Lusitanian Basin
Short field trip

Rui Pena dos Reis
penareis@ci.uc.pt
Dpt Earth Sciences – University of Coimbra; Portugal.

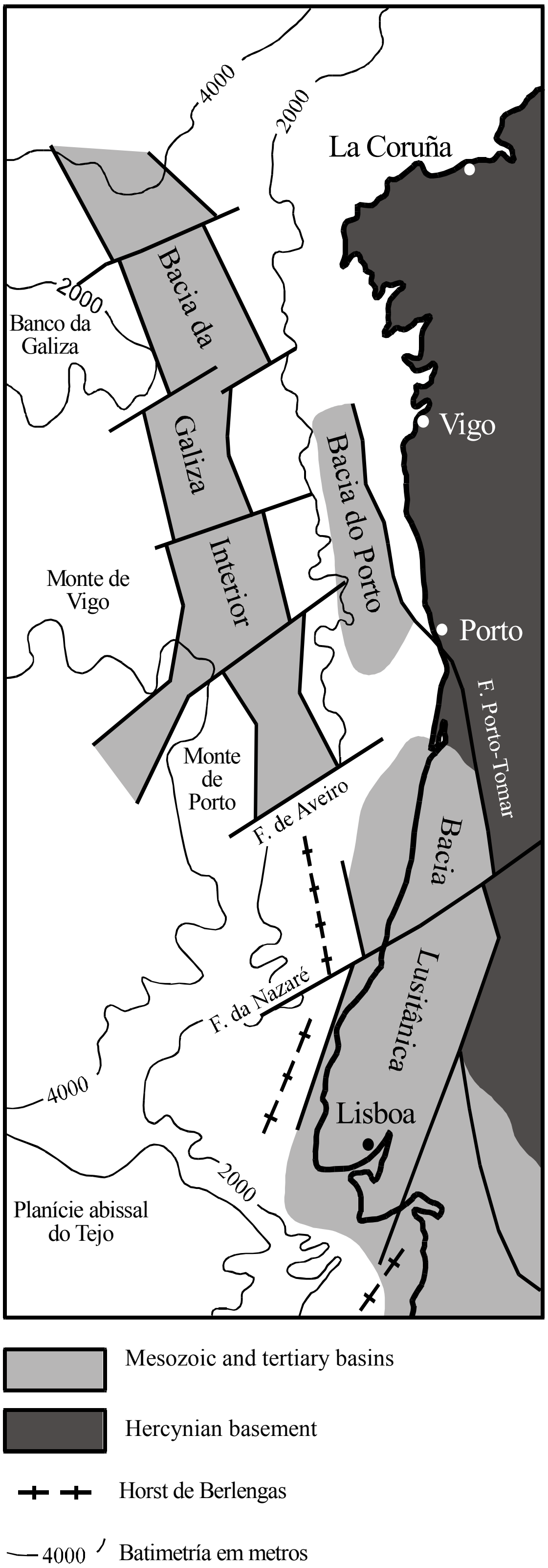

Fig. 1 – West Iberian margin with the major basins and basement blocks. Major geographic features.

I - INTRODUCTION

The Lusitanian Basin was initiated during a late Triassic rifting phase and belongs to a family of peri atlantic basins (e.g. Jeanne d'Arc Basin, Scotian Basin). It is located on the western border of the Iberian plate (Fig. 1) and extends some 250 km in a NNE-SSW trend and up to 100 km East-West. The axis of maximum subsidence follows a general NNE-SSW structural orientation.

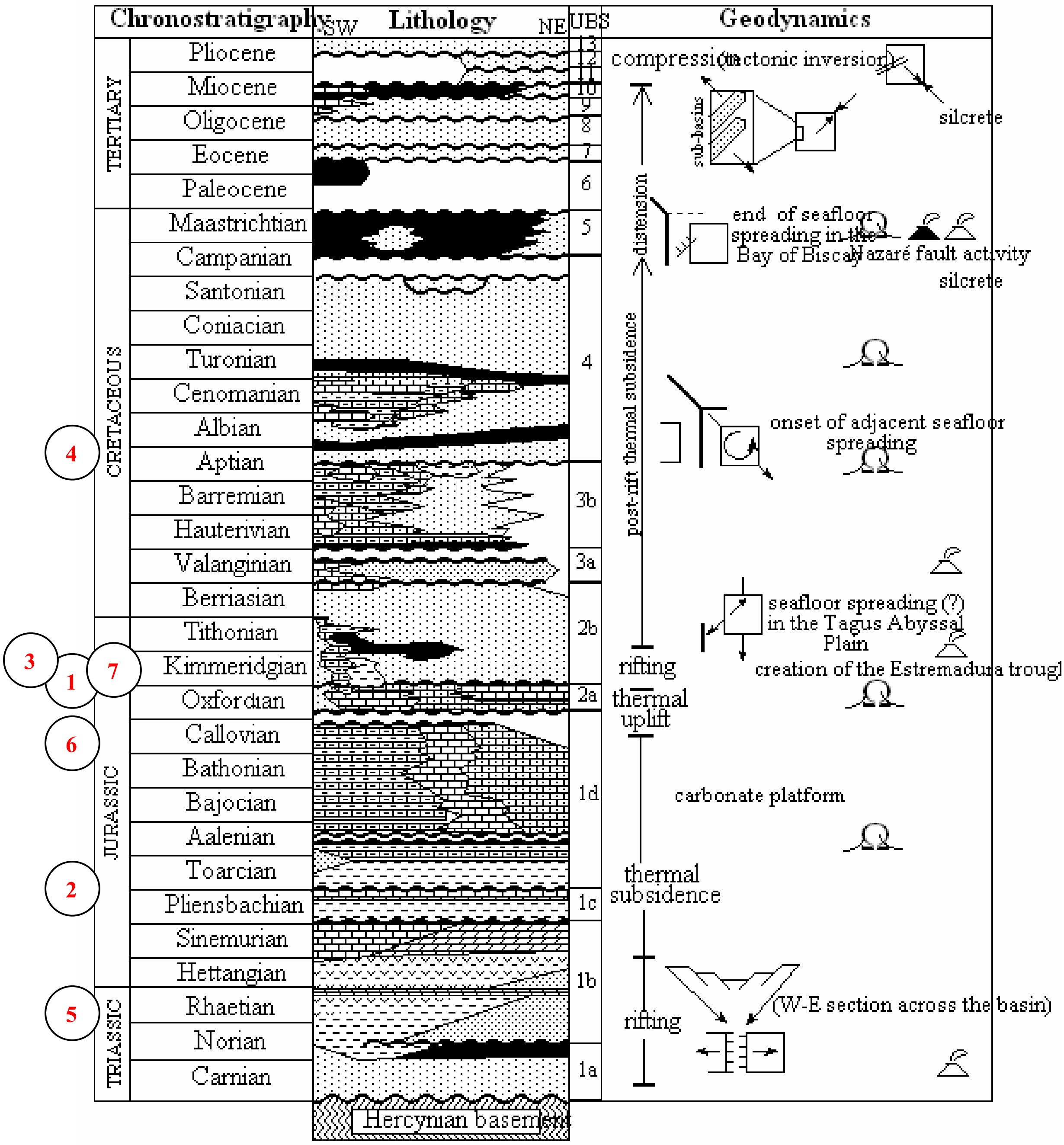

Fig. 2 – The stratigraphic and geodynamic evolution of the Lusitanian Basin. Red numbers are the field trip stops and their stratigraphic position. (Pena dos Reis *et al.,*1992).

The basin 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).
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 Capanian; UBS5) upper Campanian - Maastrichtian. During the Mesozoic and part of the Cenozoic the structures with a NE-SW and NNE-SSW direction had a distensive behaviour. But after the end of the Cretaceous and mainly during the 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 of the Mesozoic.
The geodynamic evolution includes two major rifting episodes, a passive margin interval and an inversion process.

The first rifting episode inLate Triassic
The first rifting episode that began during Late Triassic (Figs. 2, 3) led 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 covered distally by evaporates.
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.

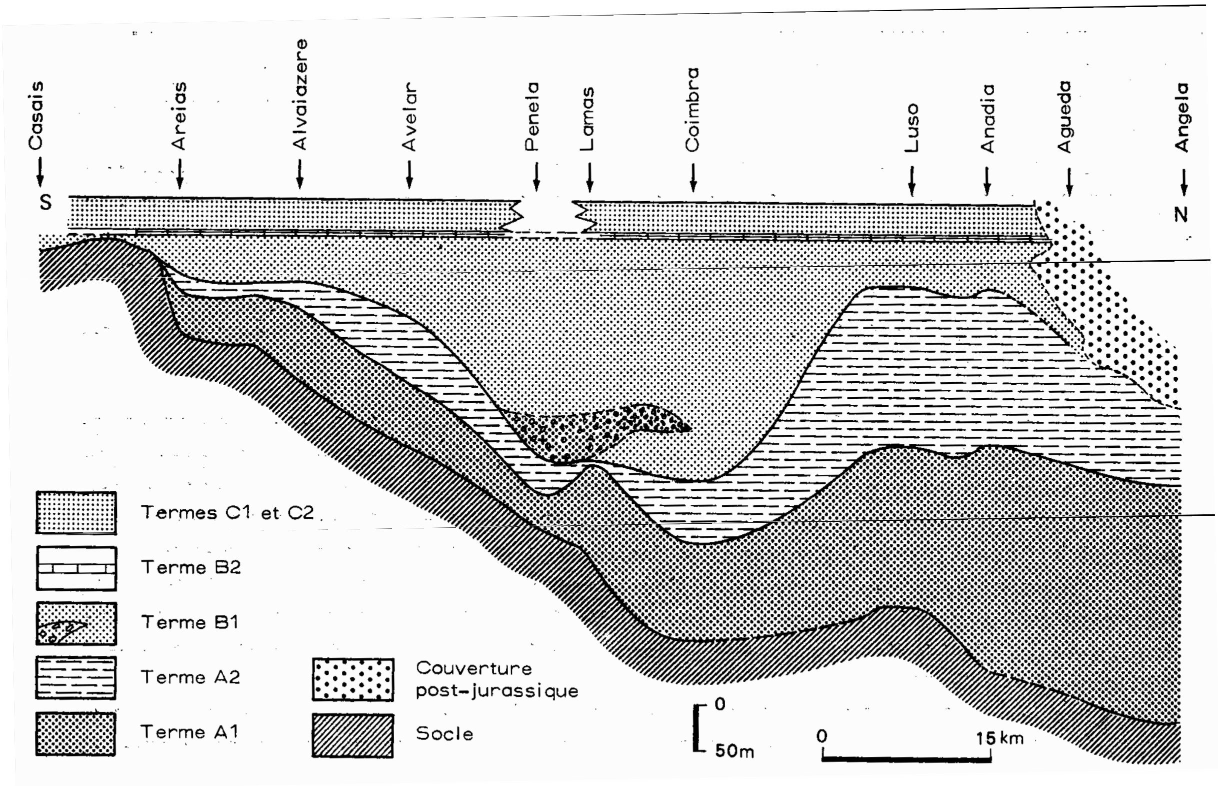

Fig. 3 – Late Triassic deposits. A NS stratigraphic panel with main units and thicknesses (Palain, 1976).

The second rifting episode in Late Jurassic-Early Cretaceous

From the middle Oxfordian to the early Aptian a second rifting phase occurred. This can be separated into three main episodes: Late Jurassic-Berriasian and two Early Cretaceous steps.

The extensional episode activated hercynian faults coupled with moderate halokinesis and also caused intrusive igneous activity towards the south of the Nazaré fault.

The Late Jurassic-Berriasian evolution of the Lusitanian Basin is divisible into three tectonic phases. The initial phase (Stage I) was the onset of rifting which resulted in widespread carbonate deposition. Extensional climax was reached during Stage II. This created highly subsident sub-basins and a significant siliciclastic influx. Stage III 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. The lithostratigraphic and depositional sequences framework and timing of each stage is considered (Fig. 4). A set of general sections through north, central and south sectors of the basin are presented in figure 5. The Cretaceous stratigraphy is presented in figure 6.

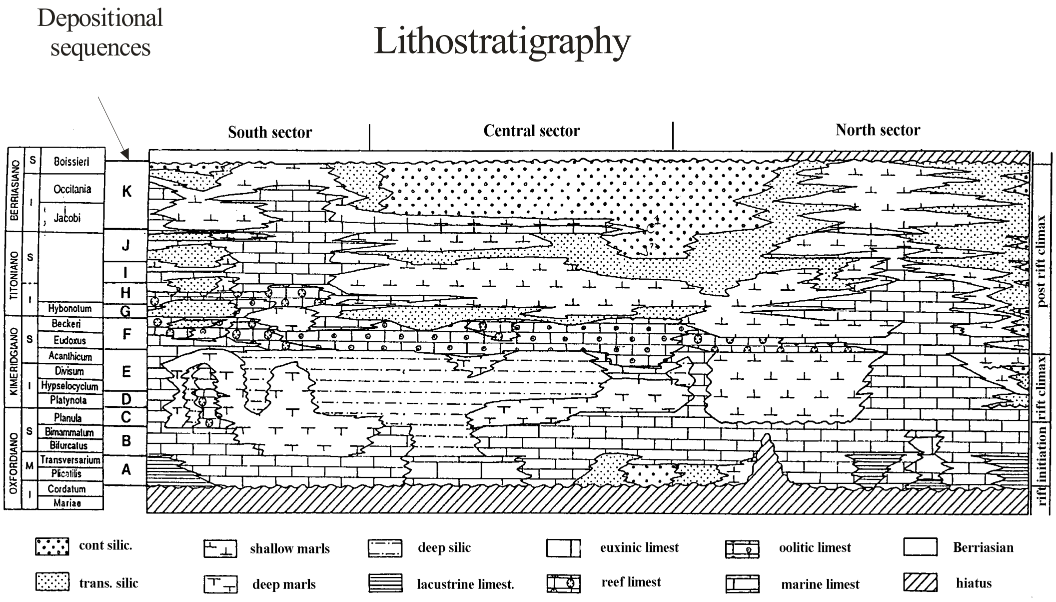

Fig. 4 - The lithostratigraphic units and depositional sequences framework for the late Jurassic-Berriasian of the Lusitanian Basin (Pena dos Reis *et al*., 2000).

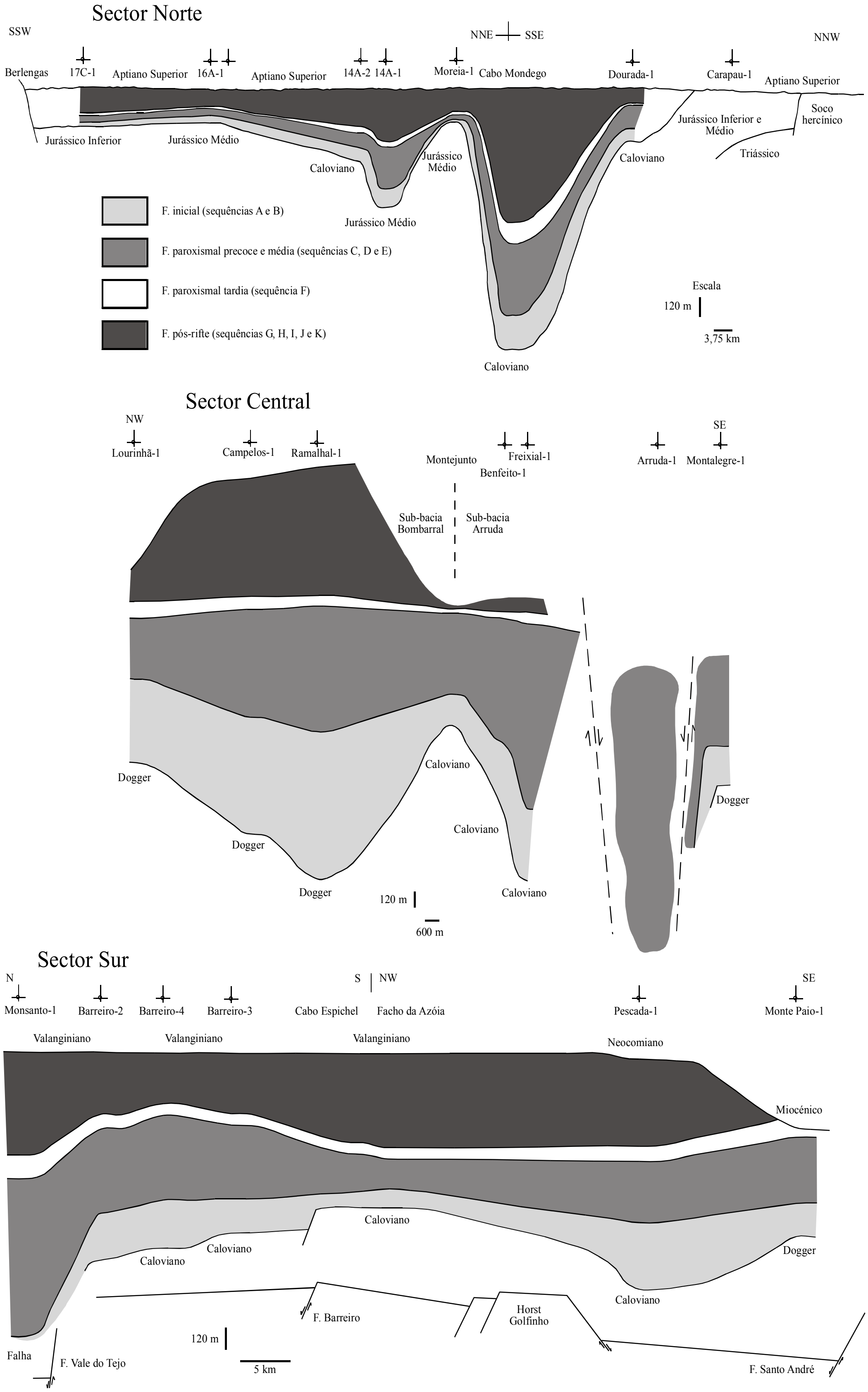

Fig. 5 – Main late Jurassic depocenters in the Lusitanian Basin (north, central and south sectors) (mod. Pena dos Reis *et al*., 1995).

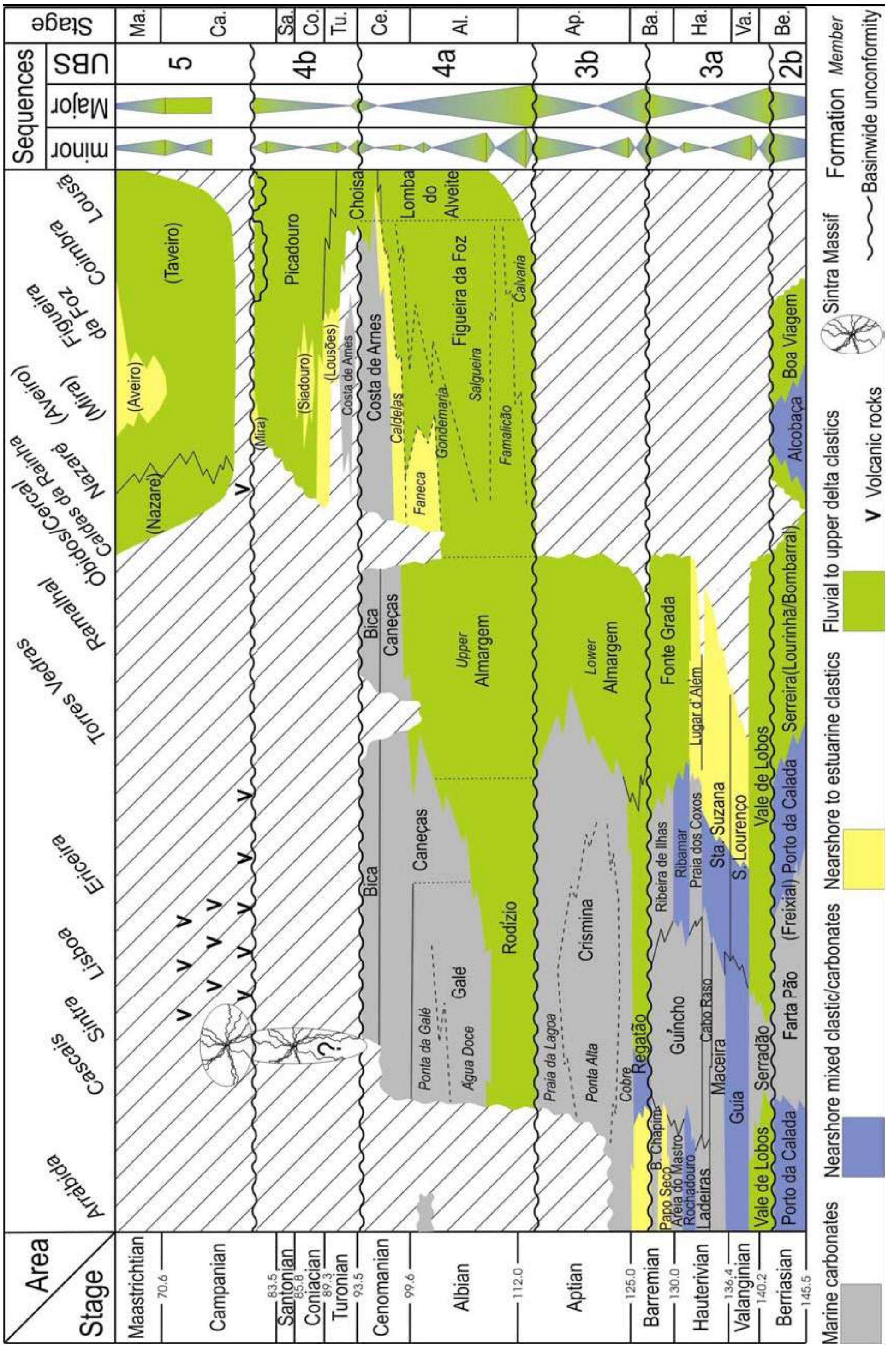

Fig. 6 – Main UBS (unconformity bounded sequences) and lithostratigraphy of Cretaceous deposits of the Lusitanian Basin (Dinis *et al.*, 2007).

II - STOPS AND OUTCROPS.

The field trip was prepared in order to include some of the most spectacular outcrops of the Lusitanian Basin sediments. Obviously, a large part of them occurs along the cliffs of the Atlantic coast line. Most of the roads are good and distances are short. As we are in front of the ocean, with latitude 40º N, the climate is temperate and humid. February is the coldest month and rain is very frequent together with strong SW winds.

Day 1 – Following the map of figure 7, the first day includes **Stops 1, 2, 3 and 4**
Day 2 – **Stops 5, 6 and 7**. Lisbon is stop **8**.

<u>Estimated car travel during the two days – 450 Km</u>

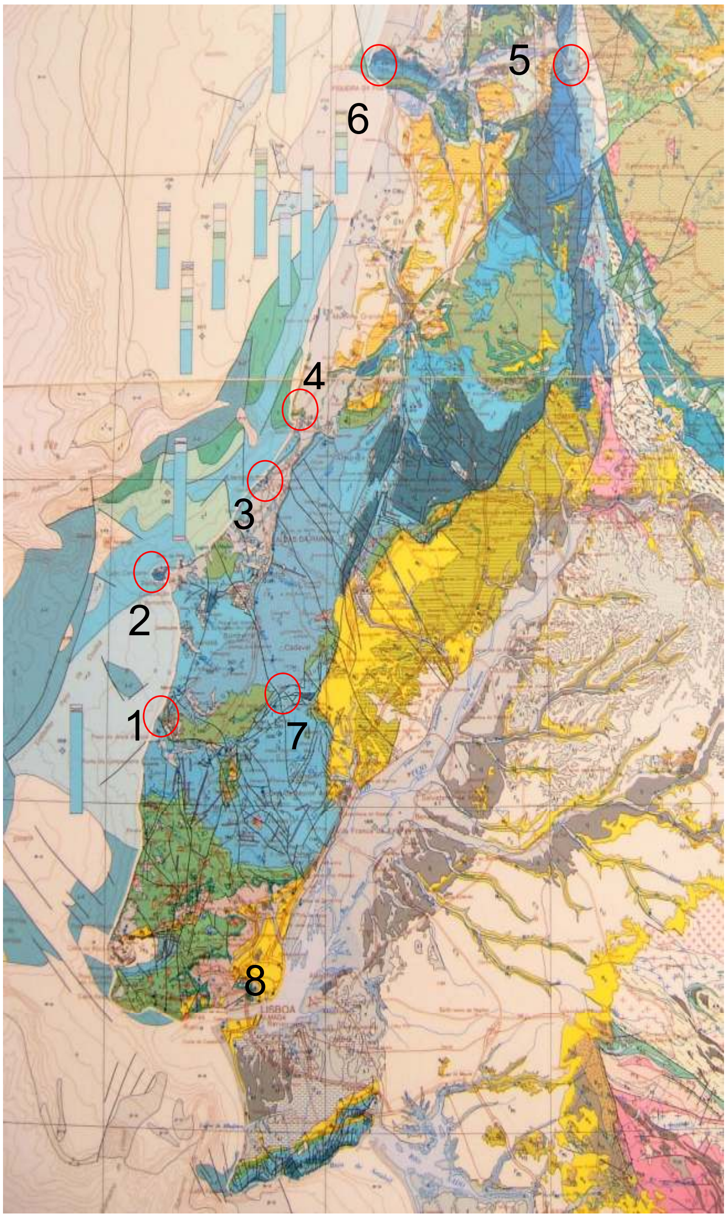

Fig. 7 – Geologic map of the Lusitanian Basin with the location of the previewed stops.

STOP 1 - SANTA CRUZ

<u>MAIN FOCUS - UPPER JURASSIC RIFTING SEDIMENTS</u>

This coastal outcrop presents upper Jurassic sediments related to the second rifting event, including climax related Kimmeridgian marls, next to a diapir wall (Fig 8 B; C). These sediments are incised by a northeastward submarine flow conglomerate (Fig. 8A). Coastal and fluvial sands above record the transition to the post climax phase.

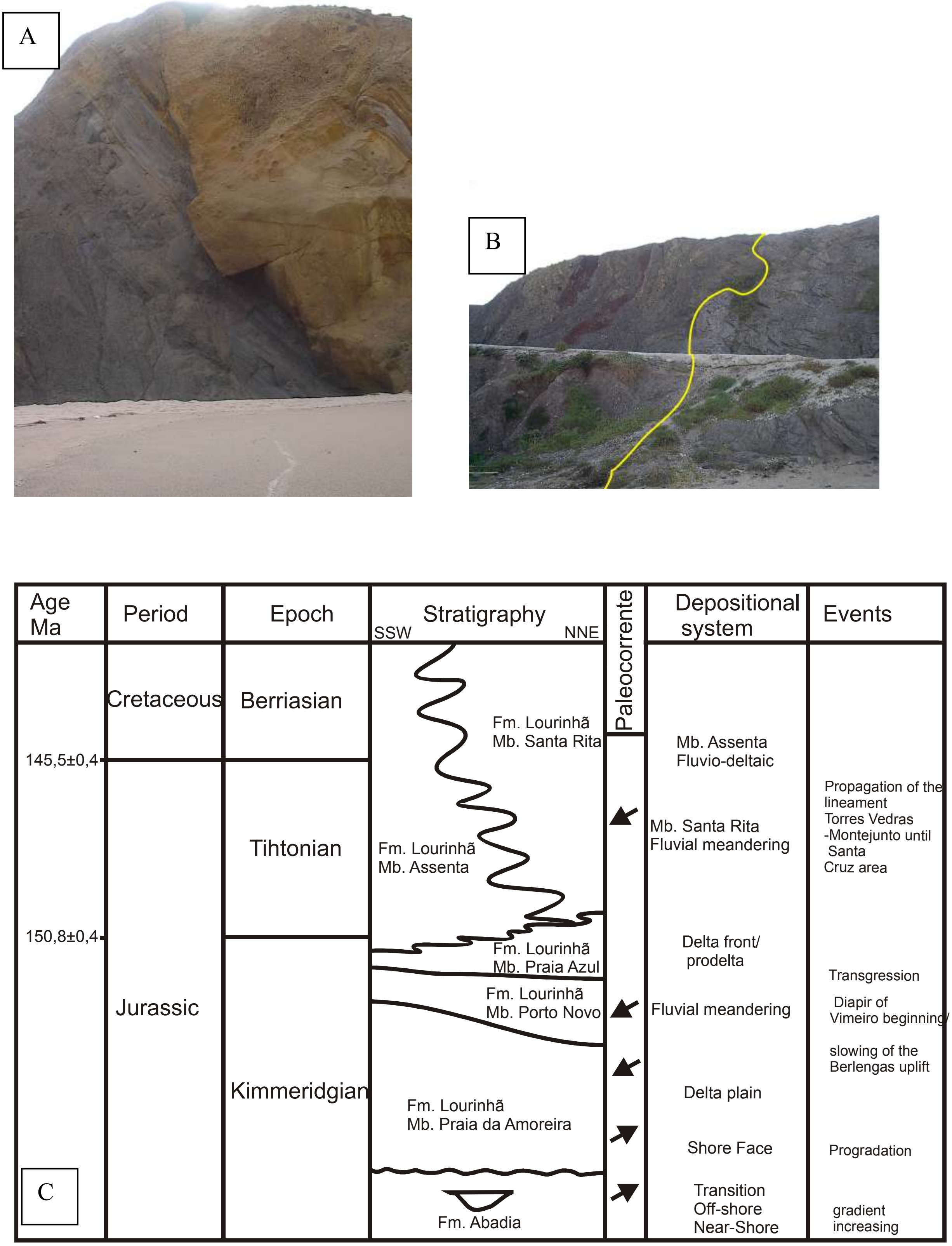

Fig. 8 – Santa Cruz stop. A: The Abadia Fm marls covered by a submarine channel. B: The contact (yellow line) of the Abadia Fm with the diapir wall. C: A general stratigraphic scheme of Santa Cruz region.

STOP 2 **– PENICHE**

<u>MAIN FOCUS - SAG INTERVAL OF THE 1ST RIFT. HIGH TOC SEDIMENTS.</u>

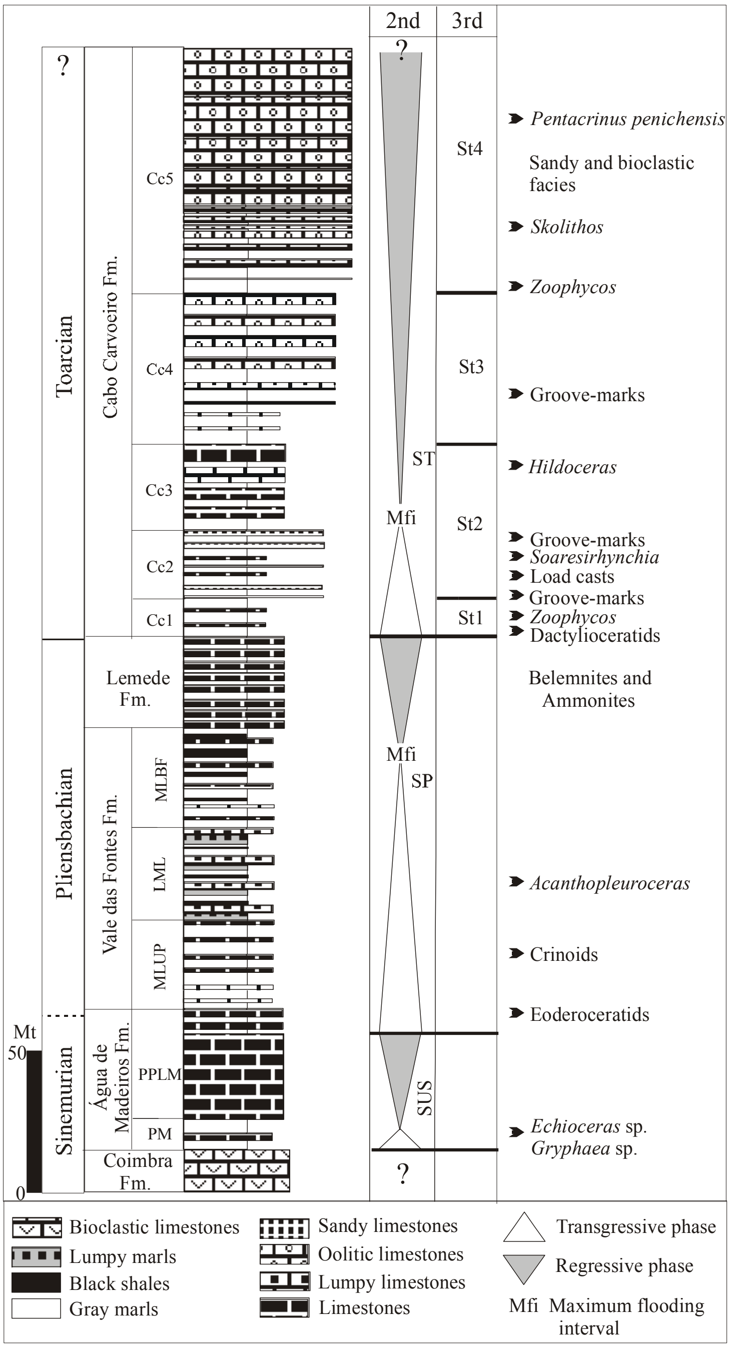

Fig. 9 – Synthetic section of Sinemurian-upper Aalenian(?) from Peniche (Duarte *et al*., 2004).

Geologic framework

In the Peniche section, some of the principal sedimentary characteristics from the carbonated Lias are observed. They allow the perception of the depositional dynamics which occurred after the deposition of "peritidal" facies that characterize the thickest part of the Sinemurian sedimentation. The base of the Pliensbaquian shows typical

hemipelagic sedimentation, occurred in a homoclinal ramp tilted in a NW direction. This depositional deepening phase, controlled by variations of the sea level, potenciated in certain periods, the accumulation and conservation of the organic matter, an event that is pointed out as a hydrocarbons generator.
Contrarily to the observed in all the other locations of the basin, the Toarcian succession shows, in Peniche, a great facies peculiarity of clastic nature, in close relation with the uplifting of the Berlengas hercynic block located to the west of Peniche. In fact, the vertical evolution of facies put in evidence a carbonate clastic progradational phase associated with turbiditic mechanisms (Fig. 9).

Observation

Along the peninsula cliffs we can observe a carbonated succession, that includes the interval between the Sinemurian and the Aalenian(?) (Fig. 9) which totalizes more than 450m in thickness, rich in organic matter ("black-shales").

STOP 3 – S. MARTINHO DO PORTO

MAIN FOCUS - UPPER JURASSIC RIFTING SEDIMENTS

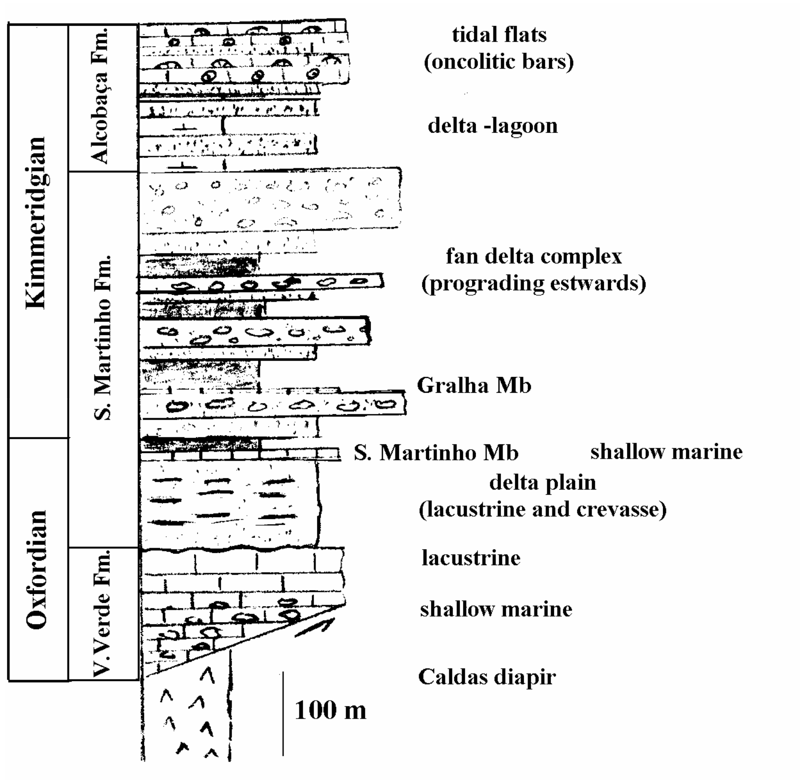

Fig.10 - Stratigraphy of late Jurassic deposits in S. Martinho do Porto region (Oxfordian and Kimmeridgian) (Pena dos Reis and Corrochano in prep).

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 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 establishes the pit domains: Peniche's block to the west (where S. Martinho is situated) is characterized by a moderate subsidence and another domain to the East (Bombarral and Ota blocks), where the subsidence is more intense.

Observations

The second upper Jurassic depositional sequence (the first one is Vale Verde Fm., Fig.10) is articulated by the first siliciclastic deposits of S. Martinho formation, that represent the sedimentation during the first phase of the rift proximal stage. The base of the sequence includes cycles of marginal lacustrine facies with edafic carbonate levels. This alluvial stage is brusquely interrupted by a marine carbonate pack denominated S. Martinho member overlying a transgressive surface (Fig. 11).
In Facho's cape cliffs we will study the progradant phases of the rest of the depositional sequences that are limited by lacustrine deposits and alluvial fans.
The alluvial deposits are constituted by heterolitic shale and sandstone deposits. The shale units have a broad band of grain sizes and contents in the clasts two extremes are distinguishable: green shales (with remains of vegetables, ostracodes and gastropods deposited in lacustrine environments).

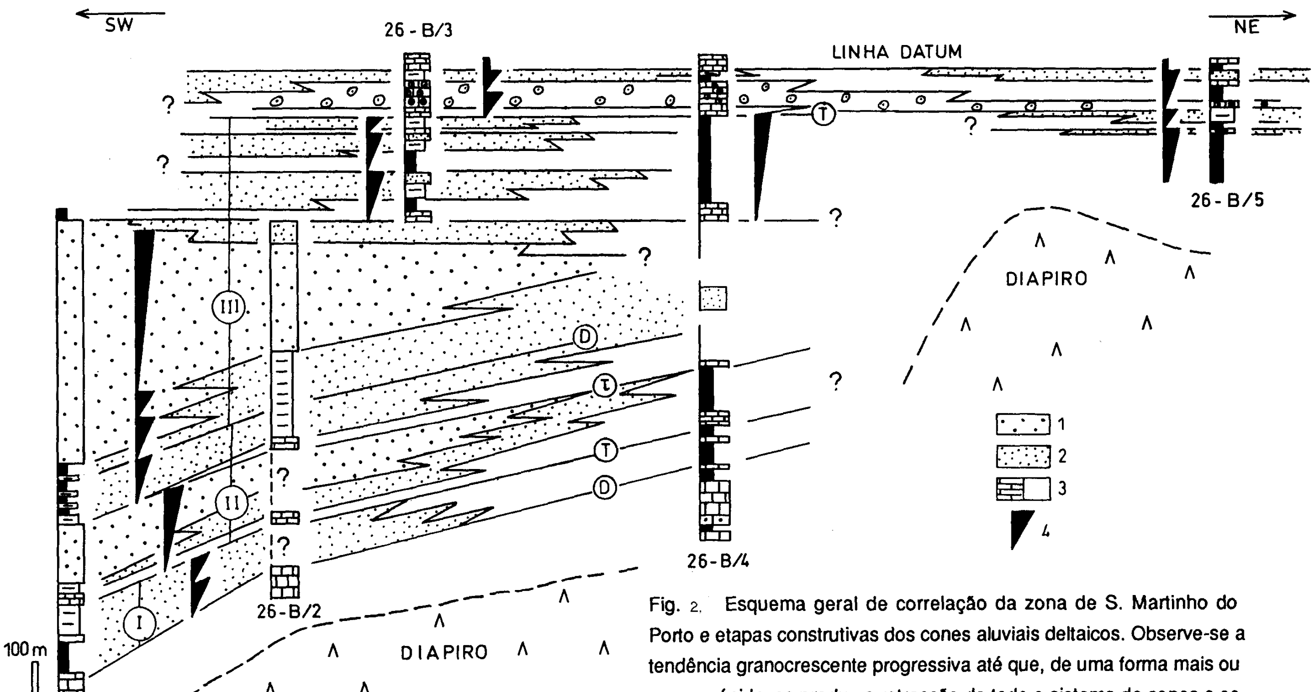

Fig. 2. Esquema geral de correlação da zona de S. Martinho do Porto e etapas construtivas dos cones aluviais deltaicos. Observe-se a tendência granocrescente progressiva até que, de uma forma mais ou menos rápida, se produz a retracção de todo o sistema de cones e se instala uma plataforma carbonatada. 1 - fácies proximais e médias; 2 - fácies distais; 3 - fácies de plataforma; 4 - arquitectura sequêncial; I, II e III - etapas construtivas; D - descontinuidades; T - superfícies transgres-sivas maiores, t - superfícies transgressivas menores.

Fig. 11 – S. Martinho region. Build up of deltaic depositional bodies and overlying shelf sedimentation (Bernardes, 1992).

***STOP 4* – NAZARÉ**

MAIN FOCUS – THE LATEST (APTIAN) UNCONFORMITY AND THE PASSIVE MARGIN SEDIMENTS.

Introduction

From late Aptian until early Campanian, defined as UBS4 (unconformity bounded sequence), the main tectonic controls include the Atlantic extension and the opening of the Bay of Biscay. The lower boundary of the UBS4 corresponds to the continental break-up unconformity subsequent to the beginning of the ocean opening in the Lusitanian Basin, in the Galicia sector. 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 causes the uplift of the 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 a NE domain of the basin change upward (containing one major retrogradation-progradation boundary) to transitional systems and to a shallow marine carbonate platform that thickens southwestwards (Carbonate Formation) (Fig. 13). 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. 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.

Observation

The outcrop of Nazaré along a major cliff (Fig. 12) shows a few hundred meters thickness of Cretaceous deposits where different formations were defined. The lowermost erosive unconformity that 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 Fm.) are covered by shallow platform limestones (Carbonatada Fm.) of Cenomanian-Turonian age. Above a brecciated endokarst could indicate the first signs of the future inversion of the basin. Lousões and Grés Sup formations of senonian age lie below a very weathered basaltic layer, that separates the UBS4 from the UBS5 (Late Campanian-Maastrichtian).

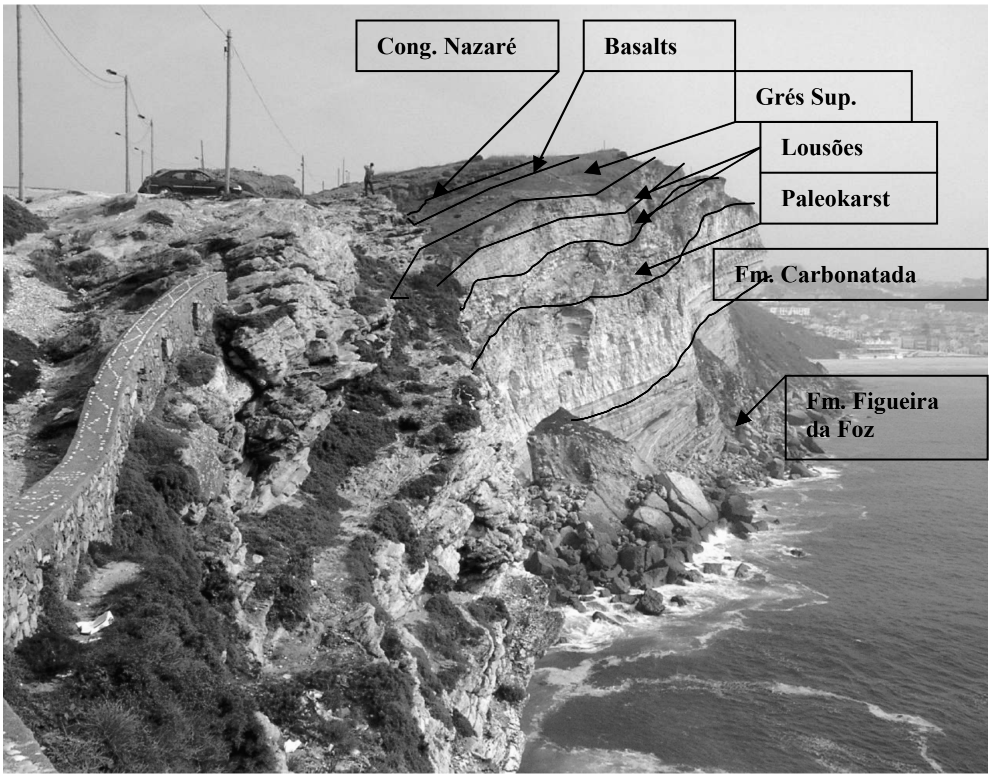

Fig. 12 – View of the Nazaré cliff. The units of the figure are visible.

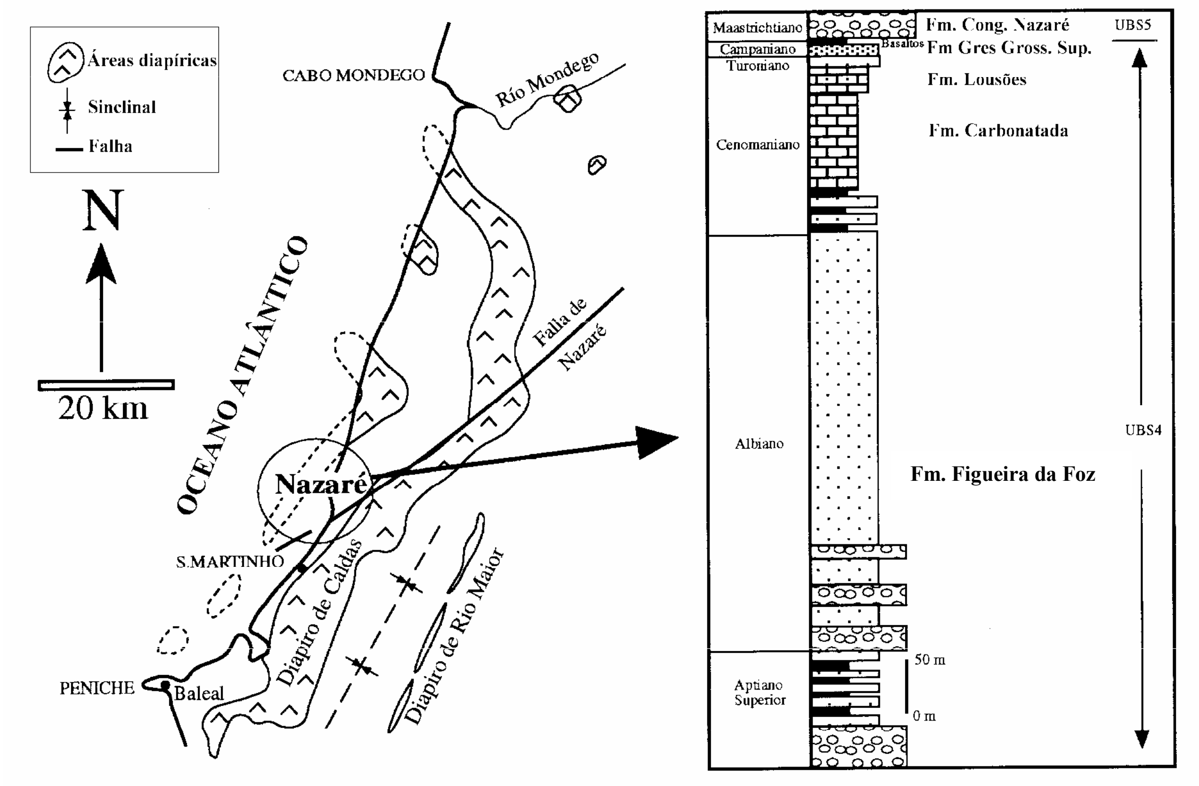

Fig.13 - Map with the major structural elements. The Cretaceous stratigraphy in Nazaré region is presented (Corrochano *et al*., 1998).

STOP 5 – **COIMBRA**

<u>MAIN FOCUS – TRIASSIC RED BEDS FROM THE 1st RIFTING EPISODE</u>

Introduction

The first rifting phase in the Lusitanian basin associated with the beginning of the fractural crustal stretching of the Pangea in the northern hemisphere began in the upper Triassic (Carnian), making use of old fractures and faults (mainly with a NNE-SSW trend) from the end of the varisc orogeny. The beginning of the sedimentation was regulated by a system of grabens and half-grabens created by the movement of blocks

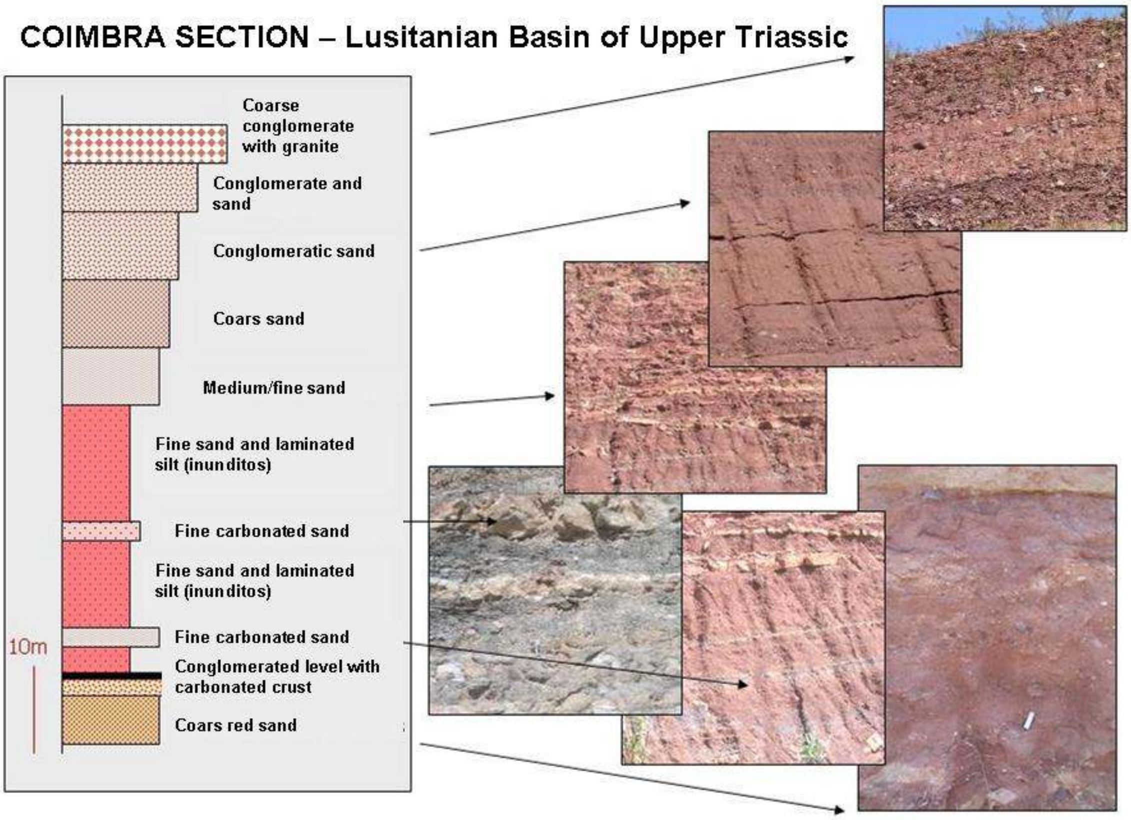

Fig. 14 - Simplified section of part of the Triassic deposits in Coimbra. The upper part of the first sequence and the first half of the second sequence are represented.

along the listric faults, that led to lateral variations in the thickness of the materials. The deposits are dominated by alluvial clastic sediments, that interfinger laterally with lutites and evaporitic deposits organized in three larger sequences (Palain, 1976).

<u>**The first sequence**</u> is formed by very coarse deposits of torrent sheets and conglomeratic-sand rivers that gradually pass to lutitic deposits with carbonates, paleosoils and salt pseudomorfoses that represent shallow lake and evaporitic conditions (Fig. 14). This succession, with two hundred meters, expresses the growing flood conditions in retrogradation geometry.

<u>**The second sequence**</u> is constituted by two hundred meters of sand deposits, with coarse intercalations, representing the installation of braided channels in a vast alluvial plain. The set evolves upwards to pelitic and dolomitic facies. They reveal an expansive tabulate geometry, in onlap and with scarce terrigenous material.

One third sequence initiates with the repetition of thin detritic sediments, sometimes arkosic that in the upper part passes to lutites and evaporites locally abundant and dolomites. This sequence is already dated from the Hetangian.

Interpretation
This sequential articulation indicates the initial existence of an alluvial environment, followed by a flooding tendency that predominates in this environment, and later on with growing periods of submersion with installation of an alluvial sheet flow succession with growing energy. This pattern can be interpreted as a response of the depositional system to the local tectonic movements, with the initial existence of some accommodation space, followed by an attenuation of this space and consequent fulfilling by flood deposits, and finally a new progressive increment of that space, with coarser alluvial filling.

STOP 6 – CABO MONDEGO

MAIN FOCUS – THE SAG DEPOSITS OF THE 1st RIFT AND THE TRANSITION TO THE 2nd RIFT

Introduction
The Cabo Mondego section is located in the Atlantic coast of Central Portugal. The section crops out along the Serra da Boa Viagem cliffs, providing exceptional exposure of a continuous record of Lower to Upper Jurassic sediments. It displays a wide range of sedimentary features, from deep marine (Toarcian–Callovian ages) to coastal and deltaic (Oxfordian-Tithonian ages) facies, resulting in a relevant set of diversified sites of geo-heritage value integrated within the same section.

Stratigraphy
The Middle Jurassic is represented by a thick series of greyish marl and limestone alternations of external marine facies. The continuity of the record, as well as the richness on the palaeontological record, especially *Ammonoidea* representatives, makes the Middle Jurassic succession of Cabo Mondego a reference section for any discussion on stratigraphic boundaries of global rank. The Toarcian-Aalenian boundary is correlative with the Aalenian Stage Boundary (GSSP); the Bajocian GSSP has been established at the Aalenian-Bajocian boundary; the Bajocian-Bathonian boundary is in a reference section for the ongoing discussion on the Bathonian GSSP definition.
The basal Upper Jurassic sediments overlay the Callovian deposits with stratigraphical discontinuity and are assigned to the Middle Oxfordian. This gap, ranging from the late Callovian to the early Oxfordian in age, is recognized over the whole of the Lusitanian Basin, at places associated to tectonic tilting and marked karstfication processes and with wider intervals of the missing record. (Fig 15).
The Upper Jurassic (Middle Oxfordian-Tithonian) section provides an excellent continuous sedimentary record of the evolution of the 2nd rifting episode. It comprises, in the lower part of the exposed section, dominant carbonate facies, usually highly fossiliferous, representing a broad range of depositional settings: lacustrine, deltaic and restricted marine. The upper part of the section shows a thick prograding siliciclastic unit: sandstones, conglomerates and claystones, mainly of deltaic nature, overlain by other terrigenous deposits of Cretaceous age. The evolution is detailed in figure 16, together with a stratigraphic scheme, where the different units are established.

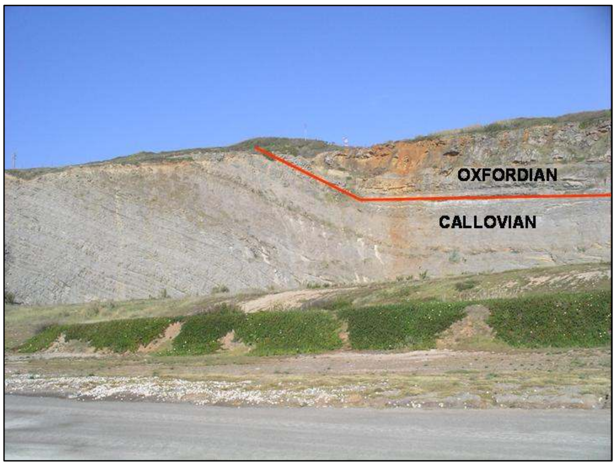

Fig. 15 – Middle-Late Jurassic transition at Cabo Mondego section. Reefal deposits (yellowish limestones) overlay greyish marly limestones of Calovian age.

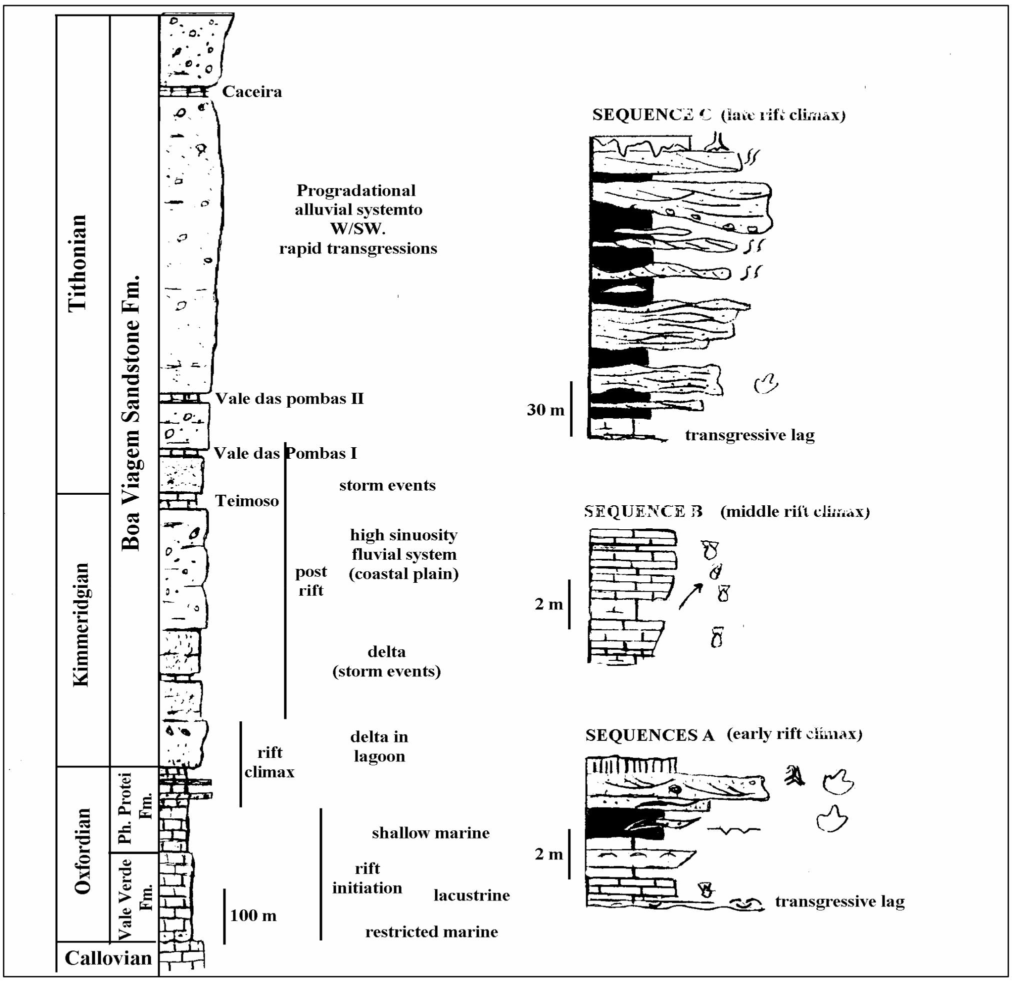

Fig. 16 – Stratigraphy and sedimentary record of the late Jurassic of Cabo Mondego. The phases and associated sequences of the 2nd rifting episode are represented; *cf* Pena dos Reis & Corrochano *in prep.*.

STOP 7 – MONTEJUNTO

MAIN FOCUS – CLIMAX OF THE 2nd RIFTING IN A BASINAL POSITION.

CRONOSTRATIGRAPHY (ATROPS e MARQUES, 1986)				FACIES	SEDIMENTARY MODELS	EVENTS	CLIMAX PHASES OF THE RIFT
KIM	Ac. Div. Hypes.	Fm.	Mb. CABRITO	*Marls *Clastics (sandstones and conglo merates, with breccia	* Shelf and basin facies * canyon-submarine fan (prox turbidites - middle) to NW	Subsidence slowing * infill and shallowing, * Incision and clastics progradation	LATE
	Plat.		Mb. CASAL DE RAMADA	*Marls and limestones. Calcareous breccia; olistolits	* Basin facies. Scree breccia and submarine fan (middle to distal turbidites) to NW	Máximum subsidence * First progradation Diferentiation of a tectonic scarp Deep carbonate sedimentation	MIDDLE
OXFO SU	Plan.		Mb. TOJEIRA	* Marls and limestones	* distal platform	Platform break-up * Subsidência speeding * Basin deepening	EARLY
	Bim.	Fm. MONTEJUNTO					

Fig. 17 – General stratigraphic framework of the Montejunto area (Pena dos Reis and Corrochano, 1998).

Introduction

Between the Caldas da Rainha alignment and the Vila Franca fault, there is a subsiding area (Fossa da Estremadura) where the activity of the structures produces three depocentres (Bombarral, Arruda and Turcifal), where about 1000m of sediments was accumulated during this stage.

The maximum subsidence occurs in the Arruda depocentre around the structural alignment of Montejunto, causing the deepening of the basin and the rupture of the carbonate platform of the Montejunto Formation, and the definition of an unconformity. Nevertheless, during this episode of low relative sea level, the sedimentation of the marls and limestones with ammonites continues in a regime of external platform controlled by NE-SW faults, and represented by the Tojeira member of the Abadia Formation. In the depocentric areas (SE) the merging of clastics, interpreted as lobules of distal turbidites arranged perpendicularly to those active faults, increases.

At the beginning of the Kimeridgian, the maximum conditions of subsidence are produced (Pena dos Reis *et al.*, 1997; Pena dos Reis and Corrrochano, 1998) (Fig. 17). At the beginning of this stage the platform restructures itself, rising blocks controlled by NE-SW directed faults, mainly next to the eastern limit of the area, where large horsts (structural horsts of Ota and Vila Franca), separated by narrow hallways, were shaped.

Observations

In this area of the basin, this stage begins with the member Casal da Ramada from the Formation of Abadia, formed by facies that are characteristic of a deep sedimentation, including marls and grey lutites with fauna that typifies the Bio zone platynota (Atrops and Marques, 1986). Depending on the active faults, strong levels of breccia and calcareous olistolits (Fig. 18) with evidences of karstification, seen as deposits of unstable slope, occur. Above, lutites and sandstones appear that correspond to deep turbidític fans (member Cabrito and higher levels from the Abadia Formation), which expose the beginning of the progradation of the siliclastics systems from SW and W, over the facies of the basin. Another source of clastics that feed the depocentre of

Arruda, are the high blocks of the faults that form the eastern banks of the sub-basins (Pragança, Montejunto and Sobral) and the sediments deriving from the Iberian Meseta.

Fig. 18 – View of the boundary between the Montejunto carbonate platform and the Abadia turbiditic border. Large blocks on the left are olistolits.

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