Upper Jurassic to Lower Cretaceous rifting was driven by the alignment of the basin with the Central Atlantic opening. The basin has been re-oriented and new NE-SW oriented depocenters developed, with intense subsidence that triggered diapiric geometries, defined earlier following former basement faults.

The Oxfordian - Berriasian evolution of the Lusitanian Basin may be divided into three tectonic phases (Pena dos Reis *et al.*, 1999). The initial phase was the onset of rifting which resulted in widespread carbonate deposition. Extensional climax was reached during phase two. This created highly subsident sub-basins and a significant siliciclastic influx. Phase three was a period of thermal subsidence overprinted by sea-level changes of presumed eustatic nature, which resulted in progradation of siliciclastic systems, overall shallowing and infill of the basin.

- **Three-stepped break-up and Drift (Early to Late Cretaceous)**

The onset of the break-up of the crust and the beginning of the drift, followed three main steps: a first Late Jurassic - Berriasian one and two Early Cretaceous steps. The break-up unconformity is therefore diachronous, jumping in three steps towards North.

The drift, begun and ended with magmatic activity, including igneous intrusions south of the Lousã - Caldas da Rainha fault, while diapirism was intensified and reached extrusion.

- **Basin's Inversion**

During the Late Cretaceous, a major geodynamic change resulted from the collision between the Iberian and African plates, leading to the beginning of an inversion process that continued through the Cenozoic with a maximum in Late Miocene. This inversion caused uplift and erosion of the central part of the basin, followed by the definition of two major tertiary basins (Mondego and Lower Tagus), on each side of the high central sector.

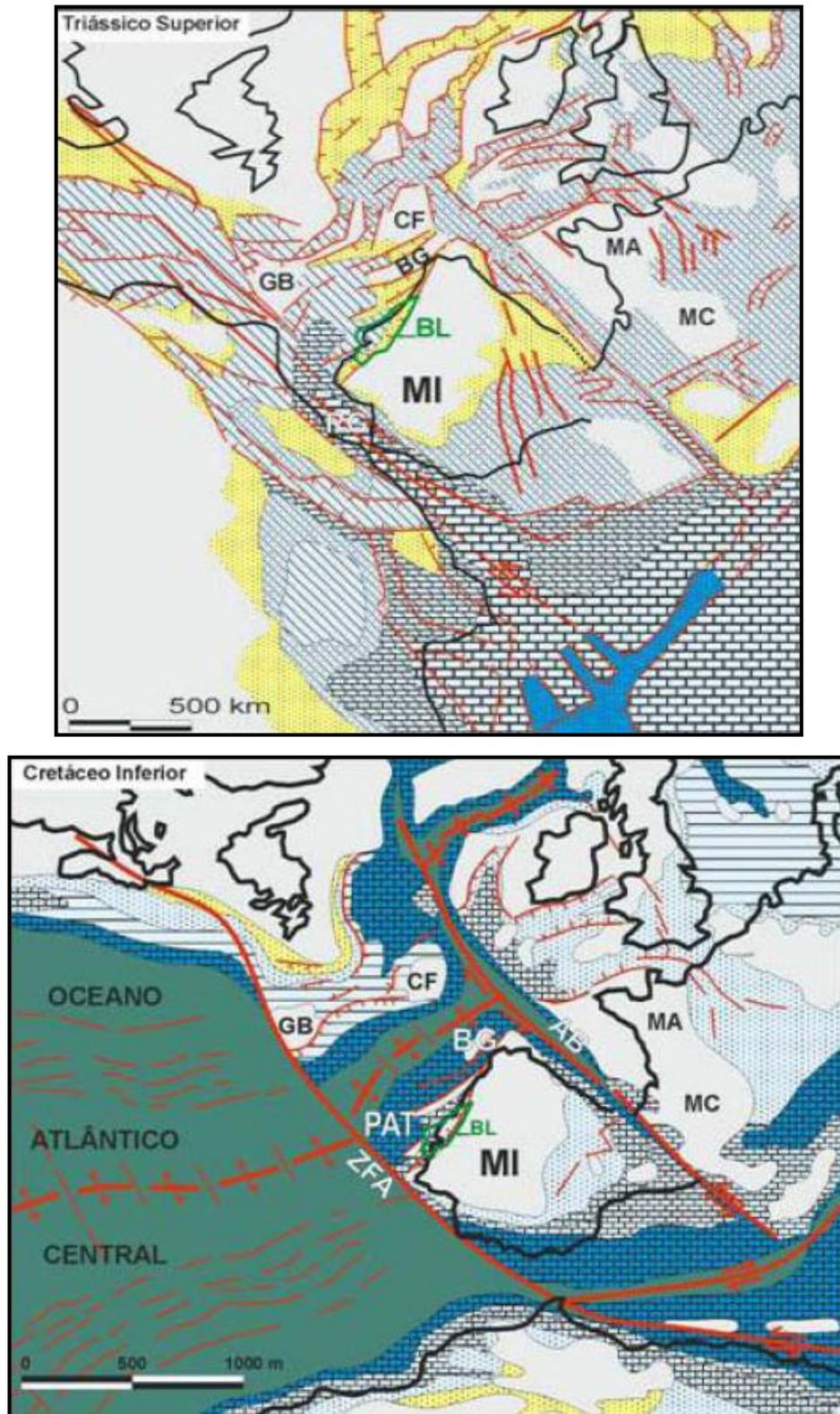


Fig. 2 – Geodynamic and paleogeographic framework of the Iberian Peninsula (MI) in Central and North Atlantic opening; a) Upper Triassic; b) Lower Cretaceous (adapt. Ziegler, 1988).
BL – Lusitanian Basin; MC – Central Massif; PAT – Tagus Abissal Plain; BG – Galicia Basin; GB – Grand Banks; CF – Flemish Cap; MA – Armorican Massif; ZFA – Azores/Gibraltar Fault; AB – Biscay Gulf.

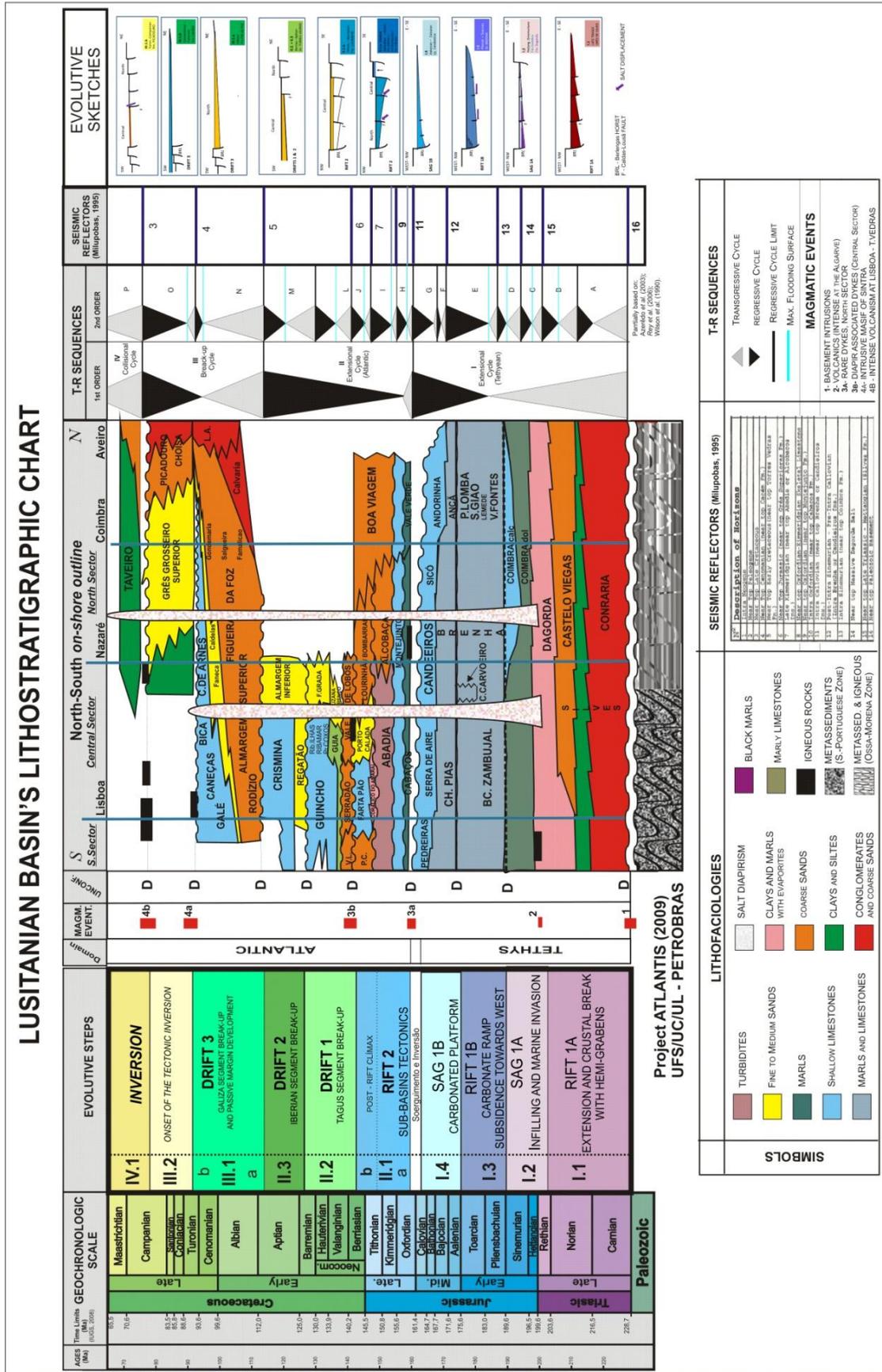


Fig. 3 - Stratigraphic chart of the Lusitanian Basin.

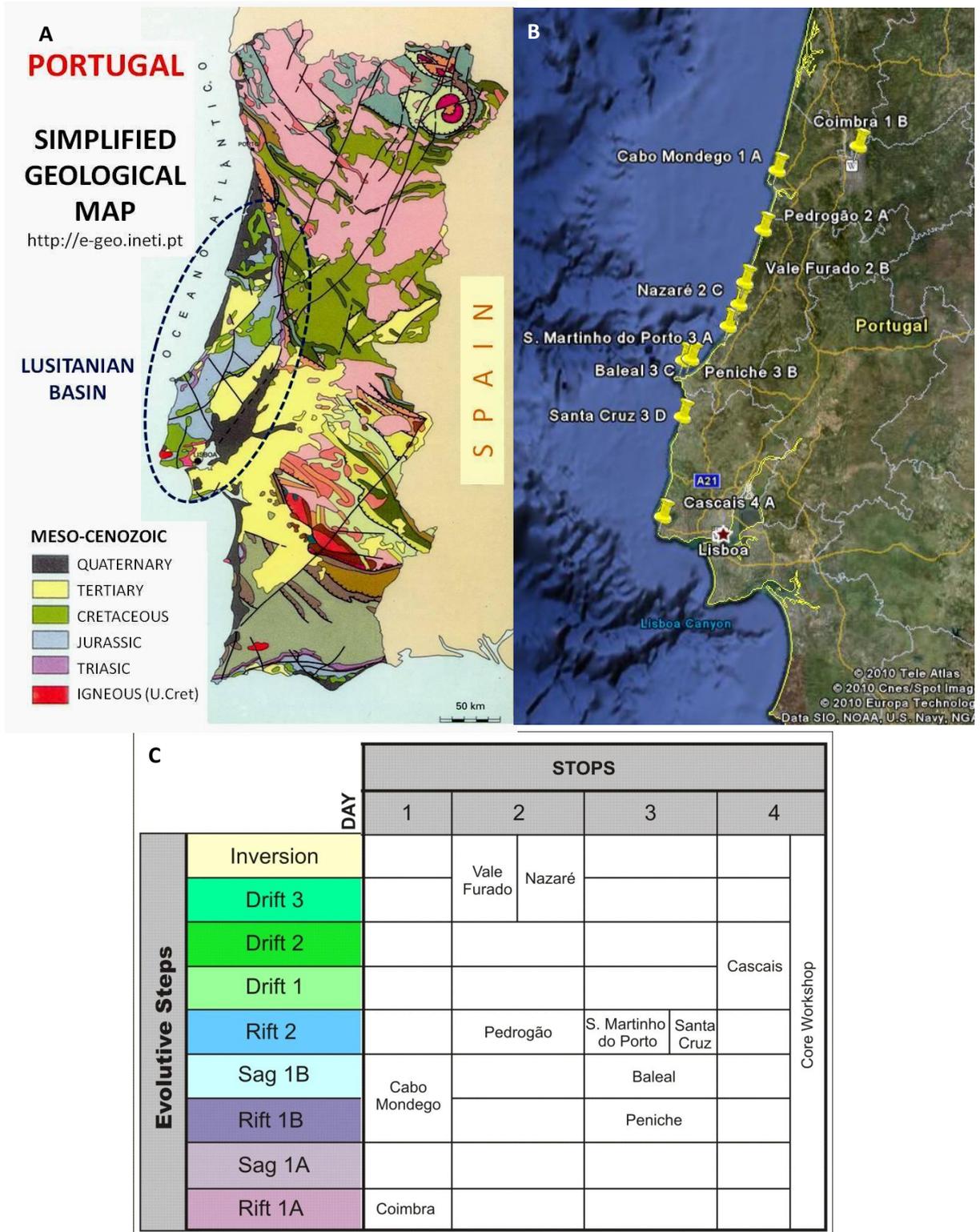


Fig. 4 - A: Geological map of Portugal with the location of Lusitanian basin; B: Google map with the position of the field –trip stops; C: Relation between the stops and the basin evolution steps.

DAY 1

25th September 2010

Lisboa → Leiria → Cabo Mondego → Botão → Coimbra

DAY 1

STOP 1A – CABO MONDEGO NORTH

Henriques¹, M. H., Canales², M. L., Neto¹, K. & Antunes³, R. L.

¹Departament of Earth Sciences and Geosciences Centre, Faculty of Sciences and Technology, University of Coimbra, Largo Marquês de Pombal, 3000-272 Coimbra, Portugal; hhenriq@dct.uc.pt; keynesmenio@gmail.com

²Departamento and UEI of Paleontología, Facultad de Ciencias Geológicas, Universidad Complutense de Madrid-CSIC, Ciudad Universitaria, 28040 Madrid, España; mcanales@geo.ucm.es

³Petrobras – Petróleo Brasileiro S.A., Av. República do Chile, 65, 14º andar, Sala 1401 – Centro, CEP 20.031-912 – Rio de Janeiro – RJ – Brasil; rogeantu@petrobras.com.br

Main Focus – Jurassic sequence at the northern border of the basin. Significant bioevents across the Bajocian GSSP.

Introduction

The Cape Mondego section is located in the European Atlantic coast of Central Portugal, about 160 Km north of Lisbon and 40 km west of Coimbra, near Figueira da Foz (40°11', 8°54'; Fig. 5). This reference section displays a thick series of greyish marl and limestone alternations around 500 m thick, corresponding to the Cabo Mondego Formation (upper Toarcian – Calovian; Azerêdo *et al.*, 2003). This quiet and monotonous sedimentation episode represents a typical external marine depositional system, providing rich and diversified ammonite fossil assemblages, where index species of ammonite biostratigraphic units are usually represented. The ammonite assemblages (graphoceratids record and other taxa, Fernández López *et al.*, 1988a, b; Henriques, 1992, 1995; Henriques & Mouterde, 2000; Henriques *et al.*, 1994; Rocha *et al.*, 1990), the

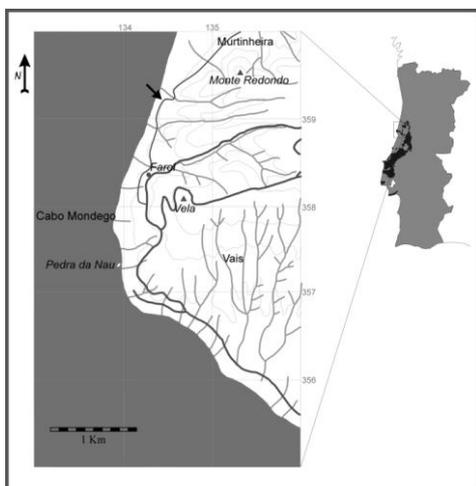


Fig. 5 – Location map of the Cape Mondego region in the Lusitanian Basin outcrops (in black) and of the Bajocian GSSP in Cape Mondego section (arrow).

calcareous nannofossils and the magnetostratigraphic reversal based the formal establishment of the Bajocian GSSP at bed AB11 (Fig. 6) in 1996 (Pavia & Enay, 1997), the first stage boundary established for the Jurassic System by the IUGS, according to ICS Guidelines for boundary stratotypes definition (Cowie *et al.*, 1986). Due to its stratigraphic relevance, the section is classified as Natural Monument since October, 2007 (ICNB, 2008).



Fig. 6 - The Aalenian - Bajocian section at Cabo Mondego outcrop, where the Bajocian GSSP has been defined.

Objectives

The main purpose of this stop is to describe different bioevents identified across the Aalenian - Bajocian boundary (the Bajocian GSSP). They include significant faunal changes in macrofossil (ammonoids), microfossil (foraminifera) and nannofossil (calcareous nannoplankton) assemblages, displaying biostratigraphic relevance, namely for calibrating biostratigraphic scales based on different fossil groups.

Stratigraphic relevance for global correlation

The continuity of the stratigraphic record, as well as the richness on the palaeontological record, especially *Ammonoidea* representatives, makes the Middle Jurassic succession of Cape Mondego a reference section for any discussion on stratigraphic boundaries of

global rank. The Bajocian GSSP has been established at the Aalenian - Bajocian boundary of this section (Pavia & Enay, 1997); the Toarcian - Aalenian boundary is correlative with the Aalenian Stage Boundary (Aalenian GSSP, established in Fuentelsaz, Iberian Cordillera, Spain; Cresta *et al.*, 2001; Henriques *et al.*, 1996; Sandoval *et al.*, 2001); the Bajocian - Bathonian boundary is the Auxiliary Stratotype section (ASP) for the Bathonian Stage (which GSSP has been established in Digne, SE France; Fernández López *et al.*, 2009).

Concerning the Bajocian GSSP, the “golden spike” has been defined within a hemipelagic lithofacies composed of alternating lime mudstone and marlstone beds with gradational bedding boundaries (Watkinson, 1986), providing rich and diversified ammonite fossil assemblages.

The Bajocian GSSP has been defined at the base of bed AB11 (Fig. 6), by the first occurrence of the ammonite assemblage including *Hyperlioceras mundum* (BUCKMAN) and related species (*H. furcatum* (BUCKMAN) *Braunsina aspera* BUCKMAN, *B. elegantula* (BUCKMAN); Fig. 7). Several nanno-horizons have been detected at the Aalenian - Bajocian transition, based on the onset of different species of *Watznaueria*. At the same level, palaeomagnetic results revealed an inversion from reversed to normal polarity (Henriques *et al.*, 1994; Pavia & Enay, 1997).



Fig. 7 – Selected ammonoids recorded across the Aalenian-Bajocian boundary (Bajocian GSSP) at Cape Mondego section: 1. *Haplopleuroceras subspinum* (BUCKMAN) (bed AB 9; Concavum Biozone; Limitatum Subzone; Aalenian); 2. *Euaptetoceras* sp. (bed AB 12; Discites Biozone; Bajocian); 3. *Toxolioceras mundum* (BUCKMAN) (bed AB 11; Discites Biozone; Bajocian); 4. *Braunsina aspera* BUCKMAN (bed AB 12; Discites Biozone; Bajocian); 5. *Toxolioceras curvum* (BUCKMAN) (bed AB 12; Discites Biozone; Bajocian); 6. *Toxolioceras incisum* (BUCKMAN) (bed AB 11; Discites Biozone; Bajocian); 7. *Toxolioceras incisum* (BUCKMAN) (bed AB 12; Discites Biozone; Bajocian). Scale bar=1 cm.

Further work on calcareous nannofossils occurrences (Perilli *et al.*, 2002; Neto, 2010; Fig. 8) and on the record of other fossil groups (benthic foraminifers and brachiopods; Canales *et al.*, 2000; Canales & Henriques, 2008, Fig. 9; Andrade González, 2004) has reinforced the relevance of this section for global correlation.

Concerning the nannofossils record, Neto (2010) pointed that close to the boundary (in the transition between Concavum and Discites Biozones), some species of Watznaueraceae display interesting records. *Watznaueria fossacincta* (Black) and *Watznaueria britannica* (Stradner) apparently show their first occurrence near the boundary. The last one shows an increase in its relative abundance upwards, in the Discites Biozone. *Lotharingius contractus* Bown & Cooper is another remarkable taxon due to its abundant occurrences. *Cyclagelosphaera margerelii* Noël and *Watznaueria manivitae* Bukry should also be mentioned as they are frequently referred to the Aalenian - Bajocian boundary in different works around the world. The lower boundary of *Watznaueria britannica* acme has been related to the Aalenian -Bajocian boundary (transition between Concavum - Discites Biozones) in the Jurassic sediments of Portugal (Bergen, *apud*. Bown & Cooper, 1998).

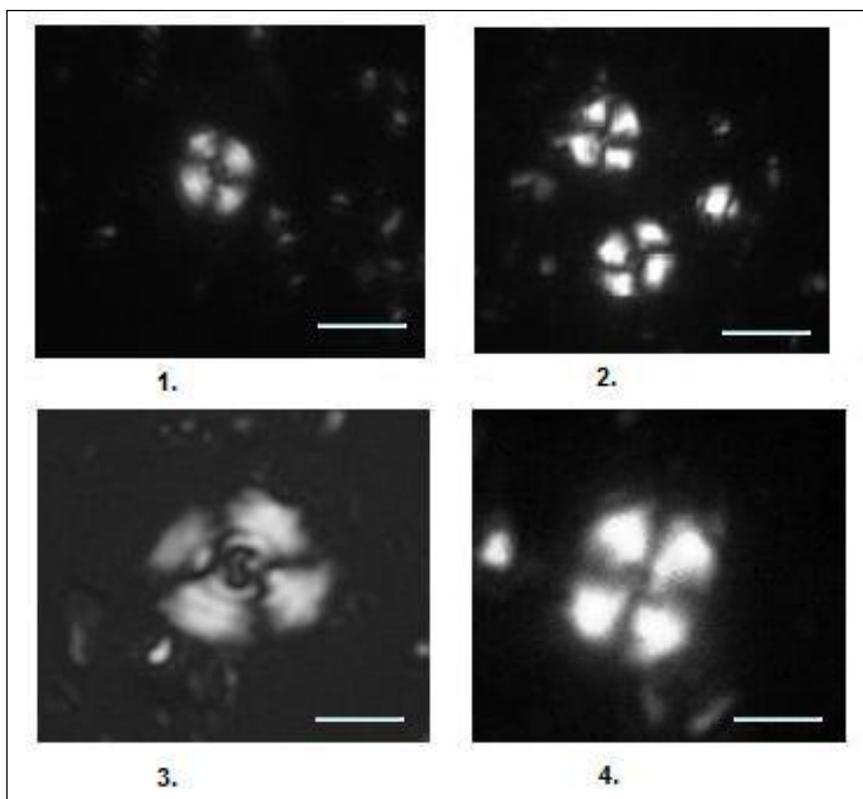


Fig. 8 - Selected calcareous nannofossils recorded across the Aalenian-Bajocian boundary (Bajocian GSSP) at Cape Mondego section: 1. *Watznaueria fossacincta* (Stradner) (bed AB7; Concavum Biozone; Limitatum Subzone; Bajocian); 2. *Watznaueria britannica* (Stradner) (bed AB12; Discites Biozone; Bajocian); 3. *Lotharingius contractus* (Bown & Cooper) (bed AB14; Discites Biozone; Bajocian); 4. *Watznaueria manivitae* (Bukry) (bed AB23; Discites Biozone; Bajocian). Scale bar=5 μ m.

Concerning the foraminiferal assemblages, a remarkable decrease on abundance and diversity is recorded across the Aalenian - Bajocian boundary in the Cape Mondego section. This fact, pointed out here for the first time, allows correlations with other coeval Iberian sections, namely those located in the Basque-Cantabrian Basin (Canales, 2001). On the other hand, the last occurrence of typical Aalenian species, such as *Astacolus dorbignyi* (Roemer) and *Nodosaria pseudoregularis* Canales, as well as the first occurrence of characteristic Bajocian species, such as *Saracenaria cornucopiae* (Schwager), *Ramulina spandeli* Paalzow and *Nodosaria plicatilis* (Wisniowski), are recorded along the Upper Aalenian (Concavum Biozone, Limitatum Subzone) - Lower Bajocian (Discites Biozone) at Cape Mondego section. In all the studied assemblages, *Lenticulina quenstedti* (Gümbel), considered the index species for the Aalenian - Bajocian transition in the north hemisphere, has also been recognized.



Fig. 9 – Selected benthic foraminifera recorded across the Aalenian-Bajocian boundary (Bajocian GSSP) at Cape Mondego section: 1. *Lenticulina quenstedti* (Gümbel) (M-291.1327; Concavum Biozone, Limitatum Subzone; Aalenian); 2. *Astacolus dorbignyi* (Roemer) (M-273.1330; Concavum Biozone, Concavum Subzone Aalenian); 3. *Spirillina orbicula* Terquem & Berthelin (M-291.1352; Concavum Biozone, Limitatum Subzone; Aalenian). 4. *Ammobaculites fontinensis* (Terquem) (AB-23.2.84; Discites Biozone; Bajocian); 5. *Nodosaria pseudoregularis* Canales (AB-29.18.100; Discites Biozone: Bajocian); 6. *Nodosaria plicatilis* (Wisniowski) (AB-29.17.144; Discites Biozone; Bajocian). Scale bar=100 μ m.

The main bioevents recognized across the Aalenian - Bajocian boundary, representing faunal changes in macrofossil (ammonoids), microfossil (foraminifera) and nannofossil (calcareous nannoplankton) assemblages are represented on Figure 10. Such bioevents, temporally referred to a section allowing global correlation, represent a major interest for calibrating biostratigraphic scales based on different fossil groups, particularly in log interpretation of sedimentary basins of Jurassic age displaying hydrocarbon potential, like the Lusitanian Basin.

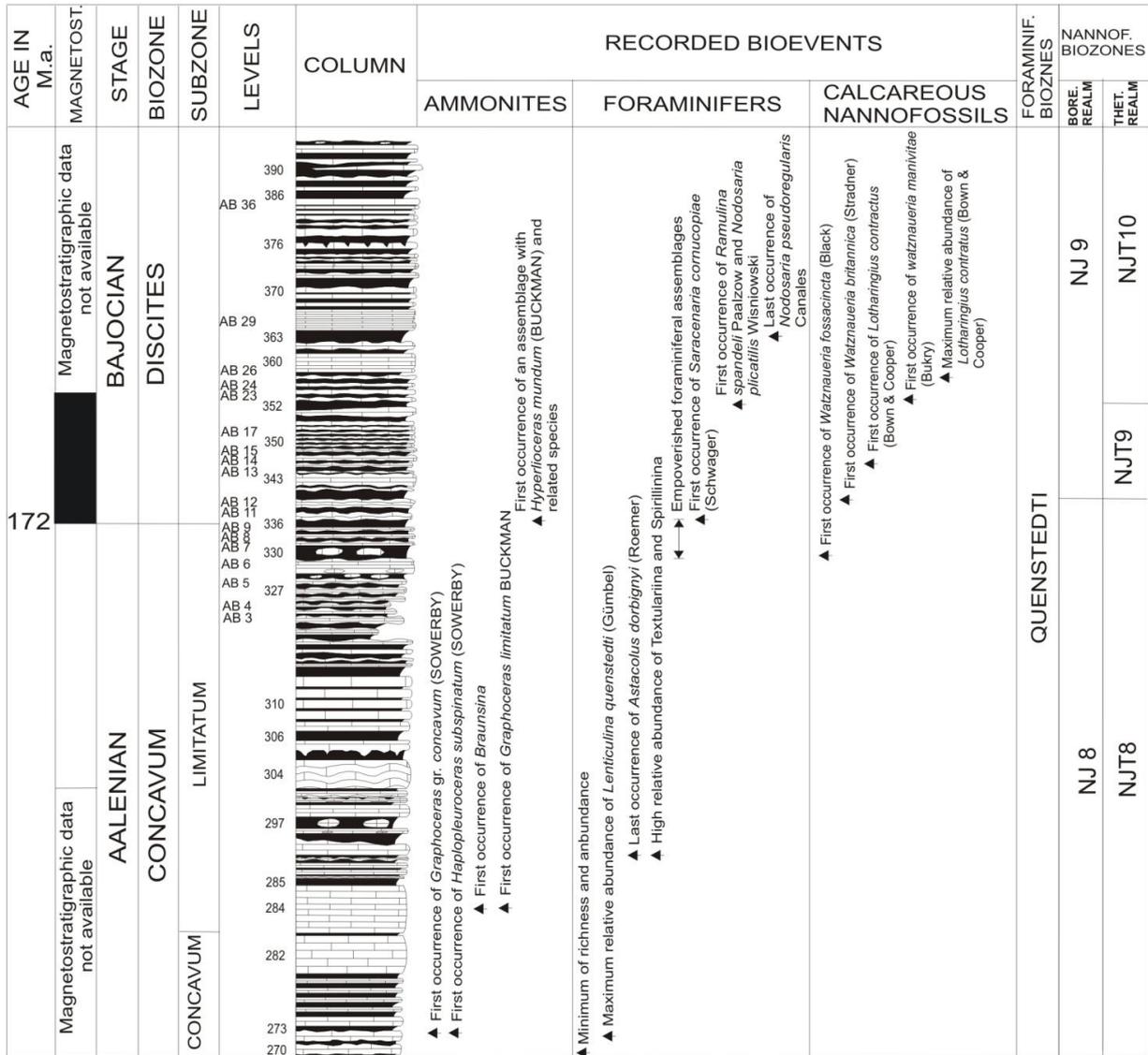


Fig. 10 - Bioevents recognized across the Aalenian - Bajocian boundary at Cape Mondego (the Bajocian GSSP).

Acknowledgements

This work is a contribution for the Project CGL2008-03112 of the Ministerio de Ciencia y Inovación (Spain) and the laboratory work has been developed with the support of the Consortium Petrobras-Galp-Partex.

STOP 1B – CABO MONDEGO SOUTH

Main focus – Upper Jurassic sin rift deposits with paralic and shallow marine transgressive systems, overlain by prograding fluvio-deltaic sediments.

Geologic framework

The Lusitanian Basin possesses an Atlantic type rifting geometry partly resulting from a major Oxfordian - Kimmeridgian extensional event (Wilson *et al.* 1990). During late Jurassic, the basin was located between two high hercynian basement blocks, the western one represented today by the Berlengas islands and eastwards, the Iberian block. The graben in between was elongated NNE-SSW, with increasing basinal and marine characters towards SW.

A regional uplift that occurred between late Callovian and early Oxfordian, is recorded by a paleokarst unconformity (Fig. 11), preceding an intense tectonic subsidence which started in late Oxfordian interpreted as the beginning of the second rift event in the basin (Pena dos Reis *et al.*, 1999). This event led to the rupture of the carbonate platform during earliest Kimmeridgian (regionally Montejunto Formation) and was followed by a thick and rapid terrigenous sedimentation, infilling the space created by the intense subsidence

Observations

The Upper Jurassic (Middle Oxfordian - Tithonian) section provides an excellent continuous sedimentary record of the evolution of the 2nd rifting episode. The tectonic subsidence reached a maximum at the earliest Kimmeridgian (Pena dos Reis *et al.*, 1997).

The resulting thick succession comprises, in the lower part, dominant carbonate facies, usually highly fossiliferous, representing a broad range of depositional settings: lacustrine, deltaic (Vale Verde Formation) and restricted marine ("Pholadomya proteii" Formation). The upper part of the section (Boa Viagem Sandstones) shows a thick prograding siliciclastic unit: sandstones, conglomerates and claystones, mainly of deltaic nature, (carbonate platform, storm beds from prodelta, shelf bars from delta-front and alluvial fan braidplain), overlain by other terrigenous deposits of Cretaceous age. The evolution is detailed in the figure 12 with a stratigraphic scheme, where the different units are established.

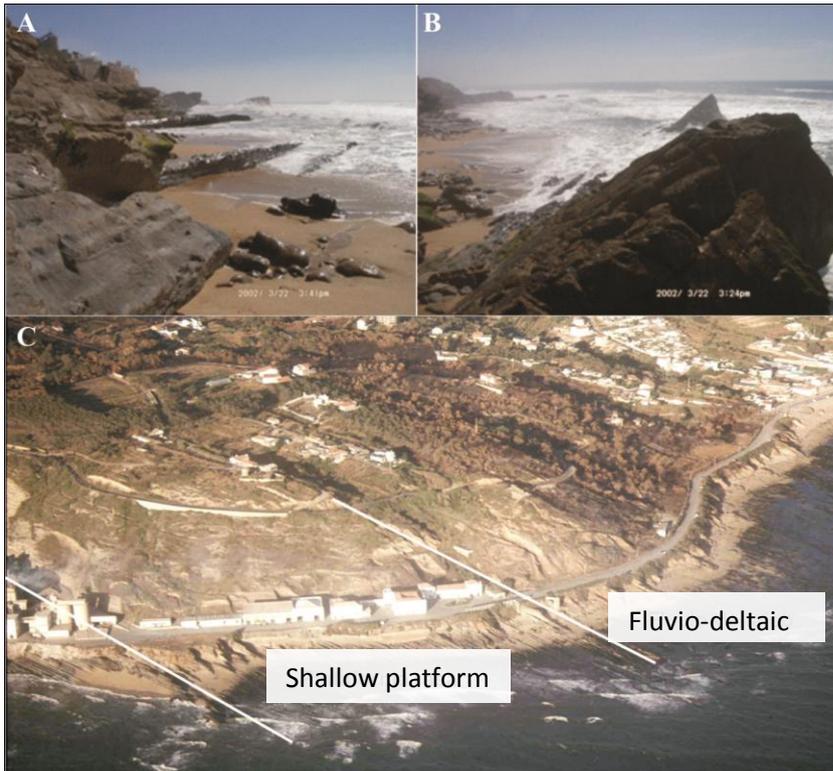


Fig. 11 - A) Picture showing lagoonal and shallow marine facies recording the beginning of the rifting event. B) The top of the tilting beds represent the major unconformity between the Calovian and the Oxfordian beds. C) Aerial view of the sinrift section of the Upper Jurassic. The main tectonic rupture corresponds broadly to the separation between the shallow platform and the fluvio-deltaic sediments.

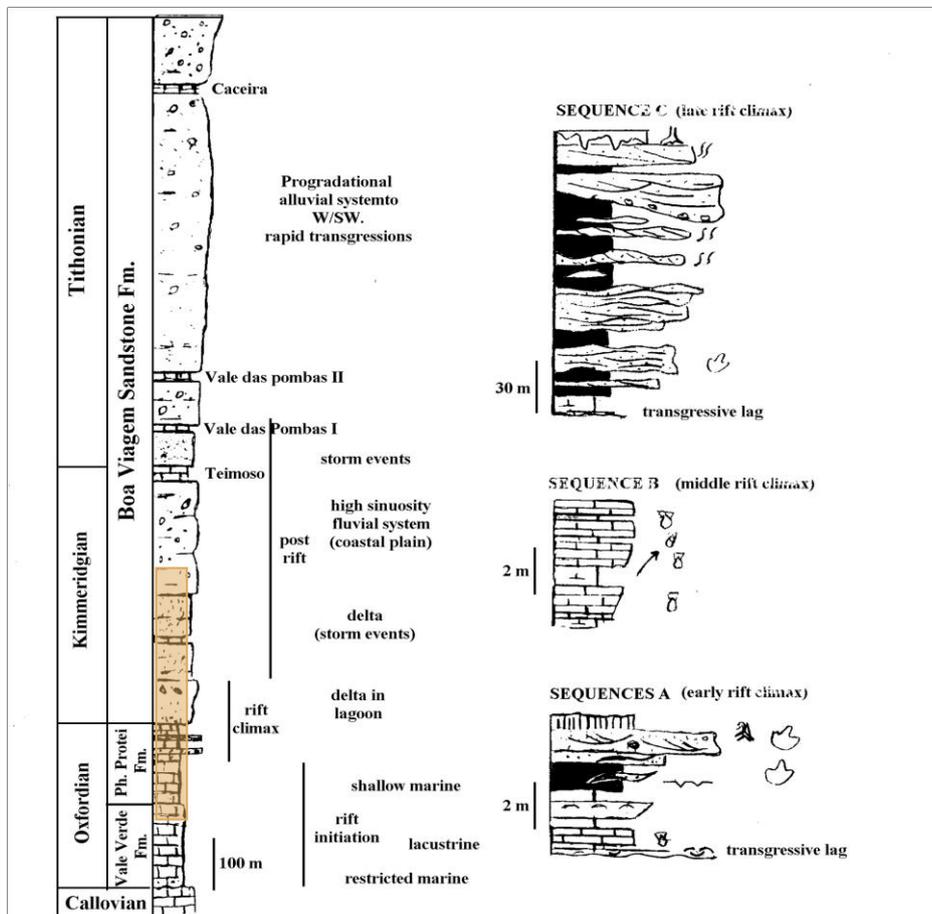


Fig. 12 – Stratigraphy and sedimentary record of the late Jurassic of Cabo Mondego. The phases and associated sequences of the 2nd rifting episode are represented. The brown strip indicates the section of the Fig. 11C.

STOP 1C - BOTÃO

Main focus – *The lowermost late Triassic alluvial fan deposits unconformably overlying the late Precambrian basement.*

Geologic Framework

The first rifting episode, that began during late Triassic and resulted from the crustal stretching of Pangeia, was clearly controlled by the reactivation of the basement structures (most oriented NNE-SSW), originated during the late variscan orogeny. This faulting led to the definition of a system of submeridian grabens and half-grabens, bounded westwards by the Galicia Bank-Berlengas trend. Therefore, the resulting sedimentation associated to these tectonic depressions, show significant thickness variations and includes coarse alluvial fan and fluvial deposits, followed by lacustrine and coastal sandstones covered distally by evaporites.

A transgressive dolomitic limestone unit marks the beginning of a thick sag phase, composed of marls and marly limestones lower and middle Jurassic in age.

Observations

The outcrop shows coarse and crudely stratified red siliciclastic conglomerates overlying an erosive surface defined over metamorphic basement rocks (intensely folded shists and graywakes belonging to the “Série negra” of the late Proterozoic; Fig. 13).

Coarse gravels (Gms) and sandstones (Sm) fácies are dominant, displaying wide plane surfaces and no scour or channel geometries. Some planar cross stratification is present. Fine sediments are absent



Fig. 13 – Unconformity separating the late Triassic red sediments from the underlying metamorphic Precambrian basement.

The location of this outcrop at the present eastern border of the Lusitanian Basin does not correspond to its actual paleogeographic limit and therefore does not exhibit the most proximal sediments. In fact the facies that are observed correspond to proximal to intermediate alluvial fan depositional systems, some kilometers far from the source areas. In fact, most eastern limits of the basin are faulted as a result of the Tertiary inversion. This outcrop, together with some others in different locations present a ramp like geometry, suggesting a hanging wall position in a possible half-graben context. This interpretation can be supported by the occurrence of evaporites in eastern areas, rather close to the present border, suggesting western footwall proximity.

STOP 1D – COIMBRA

Main Focus – Upper Triassic siliciclastics related to the initial intra-continental rifting.

Geological Framework

The first rifting phase at the Lusitanian Basin, related with crustal stretching of Pangea, begun in Upper Triassic times (Carnian?), re-activating late-variscan fractures of the basement, oriented mainly NNE-SSW and NNW-SSE. West-dipping semi-grabens originated multiple intra-continental mini-basins, filled by alluvial-fan deposits.

These deposits (*Silves Group*) are organized in three major sequences (Palain, 1976; Fig. 14): Sequence A (c.200 m thick) is composed of coarse proximal fan deposits grading to distal facies with abundant clays, paleosols and salt pseudomorphs; Sequence B (c. 200 m thick) corresponds to a re-activation of the depositional system, with coarse median facies grading to distal and sabkha-like facies, showing expansive onlapping geometry; Sequence C (c.50 m thick) is composed of fine silts and clays with dolomitic layers, deposited on distal and peritidal areas. These deposits are covered by Early Jurassic shallow-marine and coastal dolomitic deposits (*Coimbra Formation*).

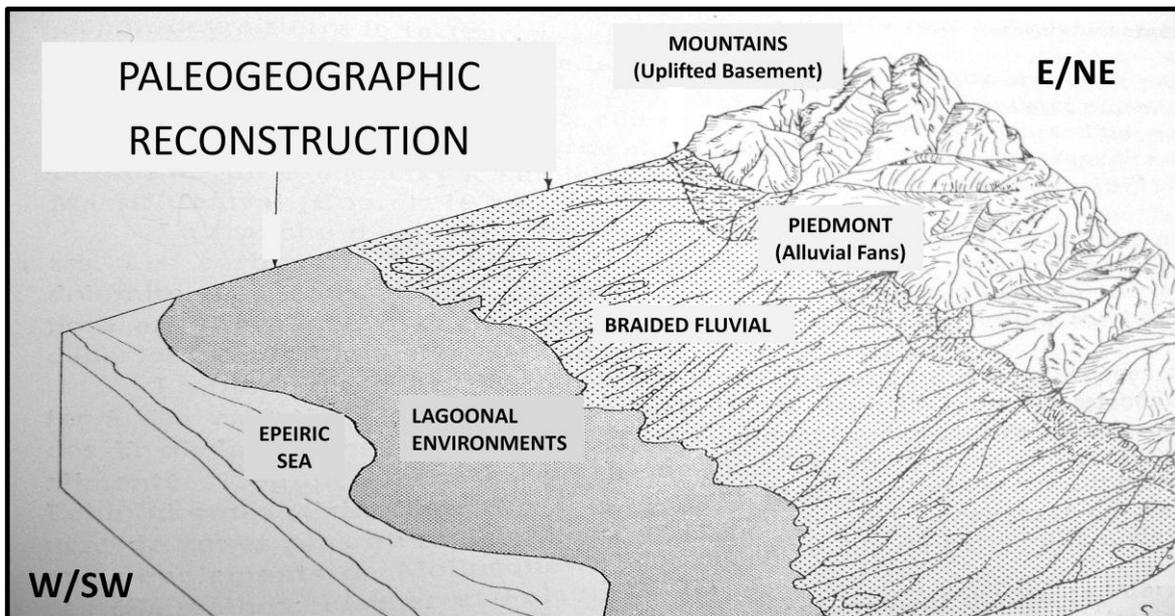


Fig. 14 - Paleogeographic reconstruction for the Upper Triassic deposits of the Lusitanian Basin (adapt. from Palain, 1976).

Observations

The Coimbra outcrops expose the upper part of Sequence A and the base of Sequence B (Pimentel & Pena dos Reis, 2006). Coarse reddish sandstones give place to finer clayey deposits, with frequent flooding features, hydromorphic mottling and carbonate concretions. The transition to Sequence B is marked by sandy layers with increasing thickness and coarseness, with conglomeratic layers towards the top of the outcrop (Fig. 15 and 16).

Although close to the present basin-border, these alluvial fan deposits do not correspond to proximal facies, suggesting an extension of the basin towards East. Intense fracturation may be observed, including both normal and inverse faulting. The coincidence of orientations of these two opposite types of faults, suggests that the later resulted from a compressive reactivation (Late Cretaceous – Tertiary?) of the first ones (Jurassic?) (Matos *et al.*, 2010).

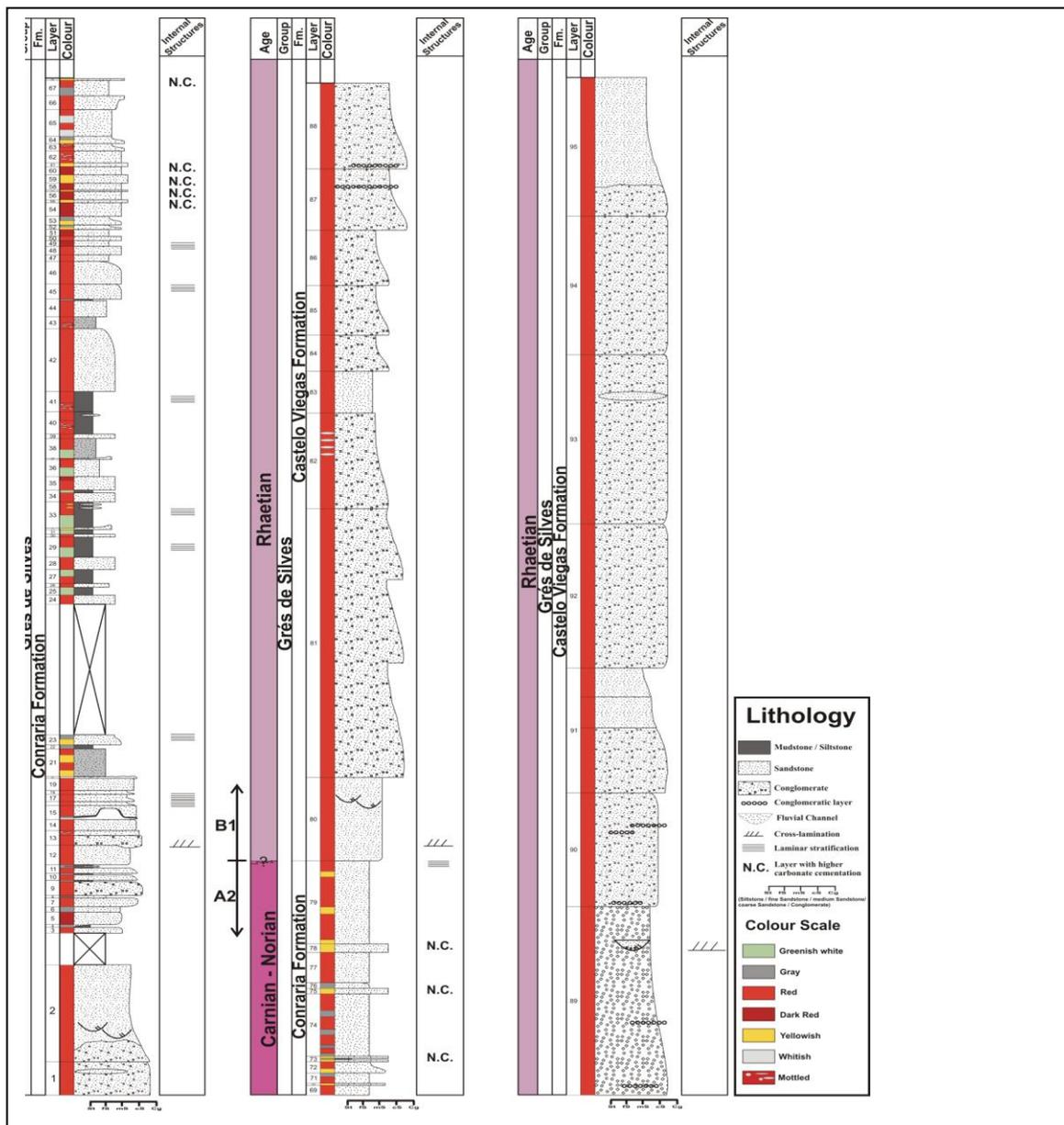


Fig. 15 - Lithostratigraphic section of Upper Triassic alluvial fan deposits in Coimbra (Miranda *et al.*, 2010).

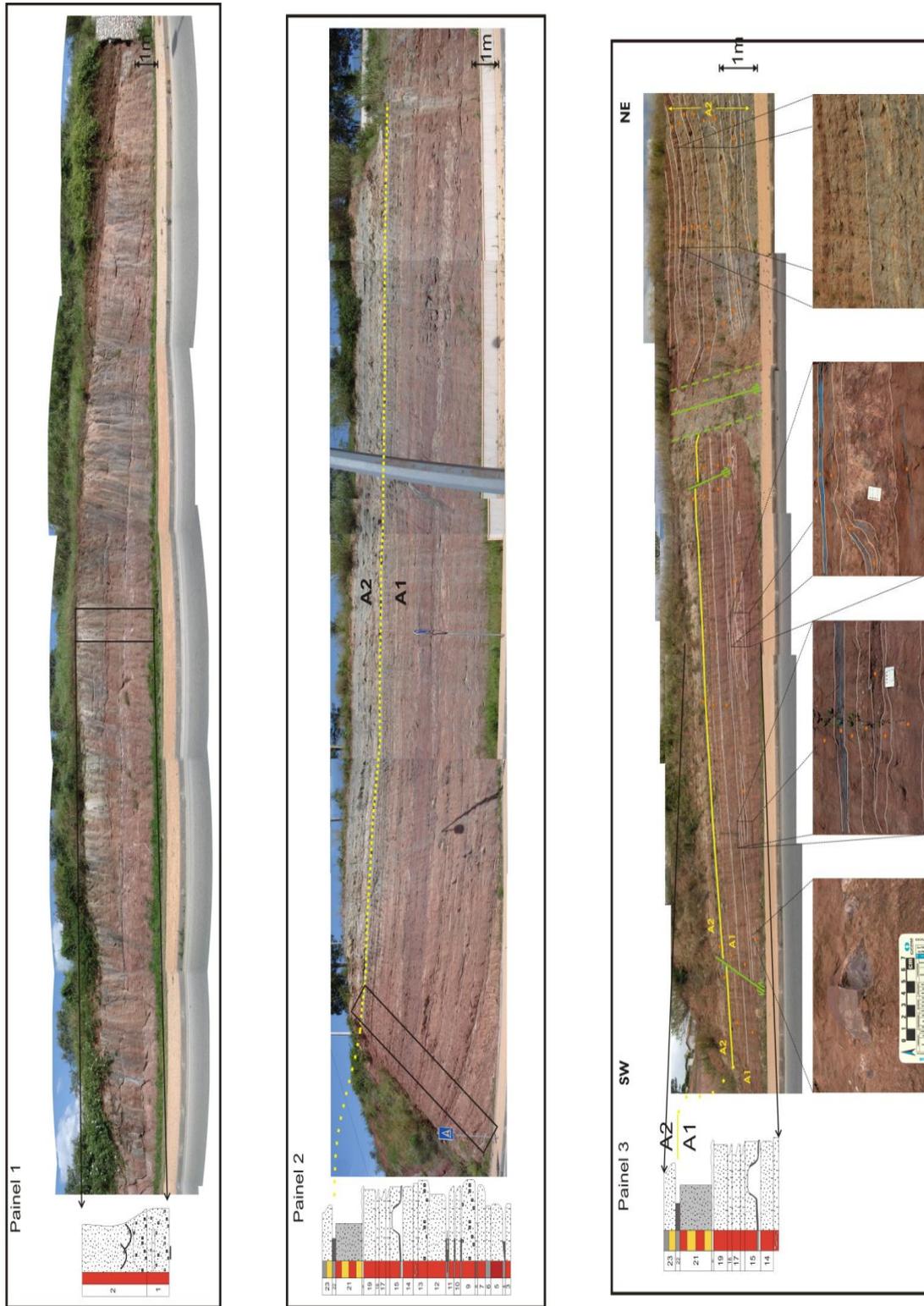


Fig. 16 – Photographic panels of outcropping Upper Triassic medial to distal alluvial fan deposits in Coimbra (Miranda *et al.*, 2010).

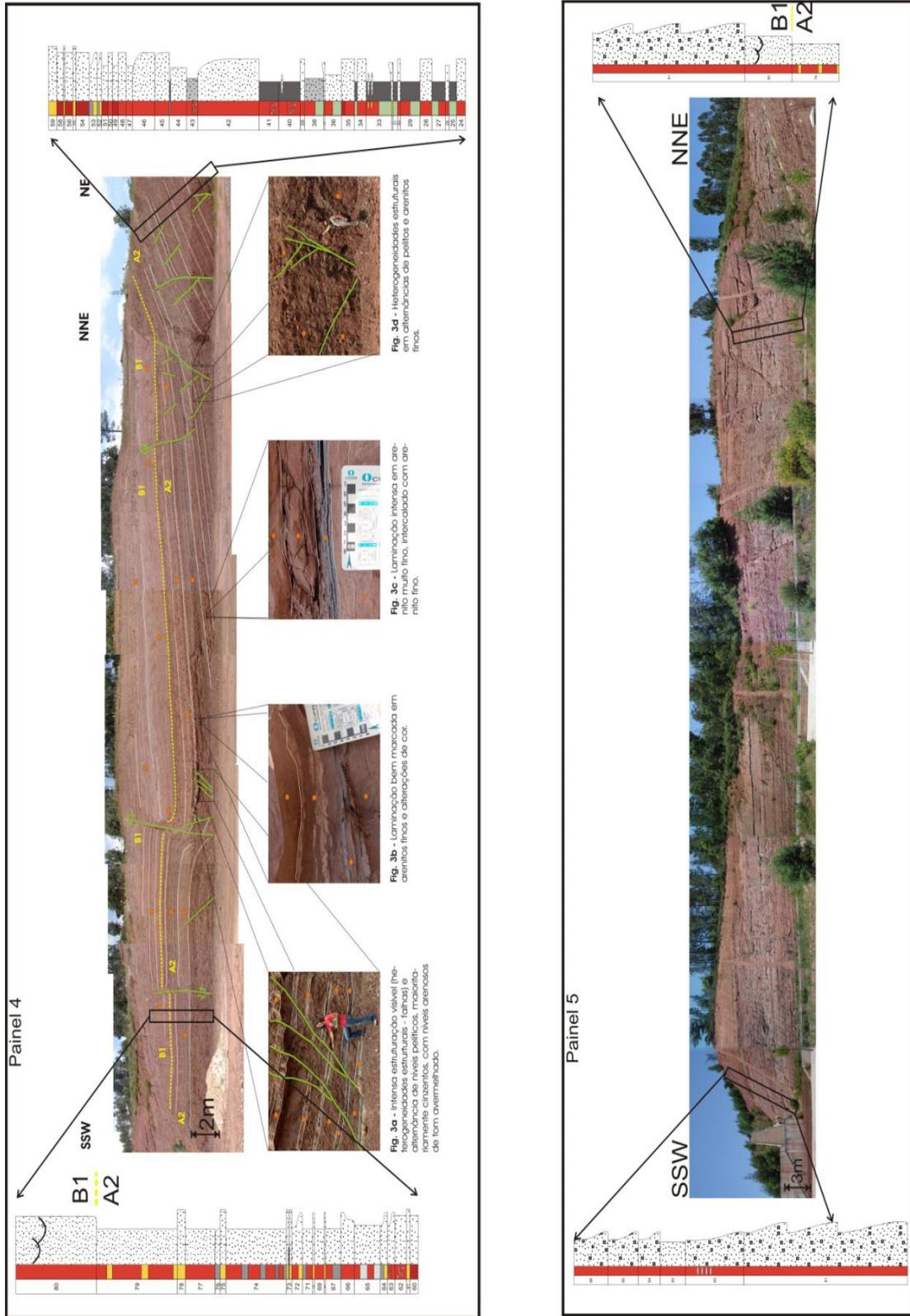


Fig. 16 – Photographic panels of outcropping Upper Triassic medial to distal alluvial fan deposits in Coimbra (Miranda *et al.*, 2010) (Continuation).

DAY 2

26th September 2010

Coimbra → Pedrogão → Vale Furado → Nazaré → São Martinho
do Porto → Peniche

DAY 2

STOP 2A – PEDROGÃO

Main Focus: *The Upper Jurassic sin-rift sedimentary record, including the basal discontinuity followed by transgressive shallow marine and brackish water limestones. The tidal sequences with algal and microbial mats as reservoir analogues above transgressive grey marls.*

Geologic Framework

In the Lusitanian Basin, the Upper Jurassic sediments overlay the Callovian marls and limestones with stratigraphical discontinuity, integrate the UBS1 (*unconformity bounded sequence*) (Wilson, 1980). They are assigned to the Middle Oxfordian and the stratigraphic gap ranging from the late Callovian to the early Oxfordian in age, is recognized over the whole of the basin, at places associated to tectonic tilting and marked karstification processes and with sometimes wider intervals of the missing record.

Observations

The Upper Jurassic (Middle Oxfordian) section provides an excellent continuous sedimentary record of the initiation of the 2nd rifting episode. These sediments, marking the base of the UBS 2 (Wilson, 1980), are part of the Vale Verde Formation, which is equivalent to Cabaços Formation, considered as the most important source rock in the central sector of the basin (Rugé-Perrot, 1961; Ramalho, 1971). It comprises, above the unconformity (Fig 17), a carbonate section (Fig. 18), representing different depositional settings: fresh and brackish lacustrine, restricted marine and oolitic shoals. The unconformity separates two ferruginous limestone beds without reworked pebbles (Azerêdo *et al.*, 2002), the upper one containing abundant ostracods and carophytes. This is followed by an alternation of marls and marly limestones, sometimes with lignite, frequently showing mud-cracks on the stratification planes (Azerêdo & Wright, 2004).

Above these sediments occurs a package of fossiliferous limestones and marly limestones, with abundant intercalations of microbial laminations (Fig. 19) and some marls. There are also frequent bivalve concentrations and some serpulid bioherms. The bed planes frequently present *Thalassinoides* and *Rhizocorallium* (Azerêdo & Wright, 2004).



Fig. 17 – Ferruginous irregular surface (arrowed), considered to be the stratigraphic boundary between the upper Callovian and the lower(?) Oxfordian.

The uppermost part of the section is dominated by calcarenites and fossiliferous limestones, with structures suggesting a high-energy setting, such as tidal oolitic and calcarenitic sand bars.

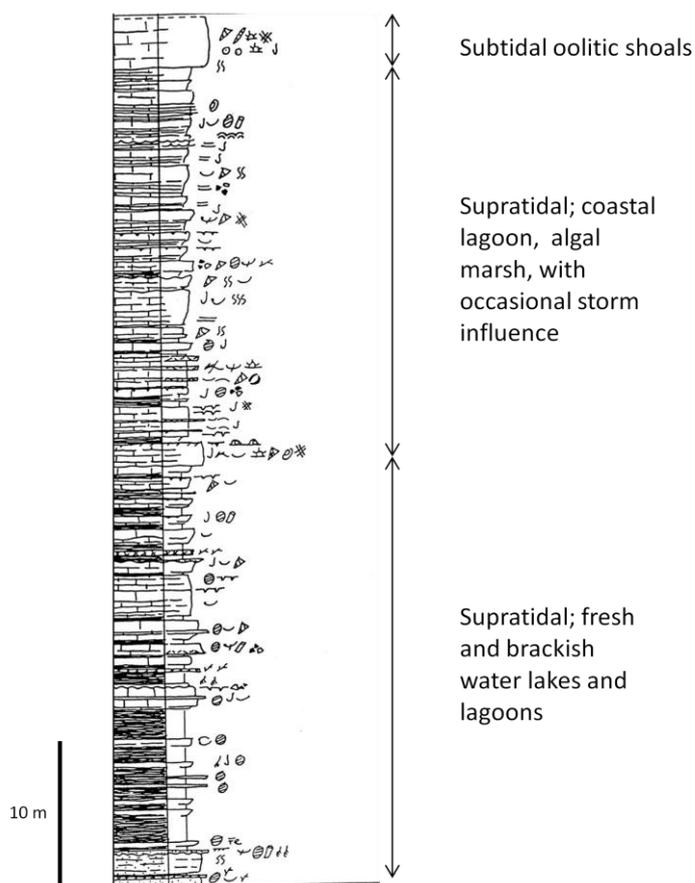


Fig. 18 - Stratigraphic section of the Vale Verde Formation at the Pedrogão outcrop (modf. from Aurell, 1995).



Fig. 19 - Microbial lamination in the middle part of the Pedrógão section, showing decimetric cyclicity.

STOP 2B – VALE FURADO

Main Focus – *Observation of a diapiric structure with bordering deformation of Cretaceous sandstones and limestones, both with oil shows.*

Geologic Framework

The thick package of evaporites (there are drill evidences of more than 2000 m in the central area of the basin) deposited during the final step of the first rift (Hetangian), show strong evidences of large-scale diapiric ascension, in close relation with the activity of major basement faults (NE-SW and NW-SE). There are three main episodes of salt diapirism controlling the sedimentation in the basin: Late Jurassic, Late Cretaceous and late Cenozoic (Pena dos Reis *et al.*, 2007).

Observations

Vale Furado is a coastal cliff located 10 km North of Nazaré beach, where Cretaceous and lower Tertiary rocks outcrop, in both sides of a diapiric structure.

This outcrop shows a coastal cliff oriented N-S. It includes a diapir of clays and evaporates, oriented NE-SW that enters in the sea (between red dots in figure 20). It is bounded to the North by a sandstone package of Pliocene sediments dipping to the North. The southern border of the diapir is composed of four main Cretaceous units spanning from Aptian to Maastrichtian. This units are, from base to top: Figueira da Foz Formation, a fluvial sandy and conglomerate succession (the top is the yellow line in figure 20); Carbonate Formation, Cenomanian shallow limestones (limited by the blue line in figure 20) overlying the former one with an angular unconformity; Grés Superiores Formation (Fig. 21), made of fluvial sands and conglomerates overlying the carbonate breccias. The contact with the underlying carbonates is an angular unconformity with a SW thickening carbonate breccias (Fig. 22); Taveiro Formation, Maastrichtian red sands and clays recording a sinuous fluvial system (beginning over the green line in figure 20).

The southern border of the diapir shows a growth geometry, as indicated in figure 20.

It is possible to observe large volumes of highly disturbed clays and dolomites with gypsum, in the diapiric body. The bordering sandstones and conglomerates show persistent hydrocarbon impregnations (Fig. 22).

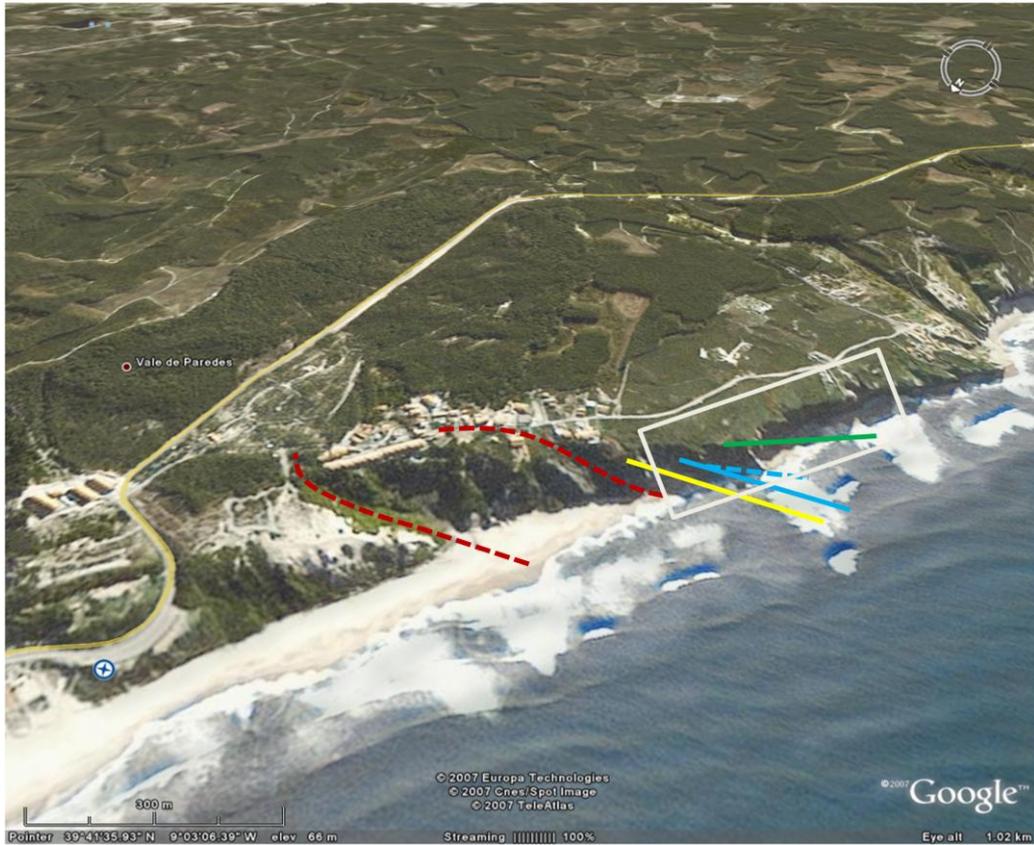


Fig. 20 – Google Earth representation of the Vale Furado area with the limits of the diapir (red) and the southern border cretaceous units. The white rectangle corresponds to the image of figure 21.



Fig. 21 - Aerial photo of the cliff indicated in figure 20.



Fig. 22 - Detail of the unconformity overlying the limestone breccia. The detailed picture presents a fissural oil show on the limestone breccia.

STOP 2C – NAZARÉ

Main Focus – *The post-break up (Aptian) sediments. A major paleokarst developed on the Upper Cretaceous sediments, records the beginning of the basin inversion.*

Geologic framework

From the late Aptian until the early Campanian, defined as UBS4, the main geodynamic controls include the Atlantic extension and the opening of the Bay of Biscay. The lower boundary of the UBS4 (Fig. 23), corresponds to the continental break-up unconformity subsequent to the beginning of ocean opening in the Galicia sector (Dinis *et al.*, 2008). It results from thermal and isostatic induced basement uplift, prior to the initiation of the post rift passive stage. The sequence follows the important diastrophic activity that caused the uplift of Berlenga horst system (western border of the basin) and the Hesperian Massif (eastern border), as well as an important enlargement of the sedimentation area. Coalescent wet alluvial fans draining from NE domain of the basin, change upwards (containing one major retrogradation-progradation boundary) to transitional systems and to a shallow marine carbonate platform that thickens southwestwards (Carbonate Formation). An important fall of the sea level follows the long term Albian - Cenomanian transgression, resulting in progradation and later incision of the depositional systems. The beginning of the progradational geometry of the infill, short after the transgressive maximum and the end of the coastal onlap, is recorded by the Lousões Sandstones Formation. The prograding upper part, mainly composed of coarsening upward alluvial sediments (Upper Sandstone Formation), is related to a sea-level fall and increasing tectonic instability inland whose first evidences occur during Turonian times and led later on (lower boundary of UBS5) to the uplift of the southern block of the Nazaré Fault. The top of this succession is regionally marked by a silcrete, testifying weathering during a long hiatus in sedimentation and a tectonically stable period, at least over the NE sectors of the basin. The beginning of the late Campanian-early Lutetian structural stage (UBS5 and UBS6) can be related to the changing of the Iberia movement relative to Europe (Pena dos Reis, 2000). At this time, the Bay of Biscay sea floor spreading axis became extinct and subduction began (lasting until Miocene), leading together with pyrenean compressional activity, to a minor inversion episode during late Cretaceous time. The late Campanian-Maastrichtian tectonic phase is marked by the emplacement of the sub-volcanic complexes of Sintra, Sines and Monchique, basaltic extrusions at Lisbon-Leiria region, diapirism and reactivation of the Nazaré-Lousã fault (Fig. 25 and 26).

Observations

The Nazaré stop intends to show the late Cretaceous sedimentary sequence, interpreted as the first deposits above the Aptian break-up unconformity. It corresponds to a succession recording the passive margin phase, with the first signs of inversion from the latest Cretaceous on. The change from alluvial braided systems, in the base, to the Cenomanian transgressive carbonate platform, at the top, is very well exposed along the main cliff of the “Sitio de Nazaré” (Fig. 23). The lowermost erosive unconformity, which can be seen down cliff in the Monte Branco area, marks the breakup surface, associated to the beginning of sea floor spreading in Galicia sector, in the Aptian. The fluvial braided sediments of the base (Fig. Foz Formation) are covered by shallow platform limestones (Carbonate Fm.) of Cenomanian - Turonian age. Above a brecciated endokarst could indicate the first signs of the future inversion of the basin. Lousões and Upper Sandstone formations of Senonian age lie below a very weathered basaltic layer, that separates UBS4 from UBS5 (Late Campanian - Maastrichtian).



Fig. 23 - General view of the Nazaré cliffs.

In the light house outcrop (northern cliff) the main units are well exposed together with the karstic features (Fig. 24). Frequent collapsed breccias are visible at different stratigraphic levels, recording several events of infilling and fluid circulation.

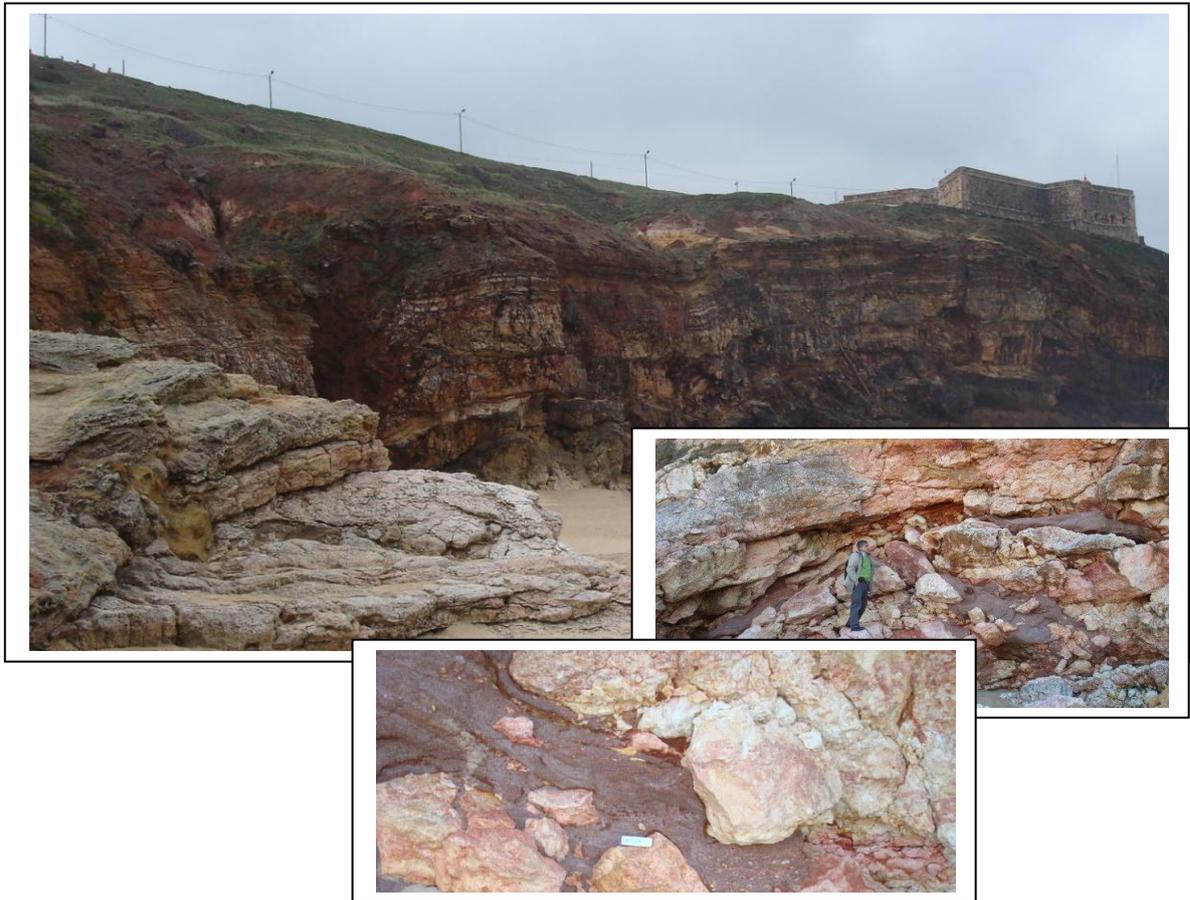


Fig. 24 - The Nazaré Lighthouse northern cliff. Field views of the paleokarst at different scales.

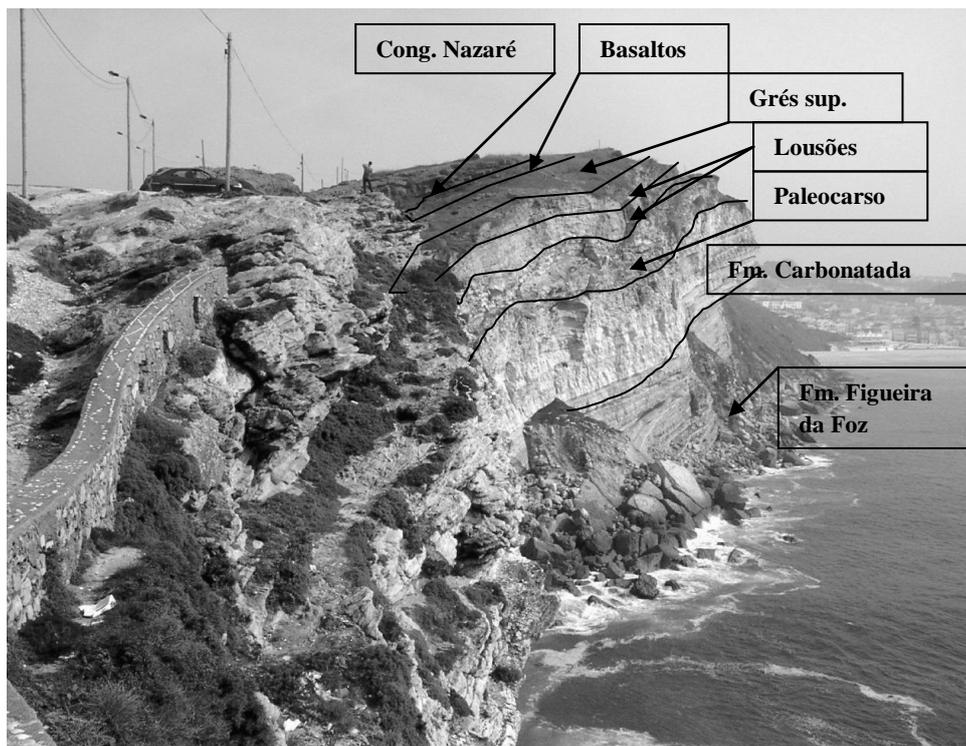


Fig. 25 – View of the Nazaré cliff. See text for explanation of the units.

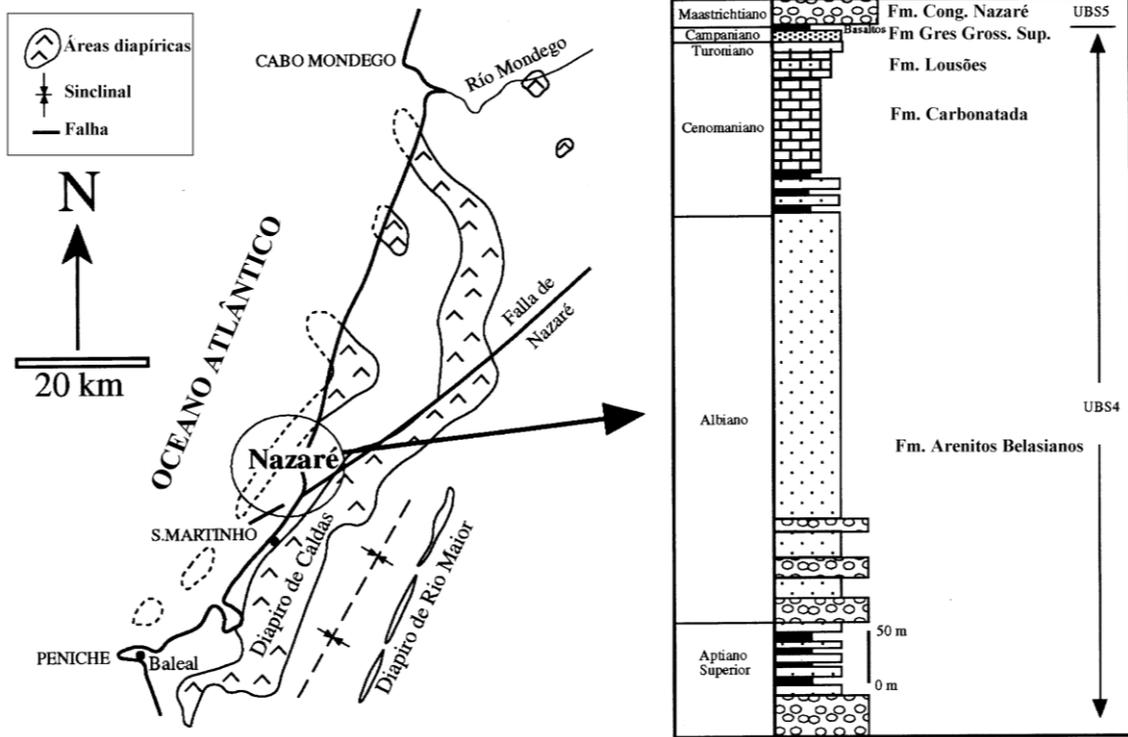


Fig. 26 - Map with the major structural elements in the region. The Cretaceous stratigraphy in Nazare region is presented.

STOP 2D – SÃO MARTINHO DO PORTO

Main Focus – Upper Jurassic rifting sediments in relation with diapiric activity.

Geological framework

The region belongs to the Estremadura trench, a cortical structure that was formed in the extensional phase of late Jurassic, with a general orientation NNE-SSW. The Caldas da Rainha salt dome (Fig. 27) is an asymmetric structure in a transversal cross section (with a low tilt in the west flank and a more abrupt tilt in the east) that separates two late Jurassic basinal domain: to the west, the Peniche block (where S. Martinho is situated; Fig. 28 and 29) is characterized by a moderate subsidence; to the East, the Bombarral and Ota blocks define a domain where the subsidence is more intense.

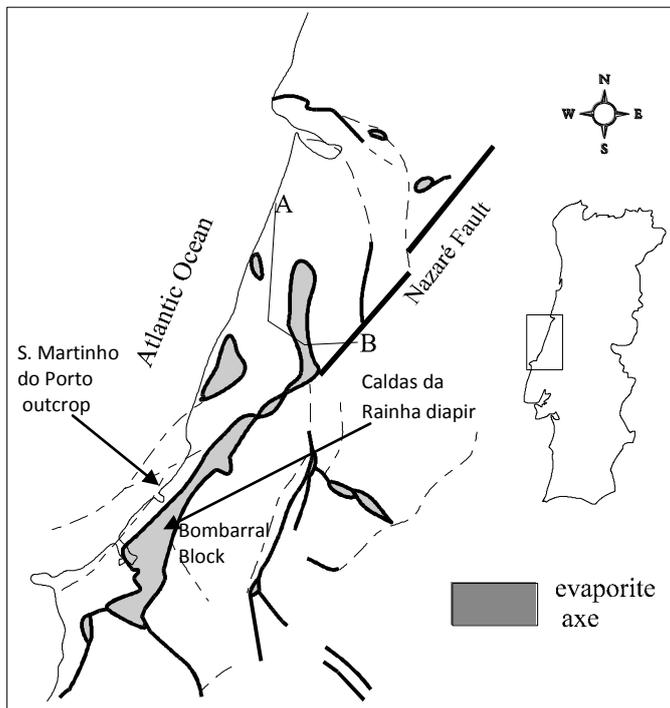


Fig. 27 – Geological framework of the Caldas da Rainha salt dome.

The thick Upper Jurassic clastic succession is organized in fluvio-deltaic systems (Bernardes, 1992), infilling a fast subsiding area following the rift climax. To the south, (Montejunto), these systems change to deep sea turbidites.



Fig. 28 – Google Earth view of Caldas da Rainha diapir, with S. Martinho location. The grey area corresponds to the observation point (round) and the observed cliff of figure 29 (square).

Observations

The S. Martinho area allows scenic and detailed observations of the western border of Caldas da Rainha diapir (Fig. 29 and 30). The Late Jurassic sediments dip westwards at a gradually decreasing angle. The lower sediments include shallow limestones and coastal bay clayey materials, overlain by a new limestone package. These sediments are followed by a thick Kimmeridgian deltaic succession shown in figure 30 (small photo). This package is limited by a major transgressive surface overlain by a thick oncolitic bar, considered Tithonian in age.

Close to the harbour, it is possible to observe an inverse fault, bounding the Hetangian evaporitic marls (from the diapiric core) of the Dagorda Formation and the Oxfordian limestones (Cabaços Formation).



Fig. 29 - Aerial view of the visited area. The red line separates the eastern diapiric depression with a half circle sea gulf, from the western coastal cliffs where the fluvio-deltaic sediments outcrop.



Fig. 30 - Stratigraphy of late Jurassic deposits in S. Martinho region (Oxfordian and Kimmeridgian), close the western border of Caldas da Rainha diapir. See figure 28 for location.

DAY 3

27th September 2010

Peniche → Paimogo → Santa Cruz → Cascais

DAY 3

STOP 3A– PENICHE

Main Focus – Lower Jurassic open marine sag deposits, related with the first Jurassic rifting, including one of the main source-rocks of the basin.

Geological Framework

After the infill of the first intra-continental rifting semi-grabens, an expansive shallow-marine sequence has been deposited all along the basin (*Coimbra Formation*). This Sinemurian dolomitic unit is separated from the overlying marly units by a regional discontinuity, a 2nd Order Sequence Limit. The overlying sequence shows a rapid transition to deep marine facies. Pliensbachian layers show increased subsidence and deepening of the basin, with deposition of black-shales presenting good source-rock characteristics. In this particular area of the basin, Toarcian layers show the increasing influence of detrital input, initially siliciclastic and then mostly calciclastic.

Observations

At the Peniche Peninsula, a continuous 450 m thick Lower Jurassic sequence may be observed along its coastal cliffs. Biostratigraphic control is based on ammonites and allows a detailed cyclicity analysis (Duarte, 2004). Several stops will be made along this sequence, to illustrate the main features and geological moments.

i) Papoa

This stop clearly shows the 2nd Order limit between the massive dolomitic *Coimbra Formation* and the laminated calcareous sequence, marked by a ferruginous bioturbated hardground. The overlying deposits start with bioclastic limestones and centimetric marly intercalations, quickly grading to marly mudstones rich in ammonites, representing an intense deepening of the basin (*Água de Madeiros Fm*) (Fig. 31 and 38).

ii) North Beach

This second stop shows the Pliensbachian *Vale das Fontes Fm.*: “Lumpy Marls and Limestones”, with TOCs up to 5%, give place to the “Marly Limestones and Bituminous Facies”, with TOCs up to 15%, marking the peak transgression phase of this sequence (Duarte, 2004). These organic-rich centimetric layers are part of the so-called “Brenha

Source-Rock”, present in most of the basin, although with different maturation stages. The palinofacies analysis pointed to a predominance of terrestrial remains (Matos, 2009), which may be explained by the proximity of the Berlengas block and its uplift in the Early Jurassic (*vd.* the following Peniche stops) (Fig. 32, 33 and 38).

The western cliffs show regressive marly limestones of the *Lemedo Fm* (Fig. 33).

iii) Trovão

This third stop shows the Pliensbachian / Toarcian proposed GSSP (Elmi, 2006). The top layers of the Late Pliensbachian yellowish marly limestones (*Lemedo Fm.*) represent condensed interval with abundant belemnites. Toarcian sedimentation (*Cabo Carvoeiro Fm.*) begins with dark gray marls and clays with pyritous ammonites; centimetrical to metrical yellowish intercalations of subarkosic sands may be seen on the western cliffs (Wright, 2004). These terrigenous inputs resulted from the uplift of the Berlengas block, an Early Jurassic rift-shoulder, active on the western border of the basin (Fig. 34 and 38).

iv) Remédios – Carvoeiro Cape

The cliffs along the road leading to the Carvoeiro Cape expose abundant whitish limestones with intense carsification, showing amalgamated channel fill geometries and clear bipolar cross-bedding structures (*Cabo Carvoeiro Fm*). An overall thickening and coarsening upward pattern may be detected along these over 300 m thick succession. These deposits have been interpreted as outer fan lobes resedimented carbonates, fed by carbonate shoals exposed at the uplifted Berlengas rift-shoulder (Wright, 2004) (Fig. 35, 36, 37 and 38).



Fig. 31 - PAPOA – Sinemurian unconformity (in dotted white) between the dolomitic *Coimbra Fm* and the marly *Água de Madeiros Fm*.



Fig. 32- NORTH BEACH – Panoramic view with the Papoa isthmus (*Coimbra Fm*) to the left and the North Beach to the right.



Fig. 33- NORTH BEACH – Pliensbachian deep marine marls and black-shales (*Vale das Fontes Fm*) followed by regressive marly limestones (*Lemede Fm*).



Fig. 34 - TROVÃO – Toarcian *Cabo Carvoeiro Fm.* with gray marls and arkosic brownish layers.



Fig. 35 - REMÉDIOS – Toarcian *Cabo Carvoeiro Fm* with stacked re-sedimented calcicastic deposits.



Fig. 36 - CARVOEIRO CAPE – Toarcian highly carsified carbonates.

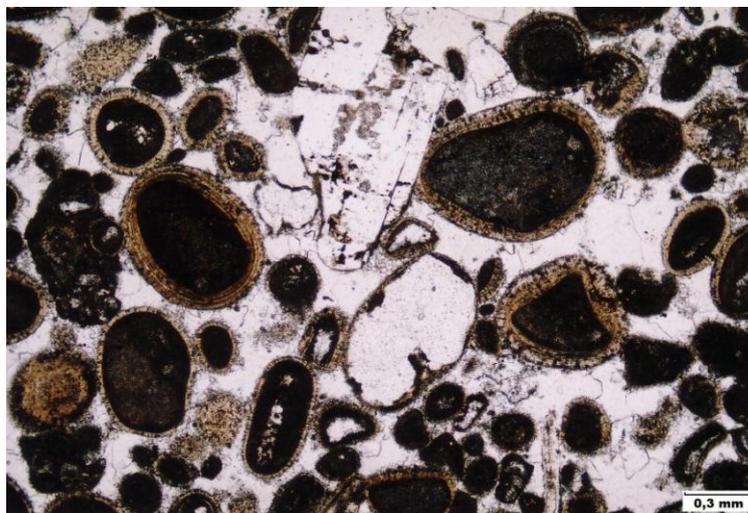


Fig. 37 - Microphotography of Oosparite Grainstone re-sedimented carbonates of the Cabo Carvoeiro Fm. (*in Duarte, 2006*).

Synthetic profile of the Sinemurian – Toarcian Peniche section (Duarte et al., 2004).

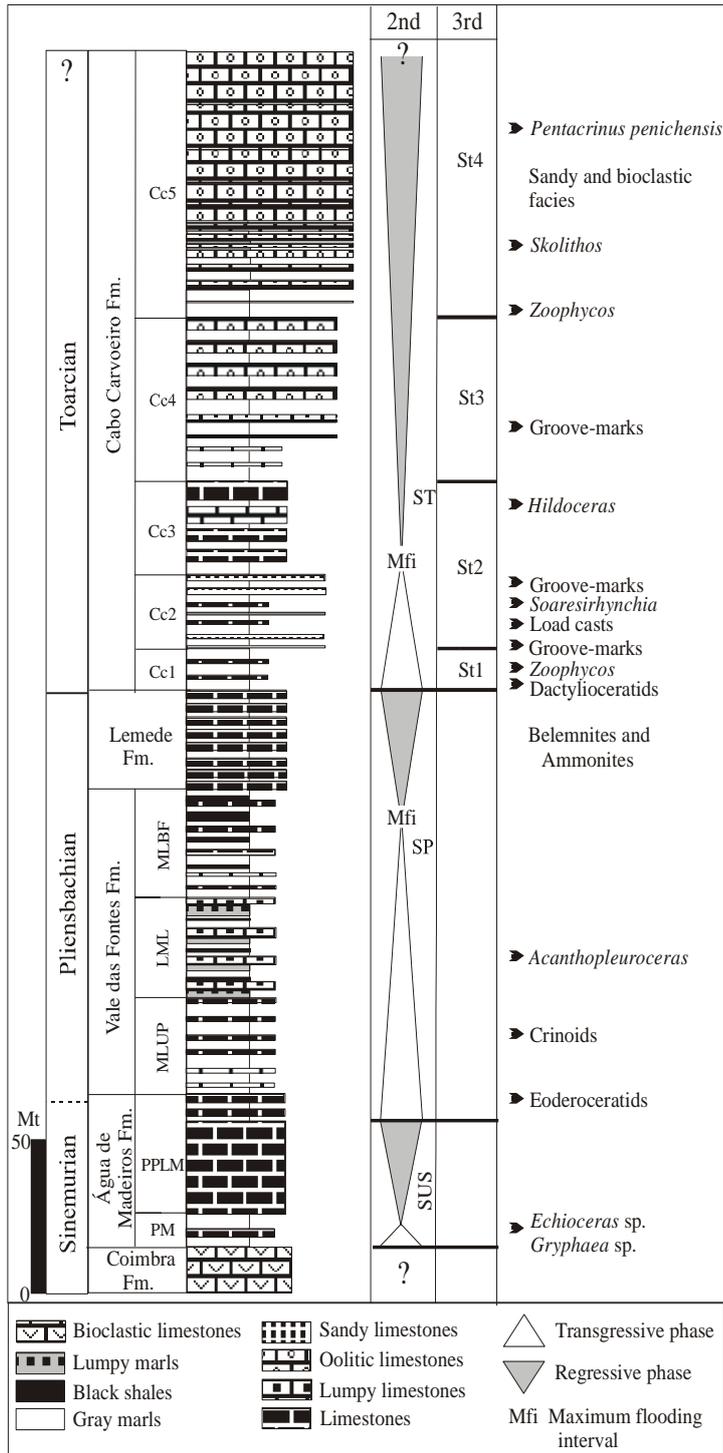


Fig. 38 - Synthetic section of Sinemurian - upper Aalenian(?) from Peniche (Duarte et al., 2004).

STOP 3B – BALEAL

Main Focus – *Middle Jurassic calcareous debris-flows.*

Geological framework

The Middle Jurassic sequences outcropping at Lusitanian basin's eastern border (Maciço Calcário Estremenho) correspond mainly to high energy carbonate inner ramp depositional systems, with hundreds of meters of stacked calcareous sandbodies (Azerêdo, 2004). On the western parts of the basin, outcrops are scarcer and they show quite different facies associations, with monotonous massive to laminated limestones, deposited in deep marine conditions, interpreted as the distal parts of those carbonate ramps. Such is the case at Cabo Mondego (Stop 1A) and Baleal (Stop 3B), in both cases with clear evidences of mass-flows and gravitic re-sedimentation.

Observations

The small Baleal peninsula is composed of Upper Bajocian marly limestones (Fig. 39), proeminent from the neighboring Upper Jurassic fluvial deposits which can be seen on the beach cliffs towards the North. An overall observation at the northern tip of the peninsula shows rhythmic alternations of decimetric gray/yellowish limestones and dark gray marls, in tabular layers dipping c.36° towards ENE. A closer observation shows the presence of irregular and discontinuous layers of coarse grained calciclastic facies, described in detail by Azerêdo (1988).

Limestone conglomerates contain 2-10cm long clasts, sometimes up to 100 cm long, mainly of micritic limestones with "filaments". The matrix is composed of sandy mudstone, showing symsedimentary soft-sediment deformation. Calcareous layers are also present, isolated or capping the conglomeratic layers, with packstone and grainstone textures.

These deposits correspond to sediment gravity flows (debris-flow and mud-flow), deposited in a distally steepened ramp, resulting from sporadic inputs on a dominant low energy hemipeleagic environment (Fig. 40). Directional structures are scarce and both a provenance from the distant eastern inner ramp or from a proximal western basin border, are acceptable hypothesis for the moment (*vd.* Azerêdo, 1988; Fig. 41).



Fig. 39 - BALEAL – Upper Bajocian marly limestones.



Fig. 40 - BALEAL - Detail photo of a single calcareous-debris-flow layer.

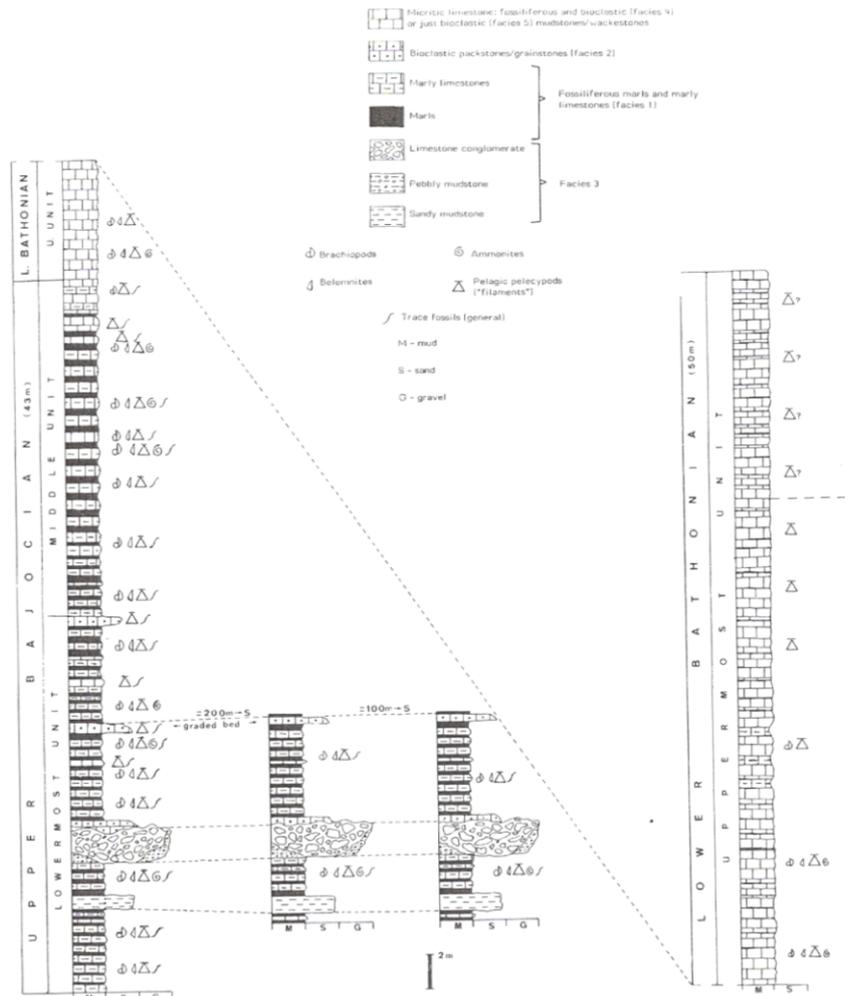


Fig. 41 - Lithostratigraphic column of the Baleal Middle Jurassic sequence (thickness of thinner beds is exaggerated) (in Azerêdo, 1988).

STOP 3C – PAIMOGO

Main Focus: Observation of Upper Jurassic fluvio-deltaic deposits with reservoir characteristics.

Geological Framework

The Upper Jurassic of the Lusitanian basin is composed of thick siliciclastic deposits, related to increased accommodation space created by intense subsidence. These deposits are the geological record of the second rifting event of the basin. The climax of this episode correspond to the deep turbiditic deposits of the Abadia Formation (which will be seen in Santa Cruz), which are followed by a shallowing and prograding siliciclastic sequence – the Lourinhã Formation (Hill, 1998).

This formation presents an association of fluvio-deltaic deposits, in which several Members have been defined according to its facies and paleoenvironments (Hill, 1988; (Fig. 42). Between Peniche and Santa Cruz, the vertical sequence presents over 500 m thickness, showing the alternation of those members, in response to mainly eustatic controls.

Observations

This large-scale outcrop, extending 2 km from the fort of Paimogo to the Areia Branca beach, shows around 100 m of Upper Jurassic fluvio-deltaic deposits from the Lourinhã Formation.

The lower part corresponds to the Praia Azul Member, with silty clays and fine sands with massive to laminated facies. Greyish color indicate preservation of organic matter and rare ostreids indicate brakish conditions. Some sandy bodies show hummocky structures, pointing to reworking in shallow and agitated conditions. The paleoenvironmental reconstruction points to a deltaic front.

As we go up in the sequence, brownish to reddish colours become predominant and sandy bodies become thicker, larger and gradually predominant. This evolution points to the progradation of meandering fluvial facies into the deltaic environment. The thicker sands represent lateral accretion point-bars, whereas the thinner bodies represent crevasse-splays intercalated in the floodplain clays.

These deposits present good reservoir facies, with porous sands in connected bodies, a good outcropping analogue to the North Sea's Statfjord Formation, for example.

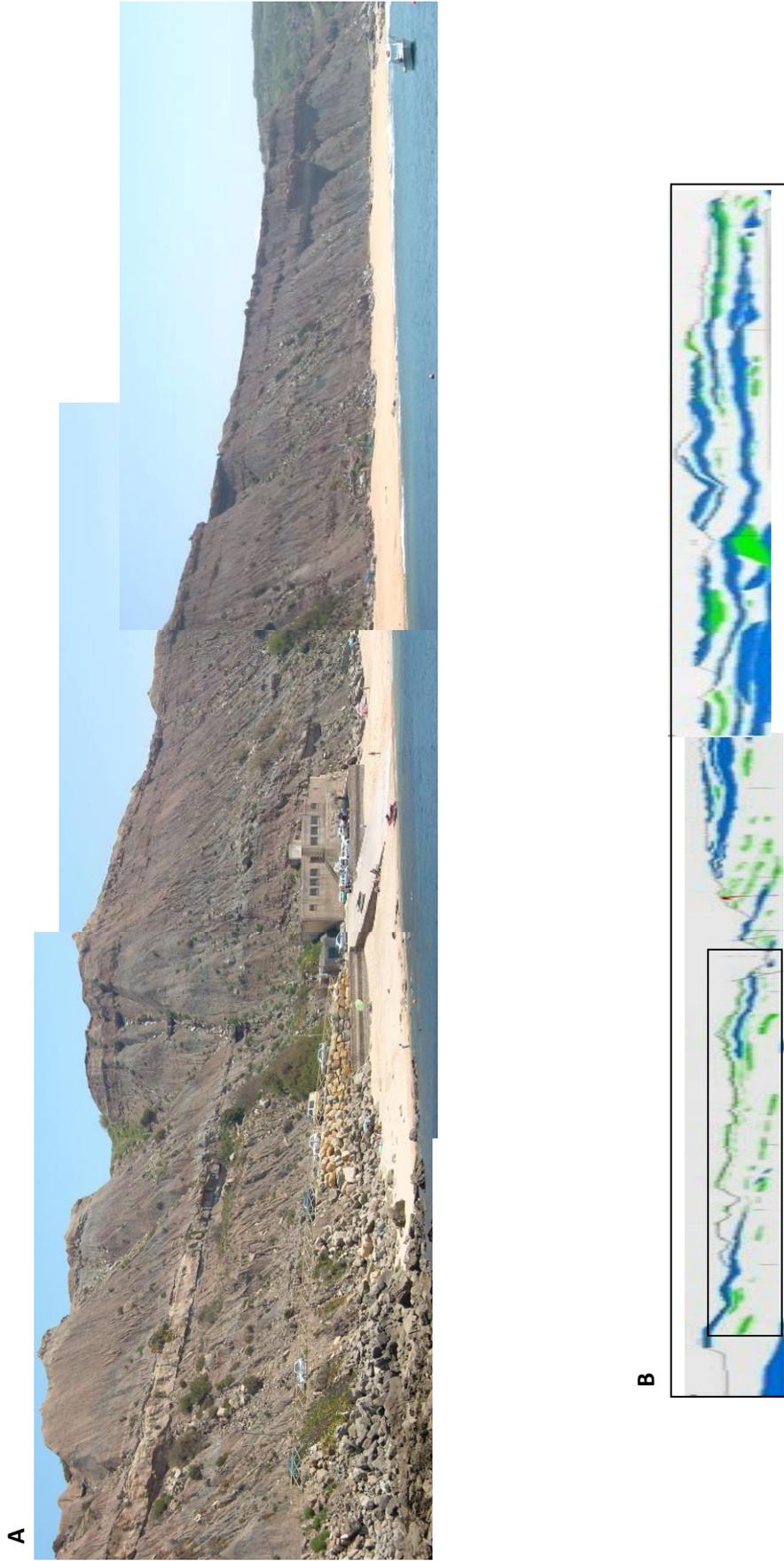


Fig. 42 – A) Photomosaic of Upper Jurassic fluvio-deltaic deposits at Paimogo, Lourinhã Formation; B) Representation of the proportion between floodplain clays (white), sandy point-bars (blue) and sandy crevasse-splays (green), S of Paimogo); the insert shows the position of photo A.

STOP 3D – SANTA CRUZ

Main Focus – Upper Jurassic rifting sediments in relation with diapiric activity.

Geologic framework

The Caldas da Rainha structure was responsible for the early separation of two major subsidence areas (Wilson, 1979, Canérot *et al.*, 1995); towards the NW reduced values are common and to the SE, corresponding to a half-graben block located between the Pragança fault and the Caldas da Rainha structure, intense tectonic subsidence occurred (Fig. 43).

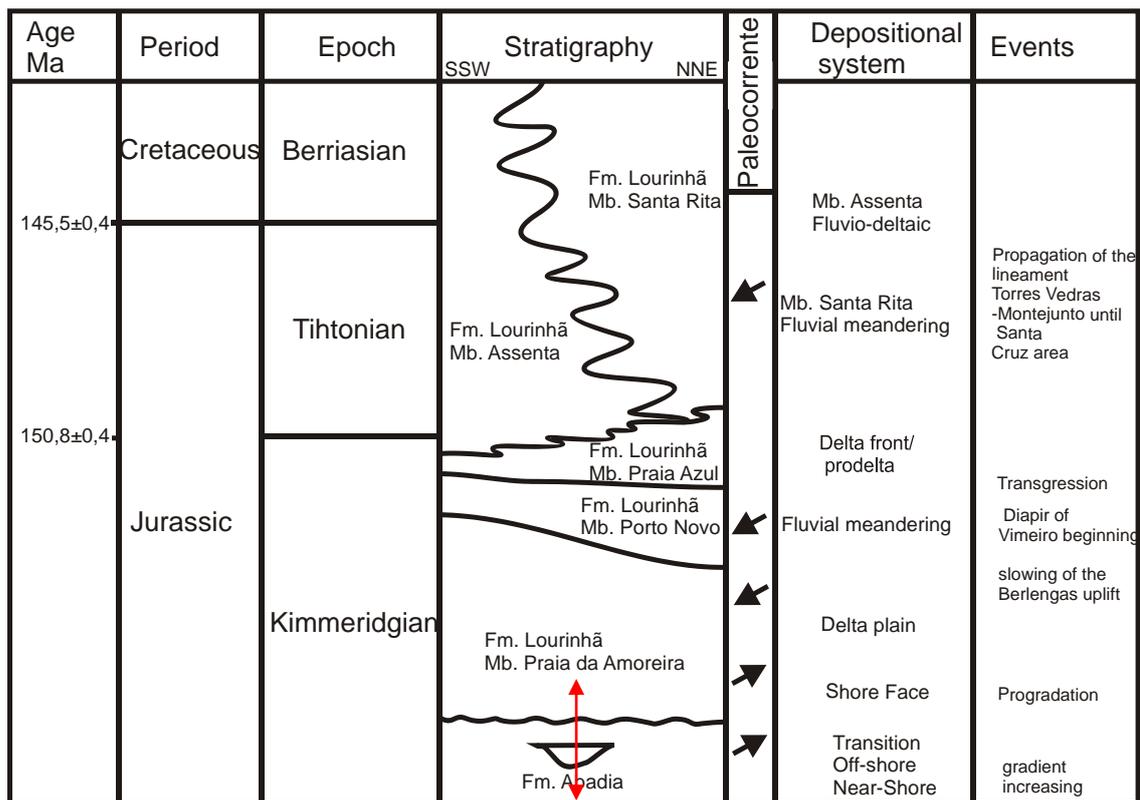


Fig. 43 - Santa Cruz stop. A general stratigraphic scheme of Santa Cruz region. The red arrowed section is outcropping in Santa Cruz beach.

The Bombarral sub-basin that corresponds to the last area, was therefore defined since the beginning of the Late Jurassic sedimentary cycle. The Santa Cruz (Fig. 43 and 44) region corresponds to the westernmost outcrop of Upper Jurassic sediments, likely related to the western basement border of Lusitanian Basin. The sedimentation is mainly

siliciclastic, organized in several lithostratigraphic units and records the more important conditions of the 2nd rifting occurrence.

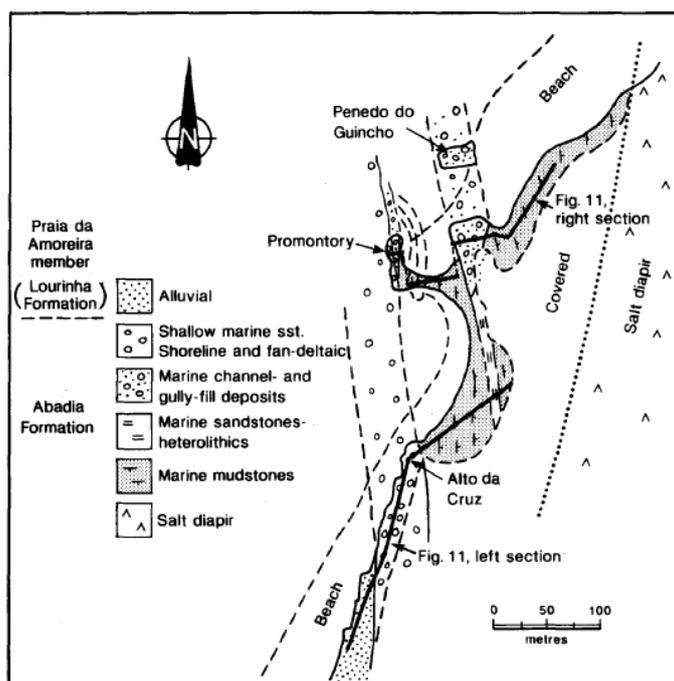


Fig. 44 - General interpretation of the Santa Cruz beach outcrop (Ravnas *et al.*, 1997).

The outcropping diapiric geometries allow the observation of geologic features suggesting the relation between the salt motion and the sedimentation.

Observations

This coastal outcrop presents upper Jurassic sediments related to the second rifting event, including Kimmeridgian turbidites related with the climax, next to a diapir wall (Fig 45A). These sediments are incised by a submarine flow conglomerate (Fig. 45B). The package is overlain by coastal and fluvial sands (Ravnas *et al.*, 1997) of the transition to the post climax phase (*Amoreira* Fm). This succession shows an apparent geometry of adaptation to the diapir, with decreasing dip towards South.

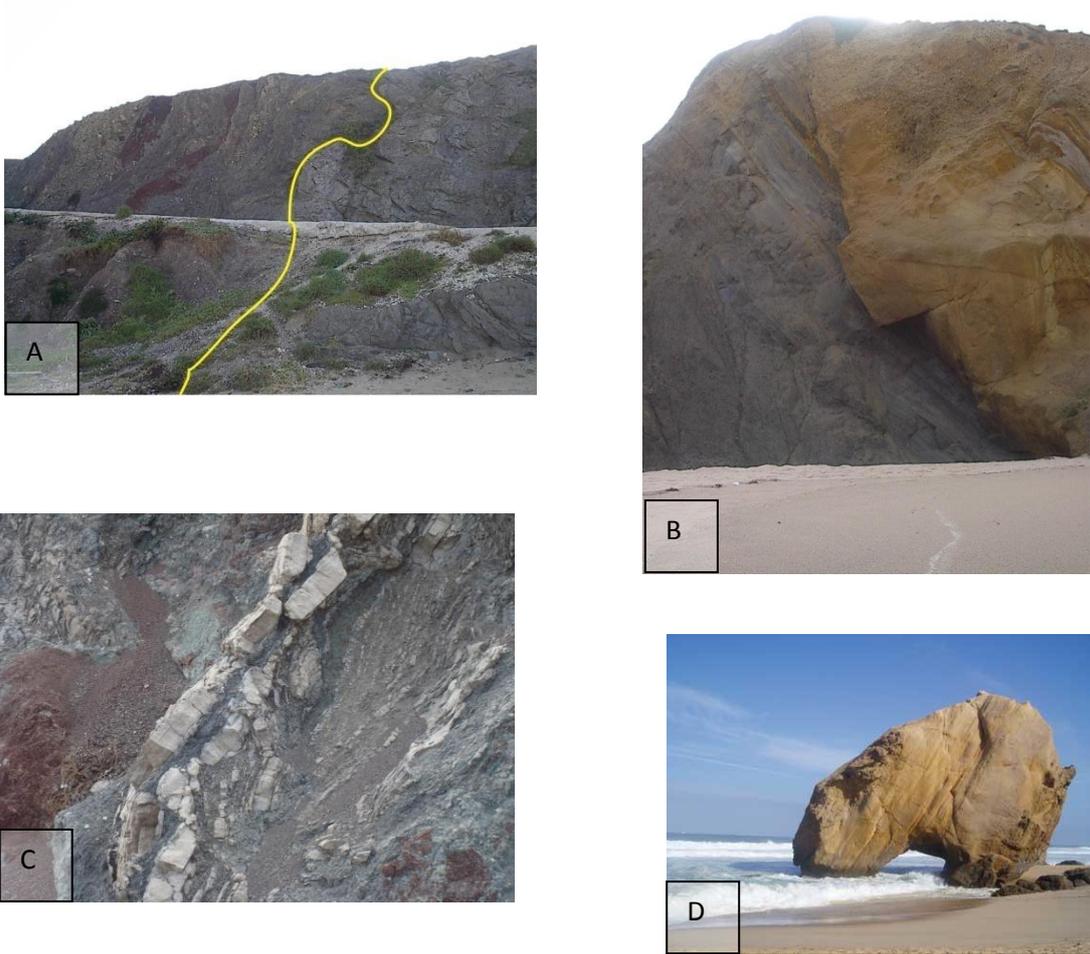


Fig. 45 – Santa Cruz stop. A: contact (yellow line) of the Fm Abadia (right) with the diapir wall (left); B: Abadia Fm. turbidites incised by a submarine channel (D); C: Deformation in diapiric evaporates.

DAY 4

28th September 2010

Cascais → Guincho → Lisboa

DAY 4

STOP 4A – CASCAIS

Main focus – *Lower Jurassic transitional sequences and unconformities, related to the North-Atlantic break-up.*

Geological framework

The Lower Cretaceous corresponds to the last hundred meters of sedimentary infill at the Lusitanian Basin. The subsidence has been strongly attenuated, due to thermal cooling following with the Late Jurassic rifting and basin extension. Early Cretaceous subsidence has been concentrated in the southern part of the basin, with the depocentric area located around the Cascais region. Paleogeographic reconstructions indicate an elongated NNE-SSW trough, as in Late Jurassic times, but with a much limited extension towards NNW (around 100 km N of Lisbon). To the west this trough was limited by a topographical barrier (Berlengas high), connecting with the open sea only towards SSW.

The Lower Cretaceous shows alternations of coarse to fine siliciclastics, as well as marly to pure limestones, including reefal constructions. The depositional environments reflect multiple progradation and retrogradations of fluvial, transitional and coastal deposits, showing 2nd Order cycles, controlled mainly by geodynamic regional events, and 3rd Order cyclicity with regional eustatic controls. 2nd Order cycles are related with the seafloor spreading and opening of the North Atlantic, which occurred in 3 diachronic segments along the West Iberian Margin (WIM): Berriasian rupture of the southern Tejo Sector; Barremian rupture of the central Iberian Sector; and Late Aptian rupture of the northern Galician Sector, with definite Atlantic opening, break-up and passive margin development.

Observations

This stop will lead us along an almost complete depositional sequence from the Barremian up to the Albian, including two of the main unconformities (Fig. 46A and B).

The observed sequence starts c.200 m S of the Crismina Fort, with inner platform limestones, containing rudistids and dasycladacean (Guincho Fm), indicating the proximity of a reefal construction which is being abandoned as a result of eustatic

shallowing. These limestones show an irregular top, with emersion and paleo-carsification, covered by marly and dolomitic clays, deposited in lagoonal environments (Regatão Fm). This unconformity corresponds to the Barremian rupture referred above and represents therefore a 2nd Order limit with an important geodynamic signature (Fig. 47).

These lagoonal deposits gradually give place to marly marine deposits, showing a transgressive pattern culminating in reefal limestones, supporting the Fort (Crismina Fm). A thinner regressive sequence may be seen, starting with an Orbitolinids-rich marly limestone and ending with marly clays. This 60-70 meters thick 2nd Order T-R sequence, represents around 10 Ma.

The narrow sandy beach north of the Crismina Fort exposes the beginning of a new T-R sequence, marked by an abrupt regression and a strong input of coarse siliciclastics (Rodízio Fm). This lithologically contrasting surface represents the Late Aptian break-up unconformity, related to the seafloor spreading in the northern WIM. The following deposits show clear fluvial structures, with multiple channels and sandy gravel bars, representing the depositional response to a dramatic geodynamic event.



Fig. 46A and B - Cretaceous outcrops at the Cascais region, south of the Guincho beach, exposing Barremian to Albian mixed carbonate/siliciclastic deposits. Two main 2nd Order unconformities are present, between the Guincho and Regatão Formations, and between the Crismina and Rodízio Formations (see Fig. 47).

In many places of the basin (e.g. Nazaré) these coarse Late Aptian deposits are well known, always with the same rupture signature. However, out of the subsident trough, towards the northern sectors of the basin, this event is marked by intense uplift and

erosion: Late Aptian coarse siliciclastics lie directly over Upper, Middle or even Lower Jurassic limestones, reflecting a dramatic change in the basins subsidence-uplift story.

These fluvial deposits are followed by transitional clays, marls and limestones and later on by coastal and reefal limestones (Galé Fm) supporting the Fort, reflecting the development of a new 2nd Order T-R sequence (Fig. 47).

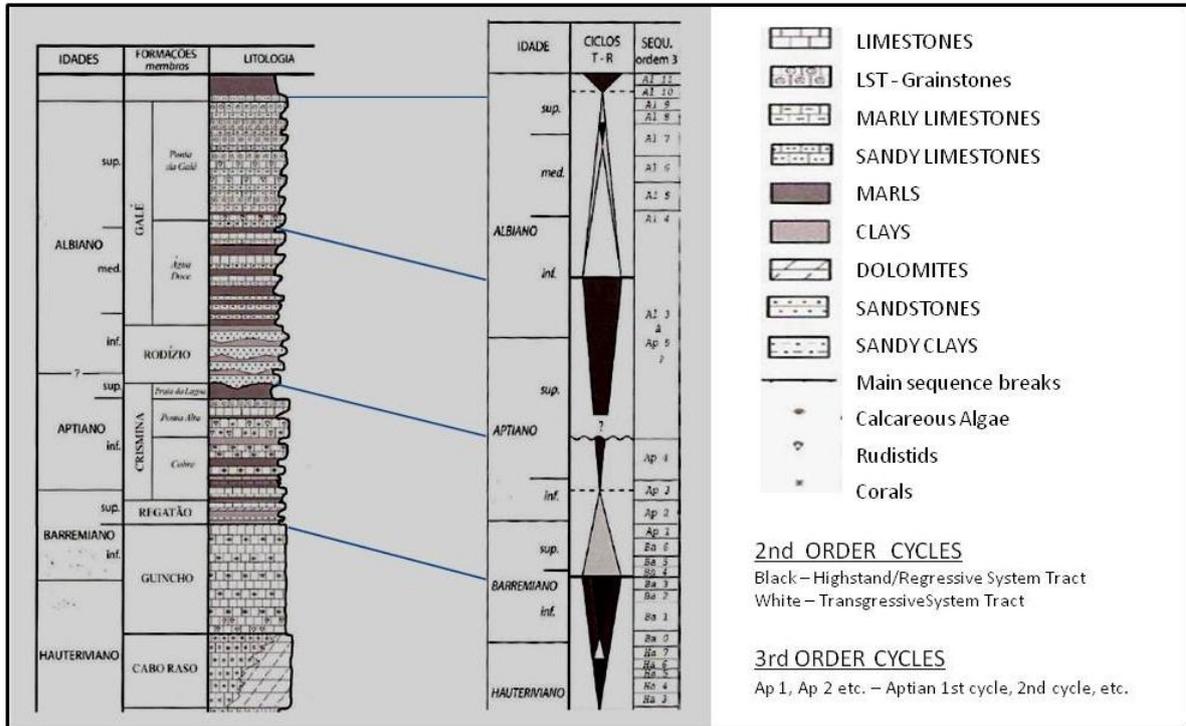


Fig. 47 - Lower Cretaceous synthetic lithostratigraphic sequence at Cascais region, with 2nd and 3rd Order cycles definition (adapt. from Rey *et al.*, 2006).

REFERENCES

- Andrade, J. B. (2006) – Los braquiópodos del tránsito Jurásico Inferior - Jurásico Medio de la Cuenca Lusitánica (Portugal). *Colóquios de Paleontología*, Madrid, 56: 5-194.
- Aurell (1995). In R. Pena dos Reis, P. Trincão, P. P. Cunha & J. Dinis, Relatório de execução do projecto “Estratigrafia sequencial e biostratigrafia do Jurássico Superior da Bacia Lusitânica”. GPEP, 188p.
- Azerêdo, A. C. & Wright, V. P. (2004) - Multi-scale signatures and events in carbonate systems (Middle to early Upper Jurassic, Lusitanian Basin). In L. V. Duarte & M. H. Henriques (Eds.), *IAS 2004, 23rd Meeting, Field Trip Guide Book, Carboniferous and Jurassic Carbonate Plataforms of Iberia*, 1: 73-91.
- Azerêdo, A. C. (1988) – Calcareous debris-flows as evidence for a distally steepened carbonate ramp in West-Central Portugal. *Comunicações dos Serviços Geológicos de Portugal*, Lisboa, t.74: 57-67.
- Azerêdo, A. C., Duarte, L. V., Henriques, M. H. & Manuppella, G. (2003) – Da dinâmica continental no Triásico aos mares no Jurássico Inferior e Médio. *Cadernos Geológicos de Portugal*, Instituto Geológico e Mineiro, Lisboa, 43 p.
- Azerêdo, A. C., Wright, V. P. & Ramalho, M. M. (2002) - The Middle – Late Jurassic forced regression and disconformity in central Portugal: eustatic, tectonic and climatic effects on a carbonate ramp system. *Sedimentology*, 49: 1339-1370.
- Azerêdo, A. C. (2004) – Middle Jurassic inner ramp lithosomes at the Maciço Calcário Estremenho. In L. V. Duarte & M. H. Henriques (Eds.), *IAS 2004, 23rd Meeting, Field Trip Guide Book, Carboniferous and Jurassic Carbonate Plataforms of Iberia*, 1: 79-86.
- Bernardes, C. A. (1992) - A sedimentação durante o Jurássico Superior entre o Cabo Mondego e o Baleal (Bacia Lusitana): Modelos deposicionais e arquitectura sequencial. *Tese de doutoramento* (não publicada). Universidade de Aveiro, 261 p.
- Bown, P. R. & Cooper, M. K. E. (1998) – “Jurassic”. In P. R. Bown (Ed.), *Calcareous Nannofossil Biostratigraphy*, Kluwer Academic, London, 34-54.
- Canales, M. L. & Henriques, M. H. (2008) – Foraminifera from the Aalenian and the Bajocian GSSP (Middle Jurassic) of Murtinheira section (Cabo Mondego, West Portugal): Biostratigraphy and paleoenvironmental implications. *Marine Micropaleontology*, 67 (1-2): 155-179.
- Canales, M. L. (2001) – Los foraminíferos del Aalenense (Jurásico Médio) en la Cuenca Vasco-Cantábrica (N de España). *Revista Española de Micropaleontología*, 33 (3): 253-438.
- Canales, M. L., Henriques, M. H. & Ureta, S. (2000) – Análisis de las asociaciones de foraminíferos del Aalenense, en los márgenes oriental y noroccidental de la Placa Ibérica: implicaciones biogeográficas y bioestratigráficas. *Actas do I Congreso Ibérico de Paleontología/XVI Jornadas de la Sociedad Española de Paleontología*, Évora, 8-9.
- Cowie, J. W., Ziegler, W., Boucot, A. J., Bassett, M. G. & Remane, J. (1986) – Guidelines and Statutes of the International Commission on Stratigraphy (ICS). *Forsch.-Inst. Senckenberg*, 83: 1-14.
- Cresta, S., Goy, A., Ureta, S., Arias, C., Barrón, E., Bernad, J., Canales, M. L., García-Joral, F., García-Romero, E., Gialanella, P.R., Gómez, J.J., González, J.A., Herrero, C., Martínez, G., Osete, M. L., Perilli, N. & Villalaín, J. J. (2001) – Definition of the Global Boundary Stratotype Section and Point

- (GSSP) of the Aalenian (Middle Jurassic) and the Toarcian - Aalenian Boundary. *Episodes*, 24 (3): 166-175.
- Cunha, P. Proença & Pena dos Reis, R. (1993) - The Cretaceous unconformity-bounded sequences (Upper Aptian - Lower Campanian and Upper Campanian - Maastrichtian?) in the Lousã - Pombal region. *Field trip guide, 1st General meeting - IGCP Project nº362 - Tethyan and Boreal Cretaceous*, 5-18.
- Dinis, J. L., Rey, J., Cunha, P. P., Callapez, P. & Pena dos Reis, R. (2008) - Stratigraphy and allogenic controls of the western Portugal Cretaceous: an updated synthesis. *Cretaceous Research*, 29 (5-6): 772-780.
- Duarte, L. V. (2004) – The Upper Sinemurian – Upper Toarcian succession in the Peniche peninsula. Lithostratigraphy and Sequence Stratigraphy. . In L. V. Duarte & M. H. Henriques (Eds.), *IAS 2004, 23rd Meeting, Field Trip Guide Book, Carboniferous and Jurassic Carbonate Plataforms of Iberia*, 1: 58-60.
- Duarte, L. V. (2006) - The Peniche Section. In R. Pena dos Reis & N. Pimentel, *Curso de Campo na Bacia Lusitânica (Portugal)*, Coimbra, 87 p.
- Elmi, S. (2006) – Pliensbachian/Toarcian boundary: the proposed GSSP of Peniche (Portugal). *Volumina Jurassica*, Warsaw, 4: 5-16.
- Fernández López, S., Pavia, G., Erba, E., Guiomar, M., Henriques, M. H., Lanza, R., Mangold, C., Olivero, D. & Tiraboschi, D. (2009) – Formal proposal for the Bathonian GSSP (Middle Jurassic) in the Ravin du Bès (Bas-Auran, SE France). *Episodes*, 32 (4): 222-248.
- Fernández-Lopez, S., Henriques, M. H. P., Mouterde, R., Rocha, R. & Sadki, D. (1988b) – Le Bajocien inférieur du Cap Mondego (Portugal). Essai de biozonation. *2nd International Symposium on Jurassic Stratigraphy*, Lisboa, 1: 301-313.
- Fernández-Lopez, S., Mouterde, R. & Rocha, R. (1988a) – Les *Zurcheria* s.l. (*Ammonitina*, *Erycitidae*) du Bajocien inférieur du Cap Mondego (Portugal). *2nd International Symposium on Jurassic Stratigraphy*, Lisboa, 1: 283-300.
- Henriques, M. H. & Mouterde, R. (2000) – Importance des Graphoceratidés dans les associations enregistrées au G.S.S.P. du Bajocien (Cabo Mondego, Portugal), Les événements du passage Lias-Dogger, Séance spécialisée de la Société Géologique de France, du Comité Français de Stratigraphie e da Association des Géologues du Sud-Ouest, Toulouse (França), *Strata*, série 1 (10): 23-27.
- Henriques, M. H. (1992) – Biostratigrafia e Paleontologia (*Ammonoidea*) do Aaleniano em Portugal (Sector Setentrional da Bacia Lusitaniana). *PhD Thesis*, University of Coimbra, 301 p.
- Henriques, M. H. (1995) – Les faunes d’ammonites de l’Aalenien portugais: composition et implications paleobiogéographiques. *Geobios*, M.S., 18: 229-235.
- Henriques, M. H., Gardin, S., Gomes, C. R., Soares, A. F., Rocha, R. B., Marques, J. F., Lapa, M. R. & Montenegro, J. D. (1994) – The Aalenian - Bajocian boundary at Cabo Mondego (Portugal). *Miscellanea, Serv. Geol. Naz.*, Roma, V: 63-77.
- Henriques, M. H., Linares, A., Sandoval, J. & Ureta, M. S. (1996) – The Aalenian in the Iberia (Betic, Lusitanian and Iberian Basins). In A. C. Riccardi (Ed.), *Advances in Jurassic Research, GeoResearch Forum*, Transtec Pub., Zurich, 1-2: 139-150.
- ICNB (2008) – Portal da Conservação da Natureza & Biodiversidade. Instituto da Conservação da Natureza e da Biodiversidade. Disponível online a 13 de Julho de 2010: <http://portal.icnb.pt/ICNPortal/vPT2007/O+ICNB/Áreas+Protegidas/Monumentos+Naturais/>

- Miranda, J. P., Pina, B., Matos, V., Calh a, A. M., Pena dos Reis, R. & Pimentel, N. (2010) - Estudo das f cies de leque aluvial em afloramento do Tri sico Superior de Coimbra. *e-Terra*, 21 (9). Online: <http://www.metododirecto.pt/CNG2010/index.php/vol/article/view/273/436>.
- Neto, K. S. (2010) – Nanof sseis calc rios da passagem Aaleniano - Bajociano do perfil do Cabo Mondego – Portugal (GSSP do Bajociano). *MCs Thesis*, University of Coimbra, 96p.
- Palain, C. (1976) - Une s rie d tritique terrig ne. Les "Gr s de Silves": Trias et Lias inf rieur du Portugal. *Mem rias dos Servi os Geol gicos de Portugal*, Lisboa, N.S. (25): 377 p.
- Pavia, G. & Enay, R. (1997) – Definition of the Aalenian - Bajocian Stage Boundary. *Episodes*, 20: 16-22.
- Pena dos Reis, R. & Corrochano, A. (1998) - Arquitectura deposicional controlada pela etapa paroxismal do rifting no Jur ssico superior da Bacia Lusit nica (Portugal). Caso da regi o a SO de Montejunto. In J. T. Oliveira & R. P. Dias (Eds.), *V Congresso Nacional de Geologia, Livro Guia das Excurs es*, 15-20.
- Pena dos Reis, R. Cunha, P. M. R., Dinis, J. L. & Trinc o, P. (1999) - Geologic evolution of Lusitanian Basin during Late Jurassic (Portugal). In Hall & Smith (Eds.), *Advances in Jurassic Research, GeoResearch Forum*, Trans Tech Pub, Zurich, 6: 345-356.
- Pena dos Reis, R. P. B. (2000) - Depositional systems and sequences in a geological setting displaying variable sedimentary geometries and controls: Example of the Late Cretaceous Lusitanian Basin (central Portugal). *Comunica es do Instituto Geol gico e Mineiro*, t. 87: 63-76.
- Pena dos Reis, R. Proen a Cunha, P & Dinis J. (1997) - Hipersubsident depositional event associated with a rift climax in Late Jurassic of Lusitanian Basin (W Portugal). *IV Congresso de Jur ssico de Espanha, Alca iz*, 101-103.
- Pena dos Reis, R., Pimentel, N. & Garcia, A. (2007) - Curso de Campo na Bacia Lusit nica (Portugal), Roteiro. Coimbra, 154 p.
- Perilli, N., Henriques, M. H. & Ureta, M. S. (2002) – Aalenian calcareous nannofossil biohorizons of some sections, from Lusitanian Basin and Basque-Cantabrian Area. *XVII Jorn. Soc. Esp. Paleontolog a*, Albarrac n (Espanha), *Publ. Semin. Paleont. Zaragoza*, 5 (1): 162-166.
- Ramalho, M. M. (1971) - Contribution   l’ tude micropal ontologique et stratigraphique du Jurassique sup rieur et du Cr tac  inf rieur des environs de Lisbonne (Portugal). *Mem rias dos Servi os Geol gicos de Portugal*, 19: 212 p.
- Ravnas, R., Winsdelstad, J., Mellere, D., N ttvedt, A., Sj blom, T. S., Steel, R. J., Wilson, R. (1997) - A marine Late Jurassic synrift succession in the Lusitanian Basin, western Portugal - tectonic significance of stratigraphic signature. *Sedimentary Geology*, 114: 237– 266.
- Rocha, R., Henriques, M. H. P., Soares, A. F., Mouterde, R., Caloo, B., Ruget, C. & Fernandez-Lopez, S. (1990) – The Cabo Mondego section as a possible Bajocian boundary stratotype. *Mem. Descr. Carta Geol. d’It.*, Roma, XL: 49-60.
- Ruget-Perrot, C. (1961) - Etudes stratigraphiques sur le Dogger et le Malm inf rieur du Portugal au Nord du Tage, Bajocien, Bathonien, Callovien, Lusitanien. *Mem rias dos Servi os Geol gicos de Portugal*, 7 (N.S.): 197p., 3map., 11est.
- Sandoval, J., Henriques, M. H., Ureta, S., Goy, A. & Rivas, P. (2001) – The Lias/Dogger boundary in Iberia: Betic and Iberian cordilleras and Lusitanian Basin. *Bull. Soc. G ol. France*, 172 (4): 387-395.
- Watkinson, M. P. (1989) – Triassic to Middle Jurassic sequences from the Lusitanian Basin Portugal, and their equivalents in other North Atlantic margin basins. *PhD Thesis*, The Open University, Milton Keynes, 390 p.

Wilson, R. C. (1980) - A reconnaissance study of Upper Jurassic sediments of the Lusitanian Basin. *Ciências da Terra (UNL)*, 5 : 53-84.

Wilson, R. C. L., Hiscott, R. N., Willis, M. G. & Gradstein, F. M. (1989) - The Lusitanian basin of west-central Portugal; Mesozoic and Tertiary tectonic, stratigraphic and subsidence history. In A. J. Tankard & H. Balkwill (Eds), *Extensional tectonics and stratigraphy of the North Atlantic margins*. American Association of Petroleum Geologists, *Memoir* 46: 341-361.

Wright, V.P. (2004) – Submarine fan evolution of the Toarcian, Peniche. In L. V. Duarte & M. H. Henriques (Eds.), *IAS 2004, 23rd Meeting, Field Trip Guide Book, Carboniferous and Jurassic Carbonate Plataforms of Iberia*, 1: 67-70.