



CIMP Faro'09

II Joint Meeting of Spores/Pollen and
Acritarch Subcommissions

**Palynostratigraphy contributions to
understand the Southwest Portugal
and Algarve Basin Geology, PORTUGAL**

Post meeting Field-trip
23-24 September 2009



UALG, Faro, PORTUGAL | 23-24 September 2009

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FOREWORD

The geology of the Algarve can be divided in two major units, the Upper Palaeozoic Variscan basement of the South Portuguese Zone, and the Meso-Cenozoic sedimentary rocks of the Algarve Basin. Nowhere else in Portugal this geological partition is so well established as in the Algarve, affecting not only the shape of the natural landscapes but also influencing some human aspects, as the use of soil for agriculture and the use of stones for construction.

This field trip follows the line adopted in previous field trip meetings organized by this team (CIMP LISBON'07 and the VIII International Meeting of IGCP Project 421) and the proposal of the organization was suggested by several colleagues during the CIMP meeting at the XII IPC in Bonn in 2008. The challenge was accepted by the team (again....!!) and it comes out the II joint Meeting of Spores/Pollen and Acritarchs Subcommission, CIMP Faro'09.

The field meeting will cover the key outcrops of the Upper Devonian to Carboniferous age that form the Southwest Domain of the South Portuguese Zone. Here we will contact with its particular geology and palynology. Although, the focus of this meeting is the palynology of the Palaeozoic, the second part of the field trip will be dedicated to the geology and palynology of the Algarve Basin, an area that is giving the first steps in the University of Algarve and LNEG. We are sure that this programme will be of major interest and will motivate discussions and change of views among the participants. Besides the scientific aspects, there will also be opportunities to appreciate the varied landscapes of the Algarve and to contact with its people and culture.

The editors of this guide and the field trip leaders are grateful and express their sincere thanks to the institutions that accepted to cooperate in this meeting. Special thanks are due Prof. Tomasz Boski, director of Centro de Investigação Marinha e Ambiental (CIMA), for support and making possible this meeting. The Universidade do Algarve and LNEG (Laboratório Nacional de Energia e Geologia - Geological Survey), provided all the facilities during the preparation of the meeting and field guide. Fundação para a Ciência e a Tecnologia (FCT) kindly made available financial support for publishing this field guide. The editors of this guide also want to express their sincere thanks to all colleagues who accepted to help in this meeting: Filipe Barreira for the conception of the design, Bruno Rodrigues, Nuno Vaz and Gilda Lopes for all the logistic and technical help.

The research carried out by J. Tomás Oliveira, Zélia Pereira and Paulo Fernandes is supported by FCT research projects PYBE (POCTI/CTE-GIN/56450/2004) and Hydrocarbon Source Rock Potential of the Algarve Basin - Southern Portugal (PTDC/CTE-GEX/72694/2006). The palynostratigraphic research of the Algarve Basin is being carried out by Marisa Borges PhD project (SFRH/BD/40428/2007) funded by FCT.

Bem-vindos ao Algarve

The Organizing Committee

September 2009

GEOLOGICAL MAP OF PORTUGAL

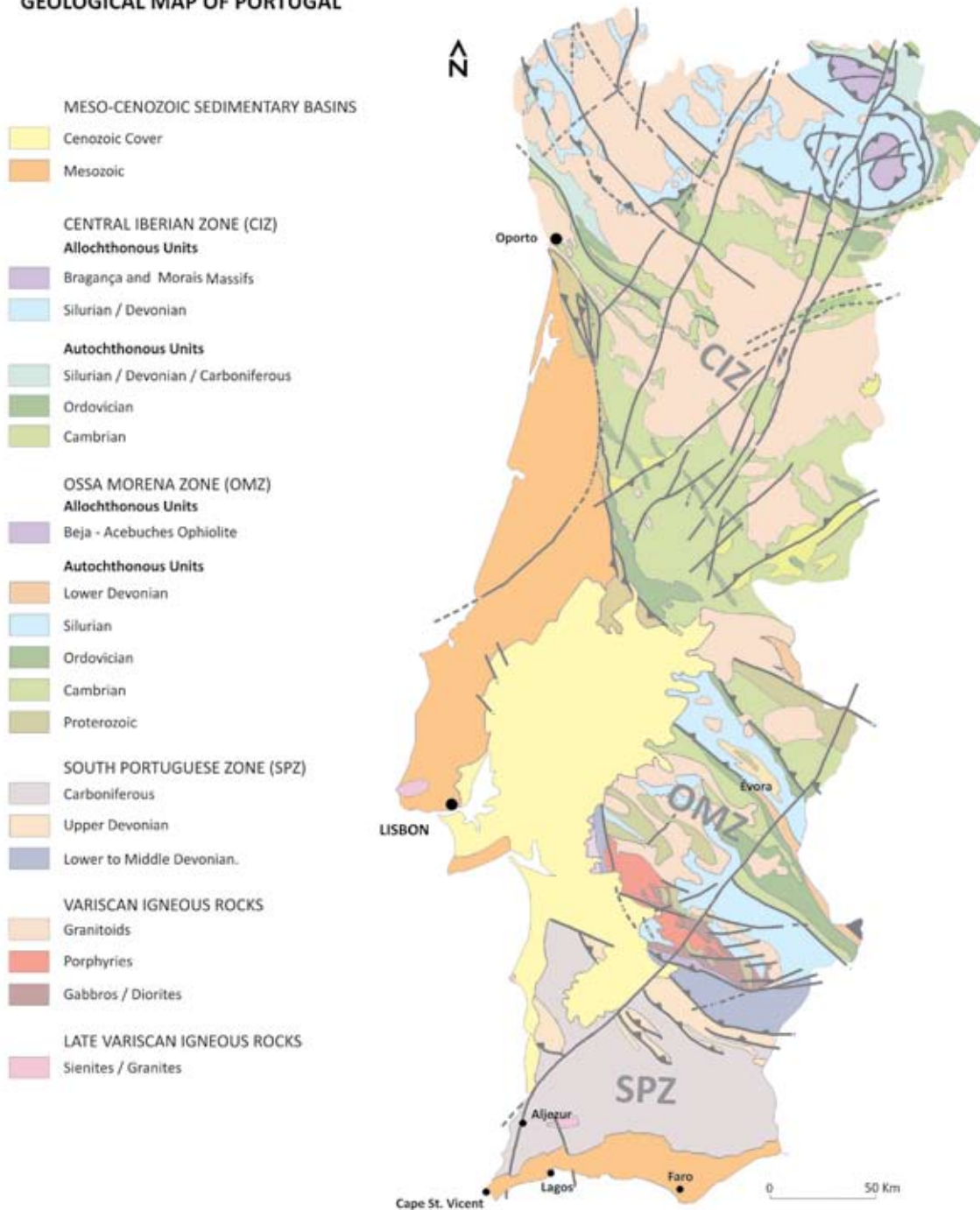


Fig. 1 Geological Map of Portugal (IGM 1998) with location of the main localities.

FIELD TRIP PROGRAMME

The field trip is subdivided in two days, the schedule programme and the main localities are presented in **Fig. I** and **Tab. 1.**:

1ST DAY | 23 SEPTEMBER

The Carrapateira Section

2ND DAY | 24 SEPTEMBER

The Telheiro Beach Variscan Unconformity and Mesozoic Algarve Basin Sections

FIELD TRIP DAYS	DATE	REGION	ITINERARY	OVERNIGHT
MEETING POINT IN FARO	23 SEPTEMBER			
FIRST DAY	23 SEPTEMBER	CARRAPATEIRA	FARO > ALJEZUR	ALJEZUR
SECOND DAY	24 SEPTEMBER	SAGRES	ALJEZUR > SAGRES > LUZ > FARO	FARO

Tab. 1 General schedule of the field trip.

GEOLOGICAL AND PALYNOLOGICAL BACKGROUND

The Portuguese territory can be divided into a Variscan substrate and Meso - Cenozoic sedimentary basins bordering the Atlantic coast. The Variscan substrate represents the southwestern portion of the Hesperian Massif, a fundamental piece of the European Variscides.

Long ago, Lotze (1945) recognized several distinct paleogeographic zones within the Hesperian massif, i. e. Cantabrian, West Asturian- Leonese, Central Iberia, Ossa Morena and South Portuguese Zones. After some modifications (Julivert et al., 1972, Ribeiro et al., 1990) the fundamentals of these divisions still remain valid and are currently used (Fig. I).

The Algarve is the southern province of mainland Portugal and is best known in Europe for its tourist attractions, especially the golden beaches and the golf courses. However, the Algarve is not just a beautiful province of Portugal and a tourist resort it has a diverse and interesting geology that marks profoundly its natural and human features.

The inland part of the Algarve, in the so-called “Serra Algarvia”, is in clear geomorphologic contrast with the littoral. The “Serra” forms a mountainous barrier that, in some way, marks the end of the Lower Alentejo plains (Fig. II). This region comprises mainly Upper Palaeozoic sedimentary rocks that, in the western part of the Algarve, extend to the littoral forming a rocky coast defined by dramatic sea cliffs. The key Devonian and Carboniferous sections that we are going to visit in this field trip are located along this part of the coast. The two major points that stand out in the “Serra”, are the Serra do Caldeirão in the

east and the Monchique Massif in the west, this last one reaches 902 metres at Fóia peak, making it the highest elevation of the Algarve. However, geologically speaking the Monchique Massif is a new feature, consisting of a pluton of alkaline igneous rocks that intruded the Upper Palaeozoic rocks during Late Cretaceous times (Terrinha et al., 2006).

South of the “Serra” is the Mesozoic Algarve Basin that comprises essentially carbonate rocks, and defines a region locally known as the “Barrocal”. The limestone lithologies of this region, form gentle elevations whose axes are aligned in an east-west strike, extending from Cap Saint Vincent to the Guadiana River on the Portuguese-Spanish border. The carbonate nature of the “Barrocal” together with ideal climatic conditions, promoted the development of karst structures that can be observed throughout this region. In the western part of the Algarve Basin the Mesozoic successions outcrop superbly along the sea cliffs from Cap Saint Vincent to Lagos. In this region we are going to visit some key coastal sections that summarise part of the geology of the Algarve Basin.

Sea cliffs of Miocene bioclastic limestones form the part of the Algarve coast that extends from Portimão to Albufeira. The conjugated action of karsification and littoral erosion, sculptured here one of the most beautiful coastal sceneries of the Algarve, with grottos, sinkholes and sea stacks, popularised in the typical tourist postcards of the Algarve.

Another remarkable geomorphologic feature of the Algarve is the “Ria Formosa”. The “Ria” con-

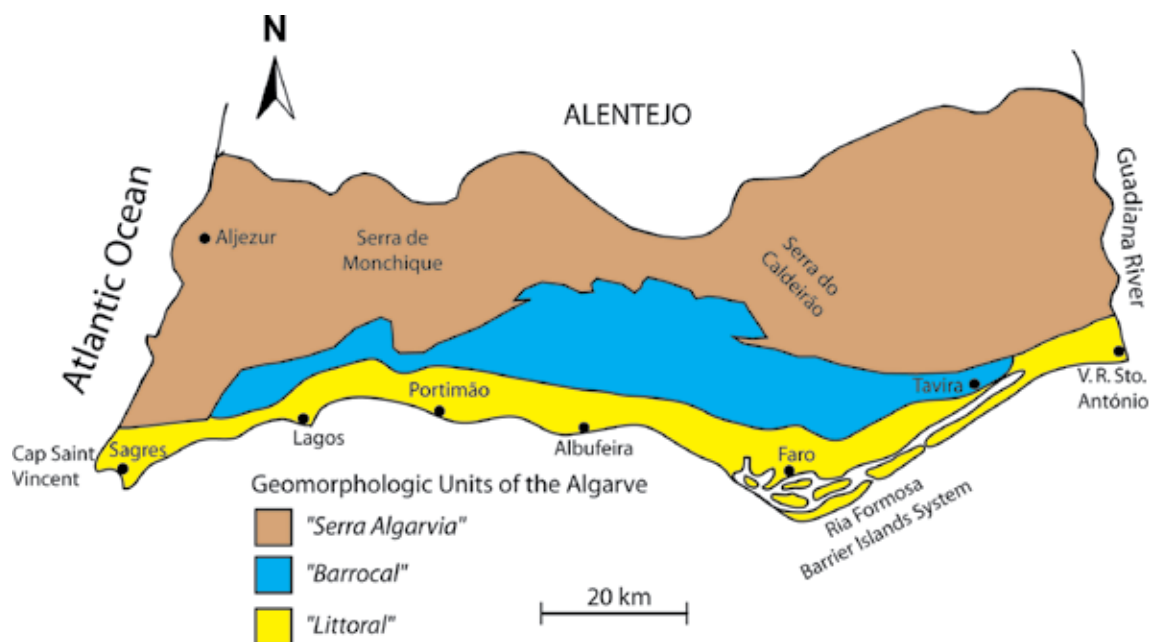


Fig. II General location of the Geomorphologic Units of the Algarve (Dias, 2001).

sists of a system of barrier islands, which associated lagoons, tidal flats and inlets that develop from Faro to Tavira (Fig. II). This is a highly dynamic geologic system that is of vital importance for the local ecology (nursery for fishes, resting spot for migrating birds) and economy (fisheries, sea salt production, tourism).

The first part of the field trip is focused in the Southwest Sector (Carrapateira Region) of the South Portuguese Zone geology, with particular emphasis on the palynostratigraphy research.

The detailed study of the Bordeira and Aljezur anticlines allow the identification of eighteen Miospore Biozones (Pereira, 1999; Pereira et al., 2008).

The second part will focus on the sedimentary cover of the Algarve Basin. The Algarve Basin is one of the sedimentary basins that developed during the break-up of Pangaea and the formation of the Central Atlantic Ocean during Mesozoic times.

The study of the biostratigraphy of the Algarve Basin started with the pioneer work of Choffat (1887). Following this study, the lithostratigraphic units were dated by macrofossils (ammonites) and microfossils (foraminifera, ostracods, angiosperm pollen and calcareous algae) (Rocha, 1976;

Palain, 1976; Ruget, 1973; Azerêdo et al., 2003; Ramalho, 1972-1973; Rey, 1986; Berthou et al., 1983; Correia, 1989; Cabral, 1995; Heimhofer et al., 2005).

Standard palynological laboratory procedures were employed in the extraction and concentration of the palynomorphs from the host sediments (Wood et al., 1996). Laboratory preparation techniques involve the use of hydrochloric and hydrofluoric acids to remove the carbonates and silicates content of the clastic sediments. The slides were examined with transmitted light, per BX40 Olympus microscope equipped with an Olympus C5050 digital camera facility. All samples, residues and slides are stored in the Department of Geology, LNEG (Geological Survey). The miospore biozonal scheme used in this work follows the standard Western Europe Miospore Zonation as explained (after: Clayton et al., 1977; Clayton, 1996; Clayton et al., 2003; Higgs et al., 1988; Higgs et al., 2000; Maziane et al., 1999; Owens, 1996; Owens et al., 2004; Streel et al., 1987; Streel, 1996). The presence of very consistent local miospore assemblages in the latest Devonian and Carboniferous of the South Portuguese Zone led to the introduction of a small modification in this scheme.

FIRST DAY, 23th September 2009

The Carrapateira Section

Leaders: J. Tomás Oliveira, Zélia Pereira - LNEG
and Paulo Fernandes - UALG

ROAD LOG

- Start from Faro at 9 AM, following the motorway A22 in the direction to Lagos, then the road Lagos to Aljezur. In Aljezur we will take the road Aljezur to Sagres and to the first stop in Pedra Ruiva.

- Aljezur is a small market town in two halves, dominated by the ruins of its hilltop Moorish Castle from which there are fine views over the surrounding countryside. It was originally settled by the Moors in the 10th century and finally conquered by Christian forces in 1246. The 13th century octagonal castle is noteworthy. The town was partly destroyed during the big earthquake of 1755. The oldest surviving building, apart from the castle, is the Misericórdia Church built in the 16th century and rebuilt after the 1755 earthquake. The newer half of the town is separated from the older by a fertile river valley. There are several really spectacular, unspoilt beaches in the vicinity. The most accessible are Amoreira, Monte Clérigo and Arrifana.

- To the east see an excellent view of Monchique Serra (sierra, mountain).

Serra de Monchique is the highest elevation in South Portugal, reaching 902 m at Pico da Fóia, from where a magnificent view of part of the Algarve province can be taken. The altitude, Atlantic

winds and relatively high rainfall (around 1,000 mm/year) originate a particular type of forest cover, which includes pine trees, cork trees, chestnut trees, acacia trees and the exotic arbustive tree whose fruits are used to prepare the famous spirit “medronho”.

The Monchique hill core is composed of peralkaline intrusive rocks, with dominant nepheline syenites, of Late Cretaceous age. This intrusion is also the type locality for the “Monchiquite”, a nepheline-rich lamprophyre.

- Road Aljezur - Sagres: the road marks the eastern limit of the Costa Vicentina Natural Park. Throughout the park excellent geological exposures along the coast, as well as endemic flora and fauna can be appreciated.

- Geological Stop 1 south of Alfambras village, to observe the quartzites of the Tercenas Formation.

- In the road, after 5 km of unpaved road, we reach the Pedra Ruiva sections (Stop 2)

- Back to the road Aljezur - Sagres and after a 4.6 km route along an unpaved road arriving to the Murração beach where Stop 3 begins.

- Concluded this visit, return to Aljezur.

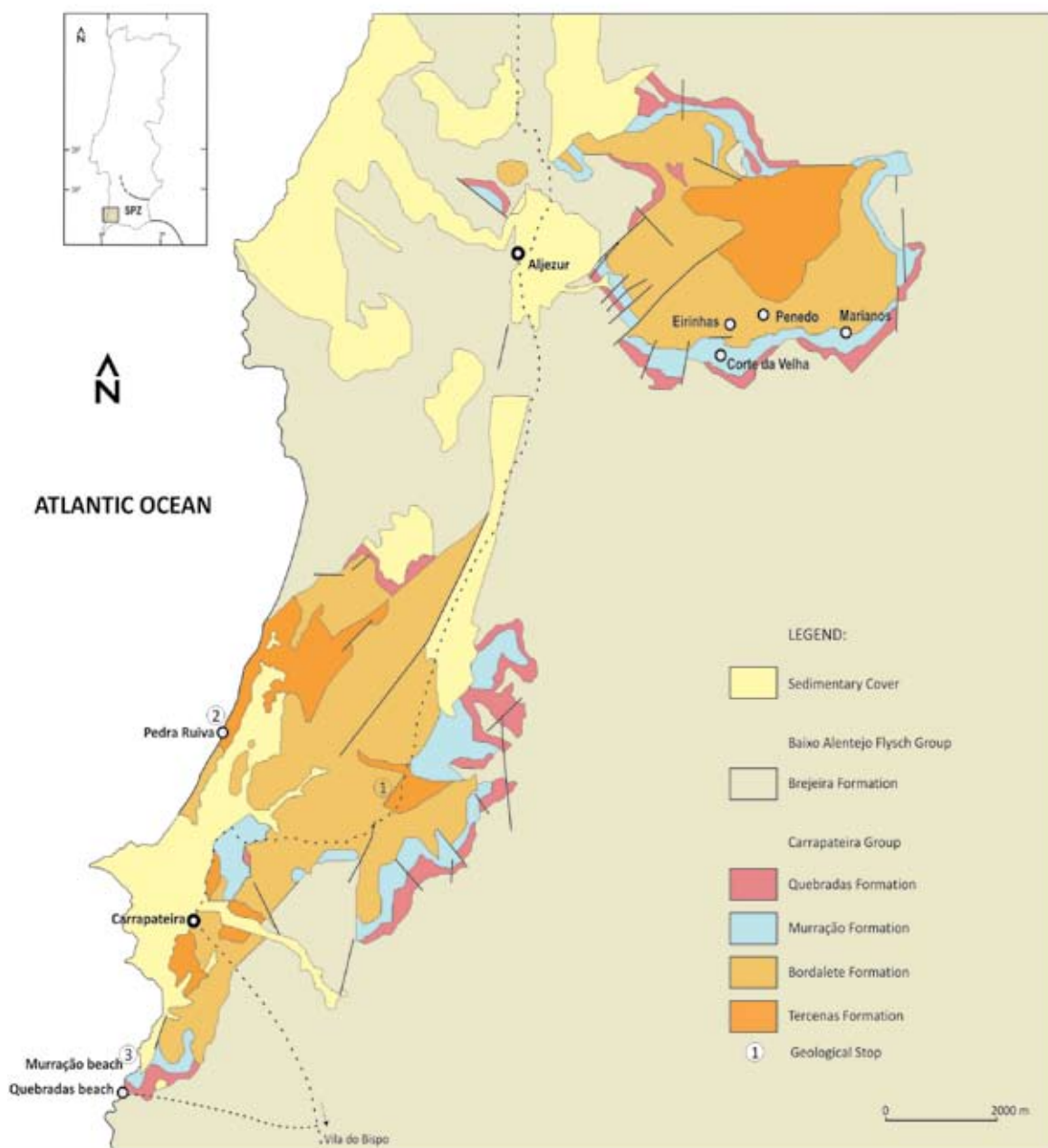


Fig. 1 Palaeozoic Geology of Southwest Portugal (Adapt. Oliveira et al., 1990).

THE PALEOZOIC STRATIGRAPHY OF SOUTHWEST PORTUGAL DOMAIN, SOUTH PORTUGUESE ZONE

Geological introduction

The Paleozoic geology of Southwest Portugal Domain (Fig. 1) is dominated by the Aljezur and Bordeira Anticlines and surrounding turbidites of the Brejeira Formation. The geology of both anticlines share the same fundamental characteristics, i. e., a shallow water clastic basement of late Devonian (Famennian) age, a mud/carbonate succession forming the Carrapateira Group of Tournaisian to middle Bashkirian age, and the overlying turbidites of the Brejeira Formation dated as lower Bashkirian to late Moscovian. The lithostratigraphic units of the Bordeira Anticline and the main sedimentary features are summarized in Fig. 2.

Tercenas Formation

In the Bordeira Anticline this unit was divided and mapped into the Barranco do Velho Member, composed of heterolithic sandstone/shale facies, and the overlying Monte Novo Member forming a 30 m thick sequence of sandstones (Ribeiro et al, 1987). More recent work (Oliveira, 1990; Moreno et al, 1996) suggests that the lithological succession incorporates two main coarsening upward sequences of sandstones and heterolithic facies (Fig. 2). This vertical arrangement, the sedimentary structures of the sandstones and bed geometry indicate tidal to nearshore sedimentation, probably linked to two transgressive/regressive pulses. In the Aljezur Anticline, the Tercenas Formation shows similar sedimentological features but no lithological divisions have been made here. The unit yielded the following faunal assemblages

(Oliveira et al, 1985; Pereira et al, 1995; Korn, 1997; Pereira, 1999):

- Ammonoids: *Cymaclimena* sp., *Cyrtoclymenia* sp., *Lissoclymenia* sp., *Linguaclymenia similis* Munster, *Linguaclymenia clauseni* Korn & Price, *Acutimitoceras* sp.

- Brachyopods: *Rugosochonetes* sp., *Syringothiris* sp., *Spiriferacea* sp.

- Miospore Biozones: *Retispora lepidophyta* - *Verrucosisporites nitidus* (LN) and the *Vallatisporites verrucosus* - *Retusotriletes incohatus* (VI) Biozones of Western Europe and South Portugal (see Fig. 3).

The ammonoid faunas indicate the late Famennian and brachyopods may reach the lower Tournaisian. Miospore biozones confirm the macro fauna age.

Carrapateira Group

Bordalete Formation

This is composed of dark shales, thinly-bedded siltstones and interbedded thin layers, lenses and nodules of calcisiltstones. At the upper levels the shales and thin bedded siltstones show pyritised burrows and develop large scale cross bedding. Its estimated thickness reaches 200 m. The unit provided fossils of (Oliveira et al 1985, Pereira et al 1995; Korn, 1997; Pereira, 1999):

- Ammonoids: *Becanites algarbiensis*, *Eocanites no-*

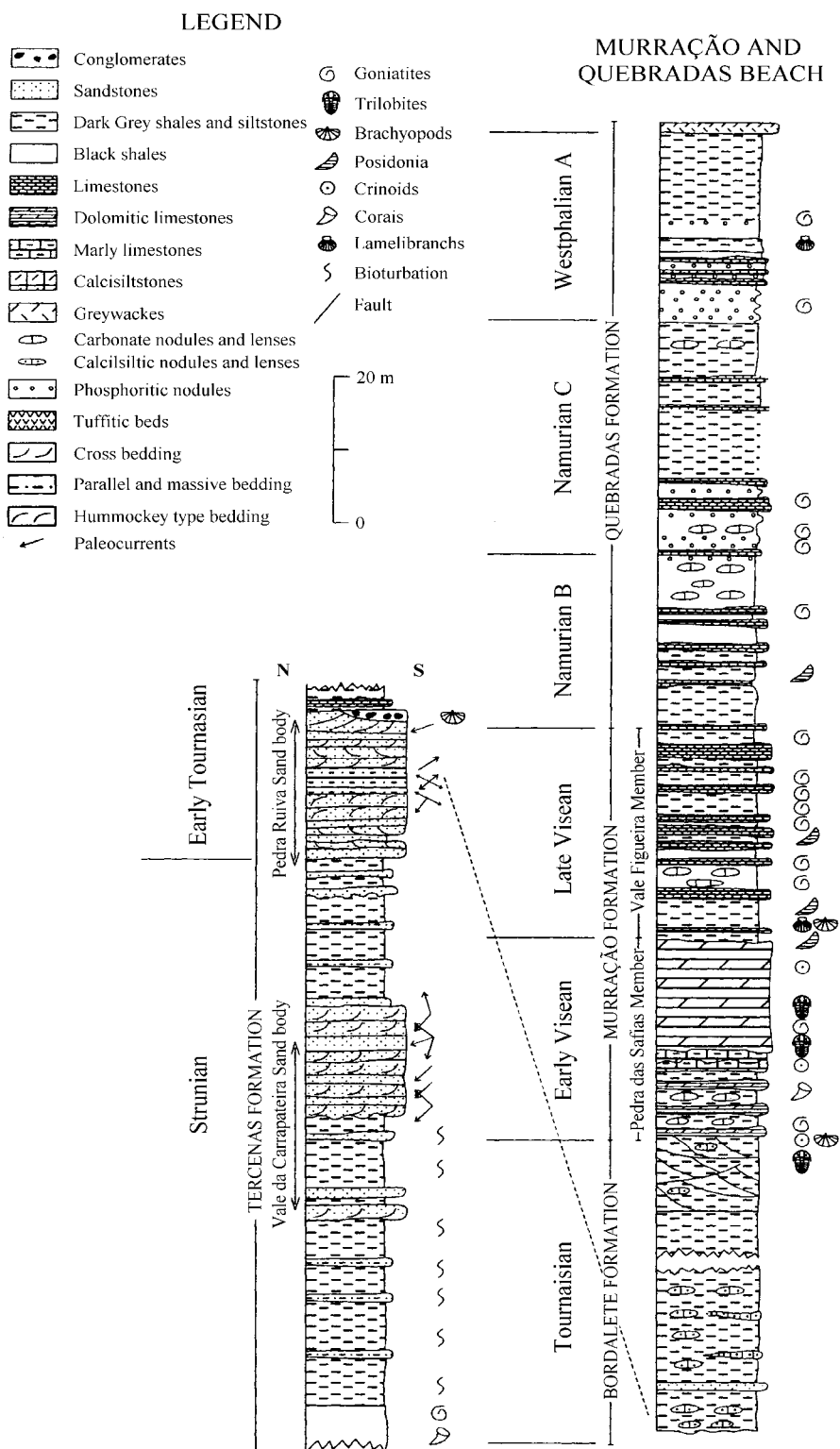


Fig. 2 Synthetic stratigraphic column of the Bordeira Anticline (adapt. From Oliveira, 1990).

dosus, *Eocanites* sp., *Muensteroceras* sp., *Peryclis* cf. *blairi*, *Zadelsdorfia* sp.

- Trilobites: *Archegonus* (*macrobole*) *drewerensis* *latipalpebrata*, *Tawstockia* *nasifrons*.

- Miospore Biozones: *Vallatisporites verrucosus* - *Retusotriletes incohatus* (VI), *Kraeuselisporites hibernicus-Umbonatisporites distinctus* (HD) and *Spelaetriletes pretiosus* - *Raistrickia clavata* (PC) Biozones.

The ammonoids and trilobites indicate middle to late Tournaisian age. The determined miospore biozones date the Tournaisian. Of the miospore biozones that date the entire Tournaisian only the uppermost CM Biozone (*Auroraspora macra-Schopfites claviger*) is missing, probably due to the presence of an hiatus.

The lithological, sedimentological and faunal characteristics of this formation suggest deposition in a quiet marine environment, probably in the outer shelf. In the Aljezur Anticline the unit has practically the same lithological composition and age.

Murração Formation

This unit has been divided into the Pedra das Safias and Vale Figueira Members (Oliveira et al., 1985), that are only recognized in the Bordeira Anticline.

The Pedra das Safias Member is made up of dark shales, bioclastic dolostones and marly lime-

stones, with a thickness of about 30 m. Faunas of crinoids, corals (*Saleelasma* sp.), trilobites (*Liobole glabra* cf. *botkei*, *Spinibole* sp., *Archegonus* (*philibole*) sp.) and rare goniatites (*Merocanites* sp.) indicate an early Visén age. The member stratotype will be visited during the field trip. No palynomorphs were recorded from the stratotype. However the biozones *Lycospora pusilla* (Pu) and *Knoxisporites triradiatus* - *K. stephanephorus* (TS), were identified in the basal Murração Formation in the Aljezur Anticline.

The Vale Figueira Member consists of alternations of bioclastic dolostones, and dark and pyritic shales. The type section has recently been revised in which the ammonoids (Korn, 1997) and palynomorphs (Pereira, 1999) are concerned indicating the upper Visén age.

The ammonoids are assigned to the Go Biozone. Miospore Biozones identified belong to the locally defined *Raistrickia nigra* - *Propriisporites laevigatus* (NL), *Savitrissporites nux* (SN), and also the *Bellisporites nitidus* - *Reticulatisporites carnosus* (NC) Biozone all indicating the upper Visén (see detailed description of Stop 3).

In the Aljezur Anticline, the Murração Formation members could not be fully recognised due to the fact that the upper part of the unit is, in general, more shaly than in the Bordeira Anticline.

The Murração Formation has been laid down in an open and distal carbonate/mud mixed platform, its more shaly character in the Aljezur Anticline suggests deepening towards the northeast.

Quebradas Formation

The dominant lithologies are dark and black pyritic shales in which bioclastic dolostone layers and lenses are interbedded. The type section has been defined in the central cliff face of the Quebradas beach (Fig. 7). Near the middle part of the type section a previously interpreted “tuffitic” layer (Oliveira et al., 1995) was re-interpreted as a debris flow (Herbig et al., 1999). Towards the upper part, levels with phosphatic nodules and laminated shales are present. In former publications (Oliveira et al, 1985; Oliveira, 1990) it was claimed that all the Namurian ammonoids biozones were represented in this unit. However, recent work (Korn, 1997) proved that only the Lower to mid Baskirian biozones are represented, suggesting a stratigraphic gap during the Serpukovian. This gap has also been found using miospore biostratigraphy (Pereira et al., 1995; Pereira, 1999), see Fig. 3.

The ammonoid biozones identified are R1a, R1c, R2a, R2b, R2c1, G1a and G2 of the lower to mid Baskirian.

Miospore Biozones identified are *Crassispora kosankei-Grumosiporites varioreticulatus* (KV) and *Raistrickia fulva* - *Reticulatisporites reticulatus* (FR).

The Quebradas Formation lithologies were probably generated in a restricted marine environment

of a mixed mud/carbonate platform, and the interbedded phosphatic nodules may well represent upwelling near its external border.

Baixo Alentejo Flysch Group

This Group comprises a southwestward prograding turbiditic succession of late Visén to late Moscovian age, which occupies more than half of the South Portuguese Zone. It is composed of three units: Mértola, Mira and Brejeira Formations. Only the latter is represented in Southwest Portugal in particular along the cliffs of the coast (Fig. 1) and will be briefly described here.

Brejeira Formation

The unit is broadly divided into two distinct sedimentological belts: one, 5 to 10 km wide, makes the transition to the Mira Formation, and is composed of decametric successions of relatively mature sandstones and interbedded shales; the other, extending southwards over a large area that includes the Bordeira and Aljezur Anticlines, is made up of immature greywackes and shales.

The unit conformably overlies the Quebradas Formation of those anticlines, but in places there are local disconformities that put in contact the turbidites with the underlying Murração and Bordaleta Formations. These disconformities are interpreted as large-scale slump scars related to syn-sedimentary tectonism. The Brejeira Formation

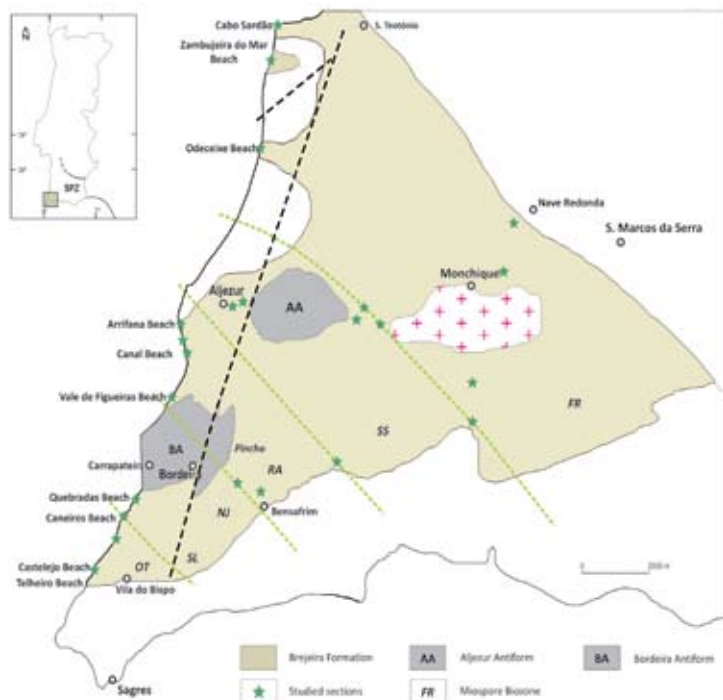


Fig. 4 Zonation of the Brejeira Formation sediments in NW-SE bands.

provided goniatites of the H, R and G biozones, which indicate a Bashkirian age. Palynological detailed work (Pereira et al, 1995) showed that the age reaches the late Moscovian. The following Miospore Biozones were identified: *Raistrickia fulva* - *Reticulatisporites reticulatus* (FR), *Triquitrites sinani* - *Cirratiradites saturni* (SS), *Radiizoonates aligerens* (Ra), *Microreticulatisporites nobilis* - *Florinites junior* (NJ), *Torisporea securis* - *T. laevigata* (ST) and *Thymosporea obscura* - *T. thiesseii* (OT) Biozones.

The base of the Brejeira Formation, in the north part of its outcrop area indicates an age similar to the Quebradas Formation, and is assigned to the FR Biozone of the middle Bashkirian. Further south, miospore assemblages are successively assigned to the SS and RA Biozones (Westphalian A) and NJ Biozone (Westphalian B) of late Bashkirian age ST and OT Biozones of the Moscovian (Westphalian C and D).

This distribution of the palynological assemblages suggest that the sediments are organised in roughly parallel NW-SE trending bands, confirming the south westward progradation of the turbidites (Fig. 4).

The Variscan tectonic deformation affected the Southwest Portugal only during the Stephanian.

Concluding remarks

Fig. 3 is a comparative biostratigraphic chart between Southwest Portugal and Western Europe.

In spite of some small differences the late Devonian and Carboniferous ammonoids and miospore biozonations agree quite well, clearly indicating that both regions were in geographic continuity and were incorporated in the same paleogeographic realm, a conclusion already postulated several years ago (Oliveira et al., 1979).

Herbig et al. (1999), presented strong arguments in favour of the existence of the widespread *Crenistria* Event in Southwest Portugal, re-enforcing so that previous interpretation.

Cronostratigraphy					Biostratigraphy			South Portuguese Zone (SPZ)	
System	Global Stage	Regional W. European Stage	Goniatites Fossil horizons SWS (Korn, 1997)		W. Europe Zones (1)	Portugal Zones (2)	Portugal index species (3)	SW Sector	
CARBONIFEROUS	Kasimovian	Stephanian			ST				
	Moscovian	Westphalian			OT	OT	<i>Thymospora pseudothiesseii</i>	Brejeira Fm.	
					SL	SL	<i>Raistrickia aculeata</i>		
							<i>Tarionia securis</i>		
			NJ	NJ	<i>Florinites junior</i>				
			RA	RA	<i>Radlizonates aligerens</i>				
	Bashkirian		G2	<i>Gastrioceras angustum</i> <i>Gastrioceras listeri</i>	SS	SS	<i>Cirratridites satumi</i>	Quebradas Fm.	
					FR	FR	<i>Dyctioidites probireticulatus</i>		
		G1a	<i>Concelloceras</i> spp.				<i>Reticulatisporites reticulatus</i>		
		R2c	<i>Bilinguities metabilinguis</i>	KV	KV	<i>Crassisporea kosankei</i>			
		R2b	<i>Marianocera hesperium</i>						
		R2a	<i>Bilinguities gracilis</i>						
		R1c	<i>Reticuloceras reticulatum</i>						
	R1a	<i>Valites kullmanni</i>							
	Serpukovian	Namurian (Lower)			SO			Lacune ?	
					TK				
			postriatum Zone		NC	NC	?		
	Visean	Visean	gracilis Zone		VF	SN*	<i>Bellisporites nitidus</i>	Murração Fm.	
			spinifer Zone		NM	NL*	<i>Savitrissporites nux *</i>		
			crenistia Zone				<i>Raistrickia nigra *</i>		
			hudsoni Zone						
			PE			TC			?
						TS	TS		<i>Knoxisporites stephanophorus</i>
						PU	PU		<i>Lycospora pusilla</i>
	Tournaisian	Tournaisian	Ga			CM	CM	<i>Schopfites claviger</i>	Lacune ?
						PC	PC	<i>Spelaetriletes pretiosus</i>	Bordalete Fm.
				BP	BP	<i>Spelaetriletes balteatus</i>			
				HD	HD	<i>Cristatisporites hibemicus</i>			
				VI	VI	<i>Cyrtospora cristifera</i>			
UPPER DEV.	Famennian	Famennian	Strunian	Wo				Tercenas Fm.	
					LN	LN	<i>Verrucosiporites nitidus</i>		
					LE	LE	<i>Indotriradites explanatus</i>		
					LL	LL			

Fig. 3 Age and correlation of the Southwest Portugal stratigraphic units, based on goniates and miospores.

(1 - Western European Miospore Zonation (CLAYTON et al., 1977; CLAYTON et al., 2003; CLAYTON, 1996; HIGGS et al., 1988; HIGGS et al., 2000; MAZIANE et al., 1999; OWENS, 1996; OWENS et al., 2004; STREEL et al., 1987; STREEL, 1996; 2 - South Portugal miospore Zonation (PEREIRA, 1999); 3 - Defined guide taxa used for the latest Devonian and Carboniferous of the South Portuguese Zone (PEREIRA et al., 2007, 2008).

GEOLOGICAL STOP 1

Tercenas Formation, Bordeira Anticline

Location: Main road from Aljezur to Vila do Bispo, south of Alfambras village (Fig. 1).

Time: 30 minutes

Breif description of the geology and palynostratigraphy

Along the main road from Aljezur to Vila do Bispo, south of Alfambras village, the lithostratigraphic units of the Bordeira Anticline crop out in several of the road cuts (Fig. 1).

One of these cuts, 1,8 km north of Bordeira village, displays thinly bedded quartzites and shales that belong to the Tercenas Formation. The quartzites show predominant massive and graded bedding and small scale cross bedding and are interpreted as distal tempestites. About 200m south of the stop locality the shales provided miospores of Strunian age (Pereira et al, 1995). The quartzites and shales develop an open antiform, which is affected by several vertical late faults with NE orientation.

On the north limb of this antiform the lower levels of the Bordaleta Formation can be observed. On the west side of the road, weathered mafic rocks of lamprophyre and dolerite composition occur.

The dolerites belong to a NE trending Mesozoic suite of which the Alentejo-Avila (Spain) mafic dike, more than 1000 km long, is the most important representative. The lamprophyres form dykes associated to the Monchique intrusion.

Westward these tempestites grade to tidal and nearshore clastic sediments (Moreno et al, 1996) particularly well exposed in the Pedra Ruiva sea cliff.



Fig . 5 Pedra Ruiva Section.

GEOLOGICAL STOP 2

Pedra Ruiva Sections, Devonian/Carboniferous boundary

Location: Pedra Ruiva cliffs

Time: 2 hours

Brief geological and palynostratigraphical description

The Pedra Ruiva section is located NE of the Pedra Ruiva Monte, in the Bordeira Anticline, outcrops near the coast in an abrupt cliff, was studied in two places, named, Pedra Ruiva and North Pedra Ruiva sections (Fig. 5 and 6).

The Tercenas Formation in the Pedra Ruiva section is made up of alternations of thin bedded layers of shales, siltstones and quartzitic sandstones, which are frequently lenticular and rippled, and are in places intensely bioturbated.

These alternations of layers grade upwards to an arenitic facies, rich in iron and manganese oxides at the top. These sandstone beds show a large variety of sedimentary structures (large scale, trough and herringbone, convolute bedding, hummocks, syndimentary folds and slumps) that indicative deposition in a tide dominate environment.

The Bordaleta Formation, in the same section, is composed of thin-bedded layers of shales and siltstones, and rare calcisiltic lenses and nodules. Centimetric thin layers of fine limestones are well exposed at the base of the unit.

No macrofaunas were recognized at this section.

However, elsewhere in the region, the lower shaly layers of Tercenas Formation provided Clymenids of Upper Famennian age and the top of the sandstones yielded reworked brachiopods and chonetacea of upper Devonian to lower Carboniferous age. Rare goniatites that indicates middle to upper Tournaisian age are preserved in nodules in the Bordaleta Formation.

The section was detailed sampled for palynostratigraphic studies. The Devonian/Carboniferous (DC) boundary can be traced quite accurately here (Fig. 6; Pereira et al., 1994).

The miospore assemblages around the DC boundary are assigned to the *Retispora lepidophyta* - *Verrucosiporites nitidus* (LN) and the *Vallatisporites verrucosus* - *Retusotriletes incohatus* (VI) Biozones of Western Europe (Higgs et al., 1988). Stratigraphically important and typical taxa are illustrated in Plates I, II and III.

Samples collected from the basal part of Tercenas formation (samples 278, 279, Fig. 6), in the facies of arenites and siltites, with small scale sedimentary structures, contain a representative LN Miospore Biozone assemblages of upper Strunian

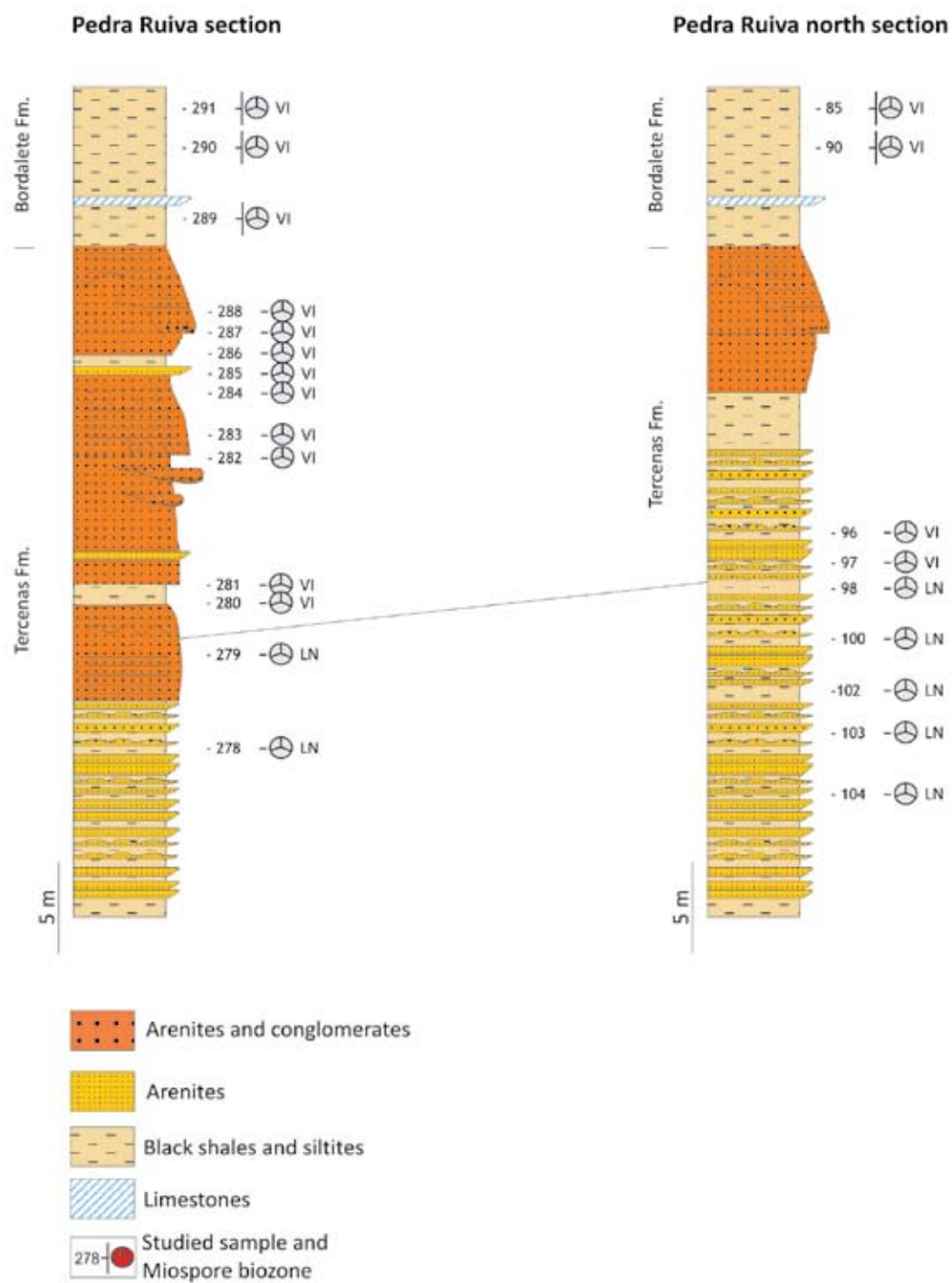


Fig. 6 Stratigraphic schematic logs studied in the Pedra Ruiva section, with palynostratigraphic results.

age. The assemblage contains the miospore species *Cristicavatispora dispersa*, *Densosporites spitsbergensis*, *Dictyotriletes fimbriatus*, *Emphanisporites annulatus*, *E. rotatus*, *Geminospora spongiata*, *Grandispora acuta*, *G. cornuta*, *G. echinata*, *Knoxisporites concentricus*, *Punctatisporites* spp., *Retusotriletes incohatus*, *Retispora lepidophyta*, *Rugospora flexuosa*, *Vallatisporites pusillites*, *V. verrucosus* and the key species *Verrucosporites nitidus*.

The assemblages recovered in samples 280 and 281 (Fig. 6) present a decrease of diversity, reflected by the absence of *R. lepidophyta* and other characteristic species present in the lower samples. Present in the assemblage are the species, *Cyrtospora cristifera*, *Punctatisporites irrasus*, *Retusotriletes incohatus*, *Vallatisporites verrucosus* and *Verrucosporites nitidus*, which indicates the basal VI Miospore Biozone of Tournaisian age. The base of VI Biozone is defined by the top of the range of the index taxon *Retispora lepidophyta* and is approximately coincident with the Devonian/Carboniferous boundary (Higgs et al., 1992).

In samples 282 to 288 (Fig. 6), recovered in the centimetric pelites interbedded in the sandstone beds, with a large variety of sedimentary structures, the assemblages of miospores recovered are very limited. These are dominated by miospores of smooth and thick exine, as *Latosporites*, *Punctatisporites* and *Retusotriletes* together with, rare *Cyrtospora cristifera*, *Vallatisporites verrucosus* and *Verrucosporites nitidus* assigned to a poorly preserved miospore VI assemblage. Rare *Retispora*

lepidophyta are present, interpreted as reworked. Acritarchs present are rare and very badly preserved and assigned to the genus *Maranhites* spp. and *Gorgonisphaeridium* spp.

An alternative but less likely interpretation of the miospore data is that the specimens of *R. lepidophyta* from samples 282 to 288 are in situ, not reworked, and that these assemblages should therefore be assigned to the LN Biozone. In this case, assemblages 280 and 281 would represent highly anomalous LN Biozone assemblages, lacking not just *R. lepidophyta* but also associated late Devonian taxa such as *Diducites* spp. and *Vallatisporites pusillites*. The presence of *Cyrtospora cristifera* in assemblages 280 and 281 leads further support to the assignment of these assemblages to the VI Biozone.

Samples studied from the Bordaleta Formation (289-291, Fig. 6), present a typical VI Miospore Biozone of lower Tournaisian age assemblage, that contain moderately preserved species of *Cyrtospora cristifera*, *Crassispora catenata*, *Endosporites micromanifestus*, *Knoxisporites* cf. *triradiatus*, *Punctatisporites irrasus*, *Pustulatisporites dolbii*, *Raistrickia variabilis*, *Retusotriletes incohatus*, *Secarisporites* sp., *Tumulispora rarituberculata*, *Vallatisporites verrucosus* and *Verrucosporites nitidus*.

The North Pedra Ruiva Section (Fig. 6) exposes the Tercenas and Bordaleta Formations. For base to top, samples yielded typical Tercenas

Formation LN Miospore Biozone assemblages of upper Strunian age (100-104). The most common species are: *Cristicavatispora dispersa*, *Densosporites spitsbergensis*, *Dictyotriletes fimbriatus*, *Geminospora spongiata*, *Grandispora cornuta*, *G. echinata*, *Hymenozonotriletes explanatus*, *Knoxisporites concentricus*, *Punctatisporites* spp., *Retusotriletes crassus*, *R. incohatus*, *Retispora lepidophyta*, *Rugospora flexuosa*, *Vallatisporites pusillites*, *V. verrucosus* and the key specie *Verrucosisporites nitidus*.

Most of the samples studied contain rich assemblages of acritarchs and prasinophytes (e.g. *Cymatiosphaera* sp., *Chomotriletes vedugensis*, *Duvernaysphaera tessella*, *D. stellata*, *D. tenuicingulata*, *Gorgonisphaeridium ohioense*, *G. plerispinosum*, *G. solidum*, *Horologinella horologia*, *Maranhites britoi*, *M. mosesii*, *M. perplexus*, *Multiplicisphaeridium ramusculosum*, *Navifusa bacillum*, *Onondagella* sp., *Pterospmella euripio*, *Stellinium comptum*, *S. micropolygonale*, *Unellium piriforme*, *Umbellaspheeridium saharicum*, *U. deflandrei*, *Veryhachium pannuceum*, *V. trispinosum* and *Winwaloeusia repagulata*.

The base of the VI Miospore Biozone was identified in samples 96 and 97, which show a reduction in diversity. Present are for the first time, *Cyrtospora cristifera* together with *Puctatisporites irrasus*, *Retusotriletes incohatus*, *Vallatisporites verrucosus* and *Verrucosisporites nitidus*.

Samples 85 and 90, collected in the basal part of the Bordaleta Formation, present a moderately

to well preserved assemblages assigned to the VI Miospore Biozone, containing *Convolutispora* sp., *Cyrtospora cristifera*, *Endosporites tuberosus*, *Puctatisporites irrasus*, *Raistrickia variabilis*, *Retusotriletes incohatus*, *Secarisporites* sp., *Tumulispora rarituberculata*, *Vallatisporites vallatus*, *V. verrucosus* and *Verrucosisporites nitidus*.

In both sections studied, the base of the upper sandstone body corresponds to the boundary between LN and VI Biozones (Pereira et al., 1994; 1999) and is approximately coincident with the DC boundary. The age of Tercenas Formation is, therefore assigned to the late Strunian to early Tournaisian, based on palynomorph evidence. The Bordaleta Formation is dated of lower Tournaisian age in the Pedra Ruiva Sections, showing stratigraphic continuity with the underlying Tercenas Formation. These data complete previous determinations and do not confirm the existence of a basal hiatus (Oliveira, 1983).

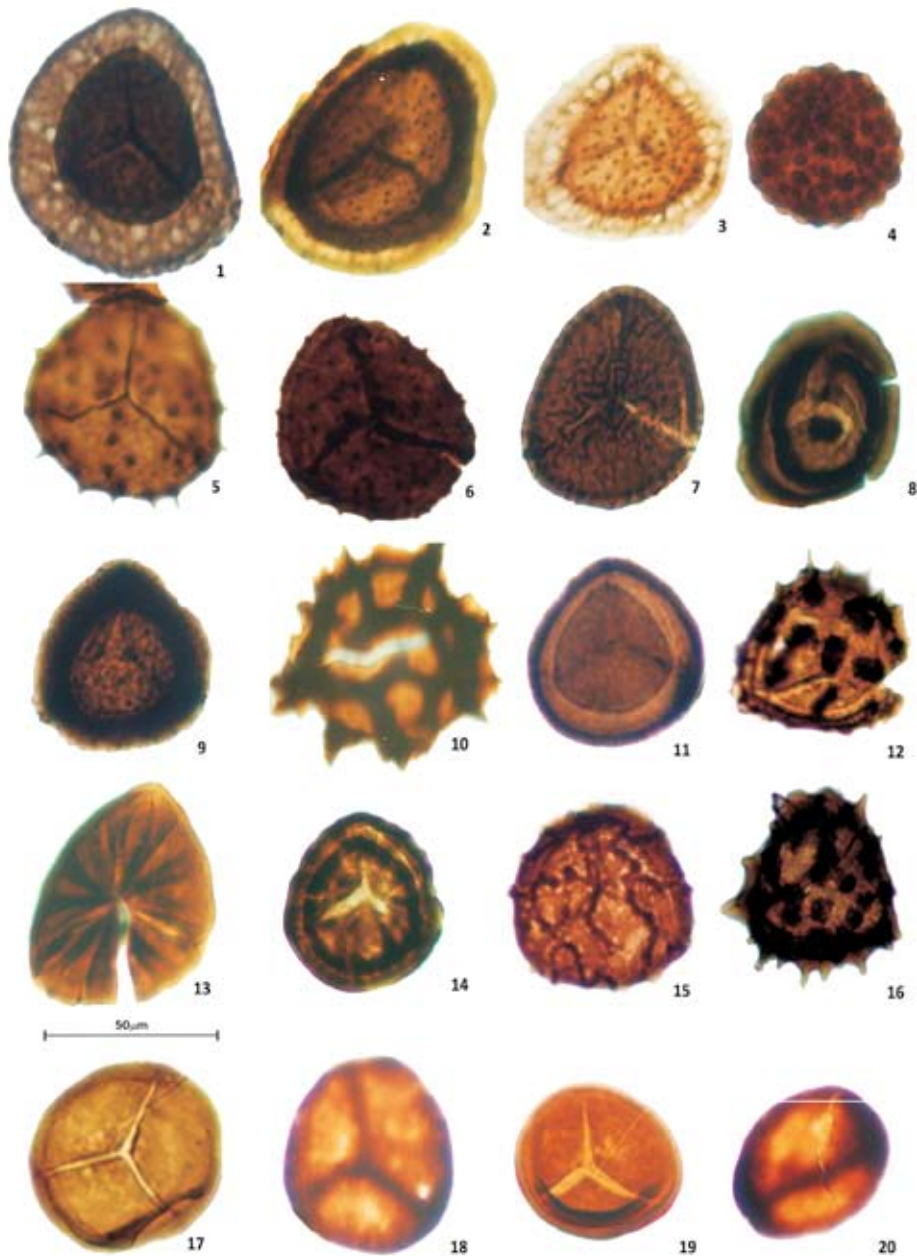


PLATE I. Miospores of Tercenas Formation, Pedra Ruiva Section.

Plate captions list the taxonomic name of the figured specimen, followed by the formation, sample number, slide number and microscopic coordinates of the specimen.

1. *Retispora lepidophyta* (Kedo) PLAYFORD 1976; Tercenas Formation, sample 105, slide 1, 1350-210.
2. *Indotriradites explanatus* (LUBER) KEDO 1963; Tercenas Formation, sample 106, slide b2, 1391-165.
3. *Vallatisporites pusillites* (KEDO) DOLBY & NEVES, 1970; Tercenas Formation, sample 283, slide c1, 1155-182.
4. *Verrucosisporites nitidus* (NAUMOVA) PLAYFORD 1964; Tercenas Formation, sample 338, slide 1, 1110-110.
5. *Grandispora cornuta* HIGGS 1975; Tercenas Formation, sample 105, slide 1, 1350-210.
6. *Grandispora echinata* HACQUEBARD emend. UTTING, 1987; Tercenas Formation, sample 106, slide b2, 1190-165.
7. *Rugospora flexuosa* (JUSHKO) STREEL, 1974; Tercenas Formation, sample 106, slide b2, 1355-105.
8. *Knoxisporites concentricus* (BYVSHEVA) PLAYFORD & MCGREGOR, 1993; Tercenas Formation, sample 106, slide 1, 1225-88.
9. *Densosporites spitbergensis* PLAYFORD, 1963; Tercenas Formation, sample 105, slide 1, 1480-97.
10. *Dictyotriletes fimbriatus* (WINSLOW) KAISER, 1970; Tercenas Formation, sample 105, slide 1, 1055-98.
11. *Geminispora spongiata* HIGGS, CLAYTON & KEEGAN, 1988; Tercenas Formation, sample 105, slide 1, 1245-230.
12. *Grandispora acuta* HIGGS, HIGGS, AVKHIMOVITCH, LOBOZIAK, MAZIANE-SERRAJ, STEMPIEN-SALEK & STREEL 2000; Tercenas Formation, sample 106, slide 4, 1390-145.
13. *Emphanisporites rotatus* MCGREGOR EMEND MCGREGOR, 1973; Tercenas Formation, sample 105, slide 2, 1180-200.
14. *Emphanisporites annulatus* MCGREGOR, 1961; Tercenas Formation, sample 106, slide 3, 1055-98.
15. *Cristicavatispora dispersa* GONZÁLEZ, PLAYFORD & MORENO, 2005; Tercenas Formation, sample 284, slide 1, 1325-32.
16. *Grandispora acuta* HIGGS, HIGGS, AVKHIMOVITCH, LOBOZIAK, MAZIANE-SERRAJ, STEMPIEN-SALEK & STREEL 2000; Tercenas Formation, sample 106, slide 4, 1390-145.
17. *Punctatisporites planus* HACQUEBARD, 1957; Tercenas Formation, sample 46, slide 1, 1446-60.
18. *Retusotriletes incohatus* SULLIVAN, 1964; Tercenas Formation, sample 284, slide 1, 1240-105.
19. *Punctatisporites minutus* KOSANKE, 1950; Tercenas Formation, sample 283, slide 1c, 1385-165.
20. *Latosporites* sp. A sensu OWENS, 1971; Tercenas Formation, sample 284, slide 2, 1420-105.

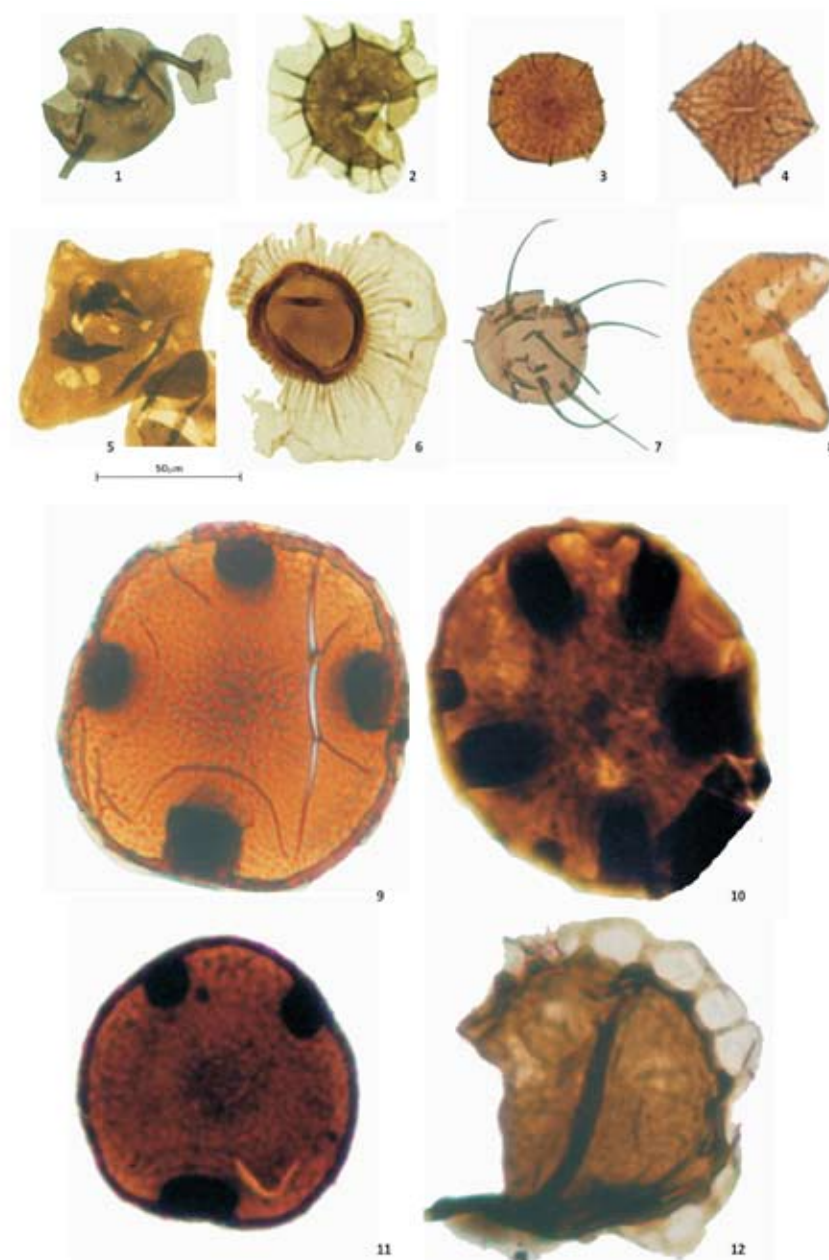


PLATE II. Acritarchs and prasinophytes of Tercenas Formation, Pedra Ruiva Section.

1. *Umbellasphaeridium saharicum* JARDINÉ, COMBAZ, MAGLOIRE, PENINGUEL & VACHEY, 1972; Tercenas Formation, sample 106, slide 1, 1478-125.
2. *Duvernaysphaera radiata* BRITO, 1967; Tercenas Formation, sample 106, slide 2b, 1295-241.
3. *Duvernaysphaera stellata* DEUNFF, 1964; Tercenas Formation, sample 106, slide 1, 1478-100.
4. *Duvernaysphaera tessella* DEUNFF, 1964; Tercenas Formation, sample 106, slide 2c, 1218-170.
5. *Horologinella horologia* (STAPLIN) JARDINÉ, COMBAZ, MAGLOIRE, PENINGUEL & VACHEY, 1972; Tercenas Formation, sample 106, slide 3, 1085-45.
6. *Pterospermella euripio* MARTIN, 1984; Tercenas Formation, sample 105, slide 2, 1472-65.
7. *Gorgonisphaeridium solidum* JARDINÉ, COMBAZ, MAGLOIRE, PENINGUEL & VACHEY, 1972; Tercenas Formation, sample 106, slide 3, 1085-45.
8. *Gorgonisphaeridium plerispinosum* WICANDER, 1974; Tercenas Formation, sample 106, slide 4, 1480-195.
9. *Maranhites mosesii* (SOMMER) BRITO, 1967; Tercenas Formation, sample 106, slide 2, 1482-165.
10. *Maranhites mosesii* (SOMMER) BRITO, 1967; Tercenas Formation, sample 106, slide 3, 1260-215.
11. *Maranhites mosesii* (SOMMER) BRITO, 1967; Tercenas Formation, sample 106, slide 1, 1180-95.
12. *Maranhites britoi* STOCKMANS & WILLIERE, 1969; Tercenas Formation, sample 106, slide 6, 1090-185.



PLATE III. Miospores of the Bordaleta Formation, Pedra Ruiva Section.

1. *Cyrtospora cristifera* (LUBER) emend. VAN DER ZWAN 1979; Bordaleta Formation, sample 290, slide 3, 1232-54.
2. *Verrucosiporites nitidus* (NAUMOVA) PLAYFORD 1964; Bordaleta Formation, sample 147, slide 1, 1180-63.
3. *Raistrickia variabilis* DOLBY & NEVES, 1970; Bordaleta Formation, sample 48, slide 1, 1382-225.
4. *Pustulatisporites dolbii* HIGGS, CLAYTON & KEEGAN, 1988; Bordaleta Formation, sample 48, slide 4, 1345-26.
5. *Tumulispora rarituberculata* (LUBER) PLAYFORD 1991; Bordaleta Formation, sample 48, slide 1, 1064-107.
6. *Tumulispora rarituberculata* (LUBER) PLAYFORD 1991; Bordaleta Formation, sample 48, slide 1, 1130-140.
7. *Tumulispora triangulatus* (ISHCHENKO) HUGES & PLAYFORD, 1961; Bordaleta Formation, sample 48, slide 1, 1340-95.
8. *Vallatisporites verrucosus* HACQUEBARD, 1957; Bordaleta Fm, sample 147, slide 2, 1205-48.
9. *Crassipora catenata* HIGGS, 1975; Bordaleta Formation, sample 46, slide 1, 1335-140.
10. *Endosporites tuberosus* GONZÁLEZ, MORENO & PLAYFORD, 2005; Bordaleta Formation, sample 334, slide 1, 1490-70.
11. *Vallatisporites microspinosus* CLAYTON, HIGGS & KEEGAN, 1988; Bordaleta Formation, sample 147, slide 4, 1320-170.
12. *Vallatisporites verrucosus* HACQUEBARD, 1957; Bordaleta Fm, Sample 147, slide 2, 1330-155.
13. *Knoxisporites* cf. *triradiatus* HOFFMEISTER, STAPLIN & MALLOY sensu SULLIVAN, 1964; Bordaleta Formation, sample 147, slide 2, 1145-120.
14. *Secarisporites* sp., Bordaleta Formation, sample 48, slide 1, 1350-260.

GEOLOGICAL STOP 3

The Stratigraphy of the Murração Beach

Location: Murração beach (Fig. 2)

Time: 3 hours

Geology and palynostratigraphy description:

The Murração-Beach is situated on the Atlantic coast. The beach region is now integrated in the Costa Vicentina Natural Park and can be reached by a 4.6 km long track starting from the main road, 4 km north of Vila do Bispo.

The region displays the best exposures of the Carrapateira Group units, and the stratotypes of the Murração and Quebradas Formations were defined here in seaside cliffs (Oliveira et al., 1985; Ribeiro et al, 1987).

Besides the stratigraphy, the frontal part of the Carrapateira Thrust is also well exposed (Fig. 7). In order to achieve the best understanding of the local geology several observation points were selected along a 1,8 km long walk, part of which presents a high level of difficulty due to cliff climbing.

The stratigraphic logs studied and sampled are presented in Fig. 9. Stratigraphically important and typical taxa are illustrated in Plates IV, V and VI. The description of the visited places follows (Fig. 7 and 8):

Point a - Whitish weathered shales and decalcified beds of the Quebradas Formation, with abundant but poorly preserved fossils of goniatites, of Late Namurian age. Bedding dips 20° to the SE.

Point b - Sub-horizontal brown weathered limestones and shales of the Vale Figueira Member. Fossils of goniatites and *Posidonia becheri* can be found.

Point c - Brown weathered limestones and marls of the Vale Figueira Member and black - laminated

shales with calcisiltitic nodules of the Bordaleta Formation. The Vale Figueira Member is folded in a syncline and has been transported over the Bordaleta Formation along the Carrapateira thrust plane. Towards SW the thrust plane is marked by a 10 cm thick fault gouge that cuts the Bordaleta Formation shales. Above the thrust plane the slaty cleavage dips 45° NE while below it is sub-horizontal.

Point d - At this point the Bordaleta Formation is composed of dark gray shales and calcisiltic layers, lenses and nodules. The bedding planes develop a large SW vergent anticline where the reverse limb appears almost vertical, with a thickness in excess of 100 m. Subsidiary minor folds are well represented. The slaty cleavage has a N330°, 25°NE orientation and a N20° crenulation lineation related to the D3 folding episode is also visible.

The Carrapateira Thrust is well exposed high in the beach cliff and is marked by the abnormal superposition of the reverse limb of a large anticline embracing the Bordaleta, Murração and the lower part of the Quebradas Formation, over the overturned anticline displayed by the Bordaleta Formation (Fig. 8). The thrust plane is clear cut and defines a duplex in the north part of the cliff.

Point e - Basic dikes cross cutting the Bordaleta Formation. These dykes have an alkaline basalt composition and show chilled margins.

They mark tensional episodes related to the opening of the Atlantic Ocean.

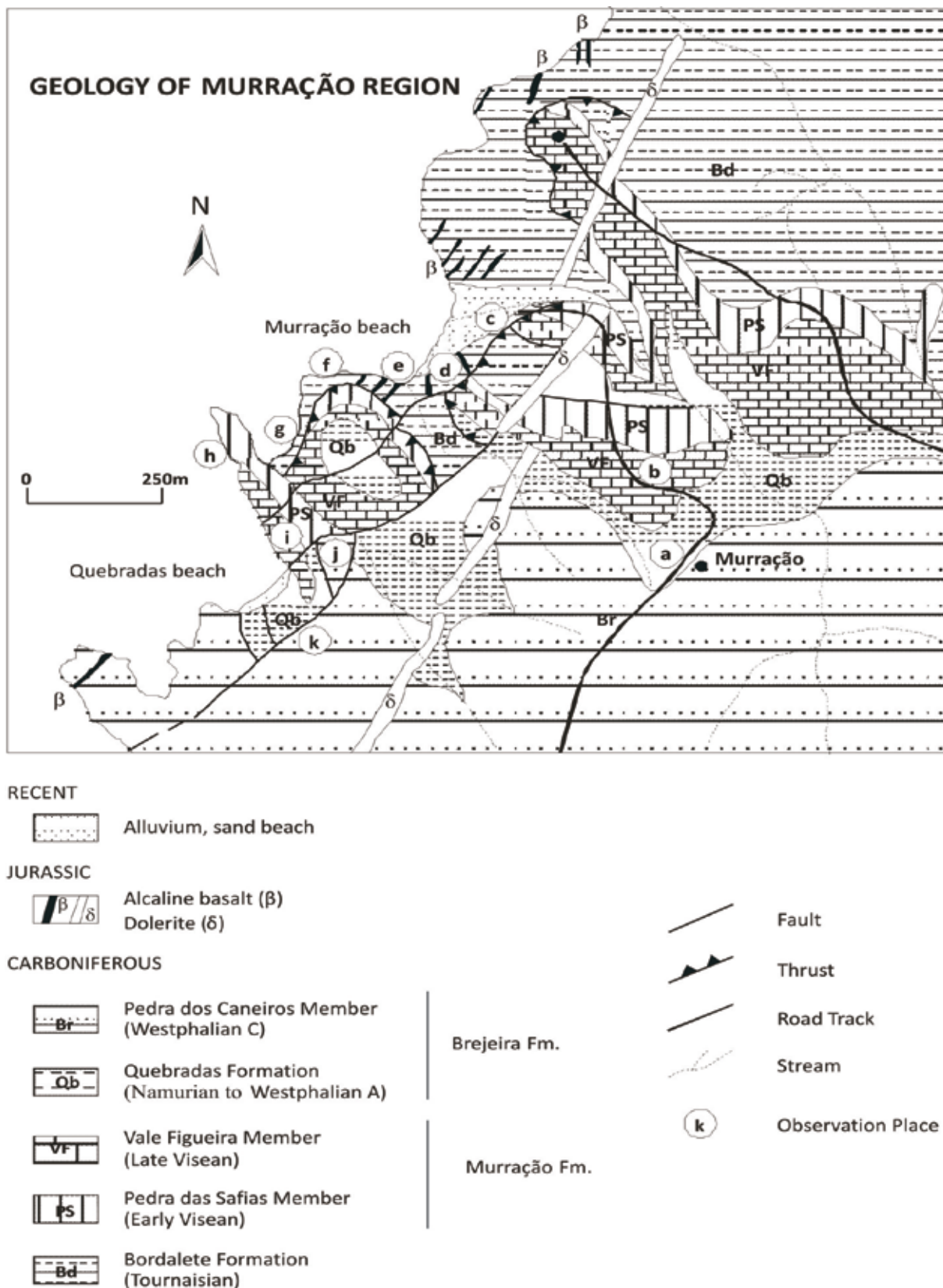


Fig. 7 Detailed geology of the Murração region and stop localities (Modified after Ribeiro, 1983).

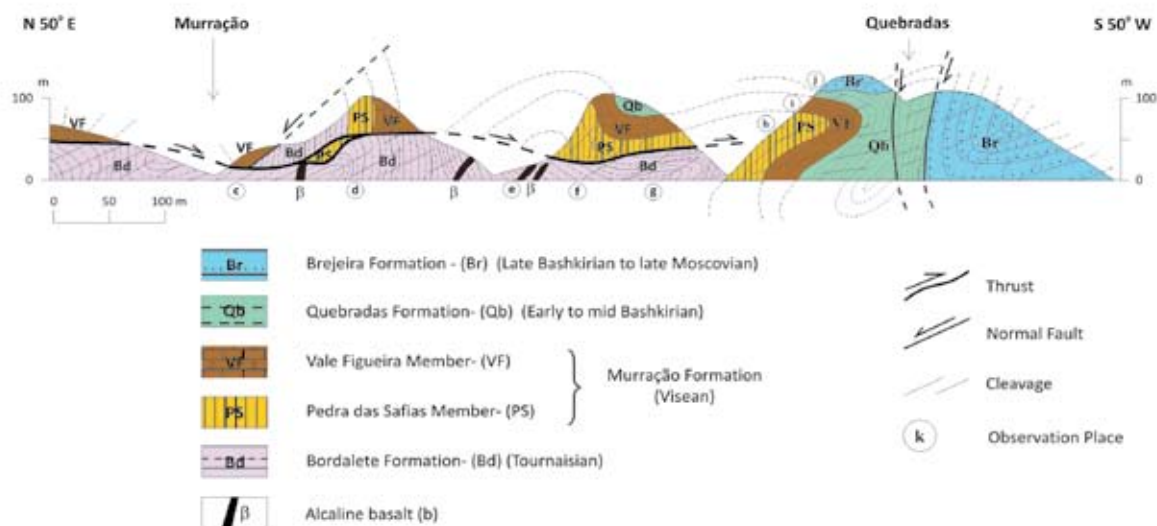


Fig. 8 Frontal part of the Carrapateira Thrust along the seaside cliff of Murração and Quebradas beaches (modified after Ribeiro, 1983).

Point f - At the cliff base the upper levels of the Bordalete Formation show sets with large scale cross bedding (see Fig. 9; Plate IV). The origin of this type of cross bedding is not yet very well understood; its relationship with gravity sliding is here tentatively suggested.

In this section Bordalete Formation dates the upper Tournaisian based on miospores. A typical, diverse and very well preserved PC Miospore Biozone assemblage was recovered from several samples along the beach (Plate IV). The assemblage is defined by the presence of the guide specie *Speleotriletes pretiosus* together with *Auroraspora macra*, *Densosporites* sp. A, *Krauselisporites fasciatus*, *K. mitratus*, *K. cf. triradiatus*, *Granulatisporites microgranifer*, *Neoraistrickia cymosa*, *N. logani*, *Raistrickia clavata*, *Speleotriletes balteatus*, *Valatisporites microspinosus*, *V. vallatus*, *V. verrucosus*, *Verrucosporites congestus*, *V. irregularis* and *V. nitidus*. *Maranhites* spp. are very common.

At the cliff wall the Pedra das Safiras Member of the Murração Formation is thrust over the Bordalete Formation. The thrust plane defines a fault with associated quartz vein lets.

Point g - Fallen blocks from the Vale Figueira Member show limestone-bedding surfaces covered with fossils of goniatites and bivalves. In situ black shales and siltstones of the Bordalete Formation show large calcisiltitic nodules, *Skolithos* type trace fossils and pressure shadows around pyrite concentrations.

Point h - Seaside cliff where the type section of the Pedra das Safias Member has been estab-

lished (Oliveira et al, 1985; Fig. 10). The beds are overturned and consist of alternating dolomitic limestones and shales passing upwards to impure limestones. The measured thickness is 30m. The section provided faunas of crinoids, coral (*Saleasma*), trilobites (*Archaeogonus* sp, *Spinibple* sp, *Liobole glabra* cf. *botkei*), goniatites (*Merocanites*), brachyopods and a nautiloid (*Lispoceras* sp. Hyatt) all indicating an Early Viséan age.

The palynostratigraphic study of the Pedra das Safias Member proved to be very difficult due to the strong dolomitization. Only in the Aljezur Anticline, in the Marianos and Corte da Velha sections, where this unit has a more shaly character, it has been possible to identify the base of the Pu miospore Biozone, based in the first appearance of *Lycospora pusilla* and the base of TS Miospore Biozone, by the first appearance of *Knoxisporites triradiatus* and *K. stephanephorus* (see Plate V).

These two miospore biozones indicate a lower Viséan age for the Pedra das Safias Member.

Point i - Panorama of the frontal fold of the Carrapateira Thrust. The cliff exposes the hinge zone of a recumbent fold affecting the Murração and Quebradas Formations. The Quebradas Formation stratotype was defined along the reverse limb of this fold (Fig. 11).

In this section samples studied in the Quebradas Formation allow to identify the upper mid Bashkirian (Fig. 12, Plate VI) *Crassispora kosankei*-*Gru-mosisporites varioreticulatus* (KV) and *Raistrickia fulva* - *Reticulatisporites reticulatus* (FR), Miospore Biozones. A diverse and relatively well preserved



Fig. 10 Pedra das Safias Member (Murração Fm.) at the North cliff of Quebradas beach.

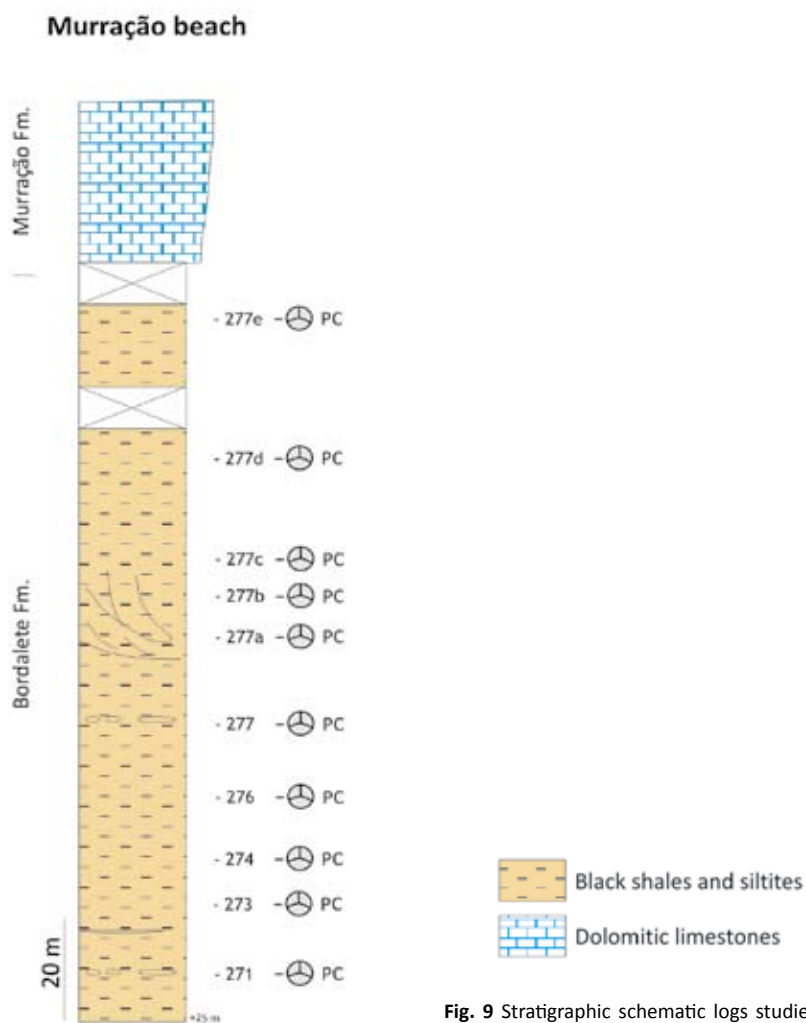


Fig. 9 Stratigraphic schematic logs studied in the Murração beach section, with palynostratigraphic results.



Fig. 11 Reversed fold at the Quebradas beach.

KV Miospore Biozone assemblage was recovered in samples 381 and 382 along the beach. The assemblage is defined by the presence of the guide specie *Crassispora kosankei* together with common species.

Assemblages of the biozone FR, recovered in samples 387-390, yielded a *Raistrickia fulva* and *Reticulatisporites reticulatus* together with *Columinisporites* sp., *Convolutispora* spp., *C. florida*, *Crassispora kosankei*, *Densosporites* spp., *Knoxisporites dissidus*; *K. hederatus*, *K. literatus*, *Reticulatisporites* Cf. *cancellatus*, *Reticulatisporites peltatus*, *R. polygonalis*, *R. rudis*, *Savitrissporites nux* and *Dyctiotriletes probireticulatus* in the upper part of the Biozone (sample 390).

Point j - Weathered greywackes and shales of the Brejeira Formation. The rocks are affected by faulting. On the south cliff of the Quebradas Beach the unit yielded miospores of Moscovian age (Westphalian C).

The absence of Westphalian B is due to a normal fault at the Quebradas/Brejeira Formations boundary.

Point k - Panorama of the north cliff of the Quebradas Beach were the stratotype of the Vale Figueira member was defined (Oliveira et al., 1995). The composing overturned beds of limestones and dark piritic shales are excellently exposed and provided a good collection of late Viséan ammonoids (Oliveira et al., 1985; Korn, 1997).

In this part of the section, the Vale Figueira Mem-

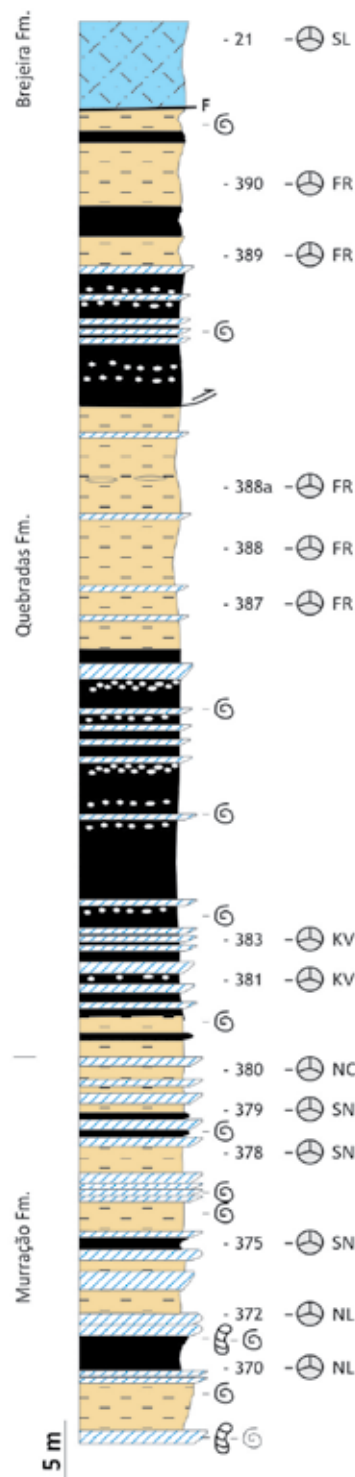
ber, in Quebradas Beach Section (Fig. 12, Plate V) has yielded moderately preserved miospore assemblages assignable to the NL, SN, and NC Biozones of upper Viséan age. Two biozones were defined as local miospore biozones, the NL (*Raistrickia nigra* - *Propriisporites laevigatus*) and SN (*Savitrissporites nux*) based respectively, on the first occurrence of *Raistrickia nigra* and *Savitrissporites nux* guide taxa (Fig. 12, plate V).

These local biozones were defined due to the absence of stratigraphically useful taxa such as *Rotaspora* spp., *Tripartites* spp. and *Triquitrites* spp. Nevertheless, the NL Biozone can be correlated with the *Raistrickia nigra* - *Triquitrites marginatus* Miospore Biozone of Western Europe based in the first appearance of *Raistrickia nigra* that occurs at the same level. *Propriisporites laevigatus* appears together with the first *R. nigra* in Southwest Portugal, but in Western Europe the first record of this specie is much higher, at the top of NC Biozone of upper Viséan to lower Serpukhovian age (Clayton et al., 1977; Clayton, 1996).

The SN local Miospore Biozone can be correlated with the VF Miospore Biozone of Western Europe, based in the first occurrence of *Savitrissporites nux*. In Western Europe, in addition to *S. nux*, the *Tripartites vetustus* Biozone is defined by the first appearance of a group of new species which includes *Tripartites vetustus*, *Tripartites nonguerikei*, *Rotaspora fracta* and *R. knoxi*, which are not represented in the upper Viséan of Southwest Portugal (Clayton et al., 1977; Clayton, 1996).

The basal part of the NC Biozone is marked by the

Quebradas beach



presence of the guide species *Bellisporites nitidus*, which was recognised in the Quebradas Beach section. The assemblage also contains the species *Crassispora maculosa*, *Microreticulatus concavus*, *Propisporites laevigatus*, *Raistrickia nigra* and *Savitrissporites nux*.

The palynostratigraphical evidence indicates that the entire Viséan may be represented in the Murração Formation (PEREIRA, 1997, 1999) confirming so previous faunal determinations (OLIVEIRA et. al. 1985; Korn, 1997).

Fig. 12 Stratigraphic schematic logs studied in the Quebradas beach section, with palynostratigraphic results.

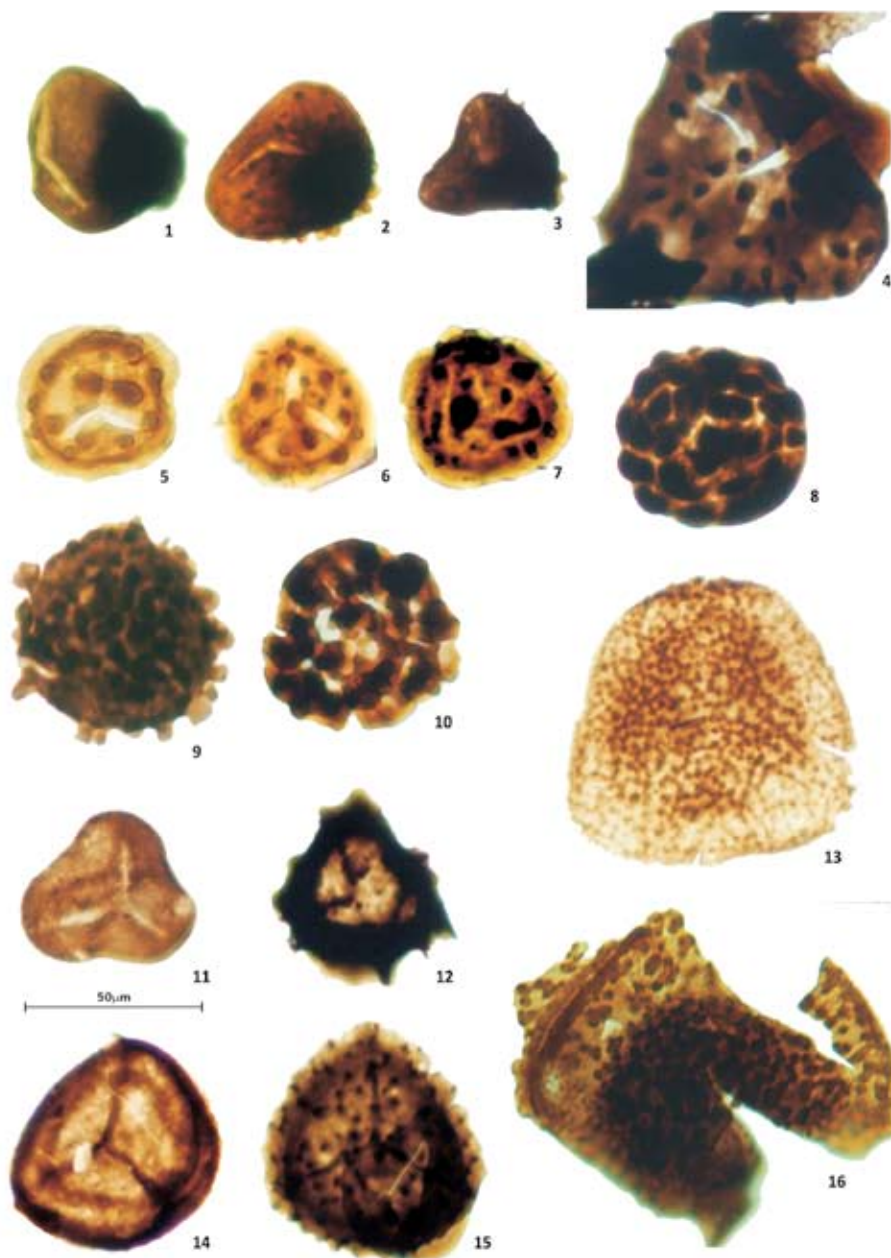


PLATE IV. Miospores of the Bordaleta Formation.

1. *Cyrtospora cristifera* (LUBER) emend. VAN DER ZWAN 1979; Bordaleta Formation, sample 147, slide 3, 1155-120.
2. *Cyrtospora cristifera* (LUBER) emend. VAN DER ZWAN 1979; Bordaleta Formation, sample 216, slide 2c, 1198-120, equatorial.
3. *Neoraistrickia cymosa* HIGGS, CLAYTON & KEEGAN, 1988; Bordaleta Formation, sample 147, slide 1b, 1205-170.
4. *Neoraistrickia logani* HIGGS, CLAYTON & KEEGAN, 1988; Bordaleta Formation, sample 147, slide 1b, 1205-170.
5. *Tumulispora rarituberculata* (LUBER) PLAYFORD 1991; Bordaleta Formation, sample 324, slide 1, 1098-105.
6. *Tumulispora rarituberculata* (LUBER) PLAYFORD 1991; Bordaleta Formation, sample 46, slide 2, 1300-206.
7. *Tumulispora rarituberculata* (LUBER) PLAYFORD 1991; Bordaleta Formation, sample 46, slide 2, 1300-105.
8. *Verrucosisorites congestus* PLAYFORD, 1964; Bordaleta Formation, sample 147, slide 3, 1300-105.
9. *Raistrickia clavata* HACQUEBARD emend. PLAYFORD, 1964; Bordaleta Formation, sample 334, slide 1, 1425-123.
10. *Secarisporites remotus* NEVES, 1961; Bordaleta Formation, sample 147, slide 1, 1123-35.
11. *Granulatisporites microgranifer* IBRAHIM 1933; Bordaleta Formation, sample 226, slide 1, 1053-215.
12. *Densosporites* sp. A.; Bordaleta Formation, sample 148, slide 1, 1325-110.
13. *Spelaotriletes balteatus* (PLAYFORD) HIGGS 1975; Bordaleta Formation, sample 147, slide 4, 1345-195.
14. *Kraeuselisporites fasciatus* HIGGS, 1975; Bordaleta Formation, sample 147, slide 2, 1305-105.
15. *Kraeuselisporites mitratus* (HIGGS) HIGGS, 1996; Bordaleta Formation, sample 147, slide 3, 1150-241.
16. *Spelaotriletes pretiosus* (PLAYFORD) NEVES & BELT, 1970; Bordaleta Formation, sample 247, slide 4, 1354-65.

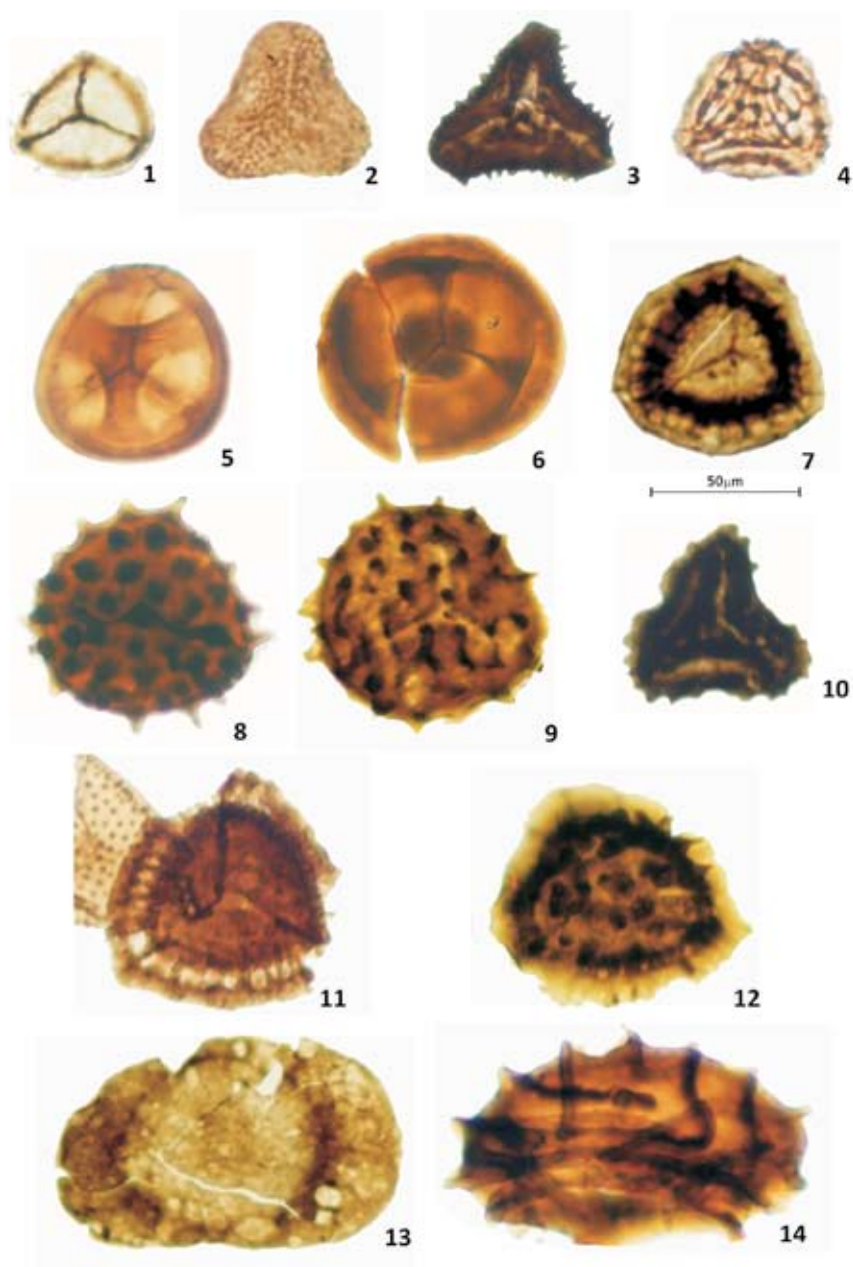


PLATE V. Miospores of the Murração Formation, Quebradas Beach.

1. *Lycospora pusilla* (IBRAHIM) SCHOPF, WILSON & BENTALL 1944; Murração Formation, Sample 280, slide 1, 1220-175.
2. *Microreticulatisporites concavus* BUTTERWORTH & WILLIAMS, 1958; Murração Formation, Sample 372, slide 1, 1305-60.
3. *Diatomozonotriletes cervicornutus* (STAPLIN) PLAYFORD, 1963; Murração Formation, Sample 9, slide 2, 1312-235.
4. *Savitrissporites nux* (BUTTERWORTH & WILLIAMS) SMITH & BUTTERWORTH 1967; Murração Formation, Sample 378, slide 2, 1160-255;
5. *Knoxisporites triradiatus* HOFFMEISTER, STAPLIN & MALLOY sensu SULLIVAN 1964; Murração Formation, Sample 379, slide 3, 1058-86.
6. *Knoxisporites stephanephorus* LOVE 1960; Murração Formation, Sample 379, slide 1, 1082-240.
7. *Radiizonates striatus* (KNOX) STAPLIN & JANSONIUS, 1964; Murração Formation, Sample 378, slide 1, 1195-190.
8. *Raistrickia nigra* LOVE 1960; Murração Formation, Sample 379, slide 1, 1455-73.
9. *Raistrickia nigra* LOVE 1960; Murração Formation, Sample 372, slide 2, 1492-160.
10. *Bellisporites nitidus* (Horst) SULLIVAN 1964; Murração Formation, Sample 229, slide 2, 1368-210.
11. *Vallatisporites ciliaris* (LUBER) SULLIVAN, 1964; Murração Formation, Sample 372, slide 1, 1423-50.
12. *Vallatisporites galearis* SULLIVAN, 1964; Murração Formation, Sample 379, slide 2, 1450-50.
13. *Schulzospora elongata* HOFFMEISTER, STAPLIN & MALLOY 1955; Murração Formation, Sample 379, slide 2, 1130-215.
14. *Propisporites laevigatus* NEVES, 1961; Murração Formation, Sample 379, slide 1, 1215-132.

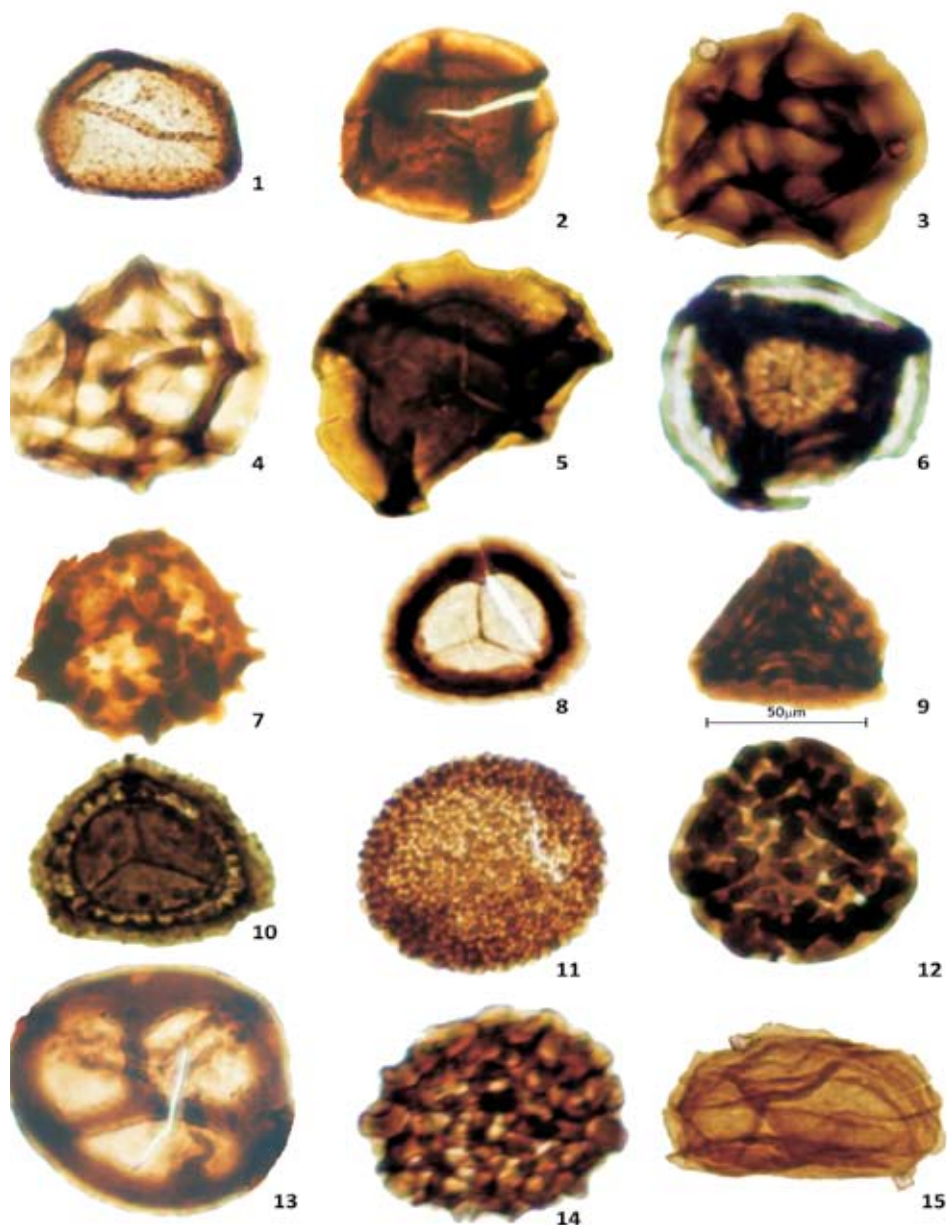


PLATE VI. Miospores of the Quebradas Formation, Quebradas Beach.

1. *Crassispora kosankei* POTONIÉ & KREMP emend BHARADWAJ 1957; Quebradas Formation, Sample 387, slide 2, 1230-95.
2. *Reticulatisporites reticulatus* (IBRAHIM) IBRAHIM, 1933; Quebradas Formation, Sample 195, slide 1, 1364-35.
3. *Reticulatisporites rudis* STAPLIN, 1933; Quebradas Formation, Sample 390, slide 1, 1270-55.
4. *Reticulatisporites cf. cancellatus* (WALTZ) PLAYFORD, 1962; Quebradas Formation, Sample 388, slide 1, 1378-230.
5. *Reticulatisporites carnosus* (KNOX) NEVES, 1964; Quebradas Formation, Sample 387, slide 2, 1480-182.
6. *Reticulatisporites polygonalis* (IBRAHIM) SMITH & BUTTERWORTH, 1967; Quebradas Formation, Sample 388, slide 4, 1215-152.
7. *Raistrickia fulva* ARTUZ, 1957; Quebradas Formation, Sample 200, slide 1, 1430-205.
8. *Cingulizonates bialatus* (WALTZ) SMITH & BUTTERWORTH, 1967; Quebradas Formation, Sample 389, slide 1, 1164-170.
9. *Savitrissporites nux* (BUTTERWORTH & WILLIAMS) SMITH & BUTTERWORTH 1967; Quebradas Formation, Sample 387, slide 2, 1160-255.
10. *Vallatisporites ciliaris* (LUBER) SULLIVAN, 1964; Quebradas Formation, Sample 390, slide 2, 1423-50.
11. *Convolutispora cerebra* BUTTERWORTH & WILLIAMS, 1958; Murração Formation, Sample 309, slide 1, 1473-145.
12. *Convolutispora florida* HOFFMEISTER, STAPLIN & MALLOY, 1955; Quebradas Formation, Sample 387, slide 1, 1342-115.
13. *Knoxisporites literatus* (WALTZ) PLAYFORD, 1963; Quebradas Formation, Sample 388, slide 1, 1340-83.
14. *Reticulatisporites peltatus* PLAYFORD, 1962; Quebradas Formation, Sample 390, slide 1, 1464-182.
15. *Columinisporites* sp.; Quebradas Formation, Sample 195, slide 1, 1235-65.

SECOND DAY, 24th September 2009

The Telheiro Beach Variscan Unconformity and Mesozoic Algarve Basin Sections

Leaders: J. Tomás Oliveira, Zélia Pereira - LNEG

Paulo Fernandes and Marisa Borges - UALG

ROAD LOG

- Departure from the hotel in Aljezur at 9 AM, following the road to Vila do Bispo.
- Arrive at Vila do Bispo village and take an unpaved road for ca. 3 km, then we will arrive to Telheiro the place of stop 1.
- Road Sagres to Cap Saint Vincent, stopping at Cap Saint Vincent and Mareta.
- Cape Saint Vincent is situated about six kilometers from the village of Sagres, the cape is a landmark for a ship traveling from the Mediterranean. The cliffs rise nearly vertically from the Atlantic to a height of 75 meters. The cape is a site of exuberant marine life and a high concentration of birds nesting on the cliffs. The present lighthouse was built over the ruins of a sixteenth-century Franciscan convent in 1846. The lighthouse, guarding one of the world's busiest shipping lanes, is the second most powerful in Europe; its two 1000-watt lamps can be seen as far as 60 kilometers away.

Cape St. Vincent was already sacred ground in Neolithic times, as standing menhirs in the

neighborhood attest. The ancient Greeks called it Ophiussa (Land of Serpents), inhabited by the Oestriminis and dedicated here a temple to Heracles. The Romans called it Promontorium Sacrum (or Holy Promontory). They considered it a magical place where the sunset was much larger than anywhere else. They believed the sun sank here hissing into the ocean, marking the edge of their world. According to legend, the name of this cape is linked to the story of a fourth-century martyred Iberian priest St. Vincent whose body was brought ashore here. A shrine was erected over his grave, according to the Arab geographer Al-Idrisi, it was always guarded by ravens. King Afonso Henriques (1139-1185) had the body of the saint exhumed in 1173 and brought it by ship to Lisbon, still accompanied by the ravens. This transfer of the relics is depicted on the coat of arms of Lisbon. The area around the cape was plundered several times by pirates from France and Holland and, in 1587, by Sir Francis Drake.

- Taking the road EN 125, Sagres to Lagos with a stop at Praia da Luz. Then return to Faro.



Fig. 13 Telheiro beach Variscan Unconformity section photo.

GEOLOGICAL STOP 1

The Telheiro Beach, Variscan Unconformity

Location: Telheiro beach (Fig. 13 and 14)

Time: 3 hours

Brief description of the geology and palynostratigraphy

The Telheiro beach is located approximately 3 km north of Cap Saint Vincent. Here it is possible to visualise the Variscan unconformity between the highly folded greywackes and shales of Brejeira Formation of Moscovian age and the Upper Triassic red sandstones and mudstones of the “Grés de Silves”. The imponent sea cliffs make this place one of the best points to observe the end of the Variscan Cycle and the beginning of the Alpine Cycle.

In the descent to Telheiro beach a narrow gully (Barranco das Quebradas) exposes the typical lithologies of the “Grés de Silves”. In this valley the dominant lithologies are red to green mudstones intercalated with rare dolomites that corresponds to the upper part of this unit. Lower in the descent and immediately above the unconformity plane, are red sandstones with current cross stratification.

On the top of the gully are pale sandstones with large scale cross stratification and rhizoconcretions that are unconformably over the mudstones of the “Grés de Silves”. These sandstones represent littoral eolian sand dunes of Quaternary raised beaches.

Fig. 14 represents the geological cross section of the Telheiro unconformity and the tectonic interpretation of the variscan structures that affect the Brejeira turbidites. In this point the Brejeira tur-

bidites are highly folded, the folds have a chevron geometry and sub-vertical axial planes. These are the product of the final folding phases of the variscan compression and are thought to have affected early structures. The structural interpretation of the variscan structures is of a large recumbent fold affected by two small thrusts whose planes are visible one above a small antiform fold with a eroded core forming a small littoral arch, and the other near the scree deposits that cover part of the cliff in the north part of the Telheiro point.

The greywackes beds of the Brejeira Formation exhibit sedimentary structures that can be attributed to sedimentation under the action of turbiditic currents, namely the Bouma sequence and sole marks (flute, groove and load casts).

The age of Brejeira Formation was obtained by palynostratigraphy at the Castelejo Beach (3 Km north).

Here the miospore recovered are assigned to the Biozone OT of late Moscovian age. The assemblage comprehends *Crassispora kasankei*, *Endosporites globiformis*; *Florinites* spp., *Lycospora* spp., *Savitrissporites* spp., *Thymospora obscura*, *T. thiessenii*, *Torisporea securis* and *Westphalensisporites* sp., together with the index specie *Thymospora pseudothiessenii* (See Plate VII).

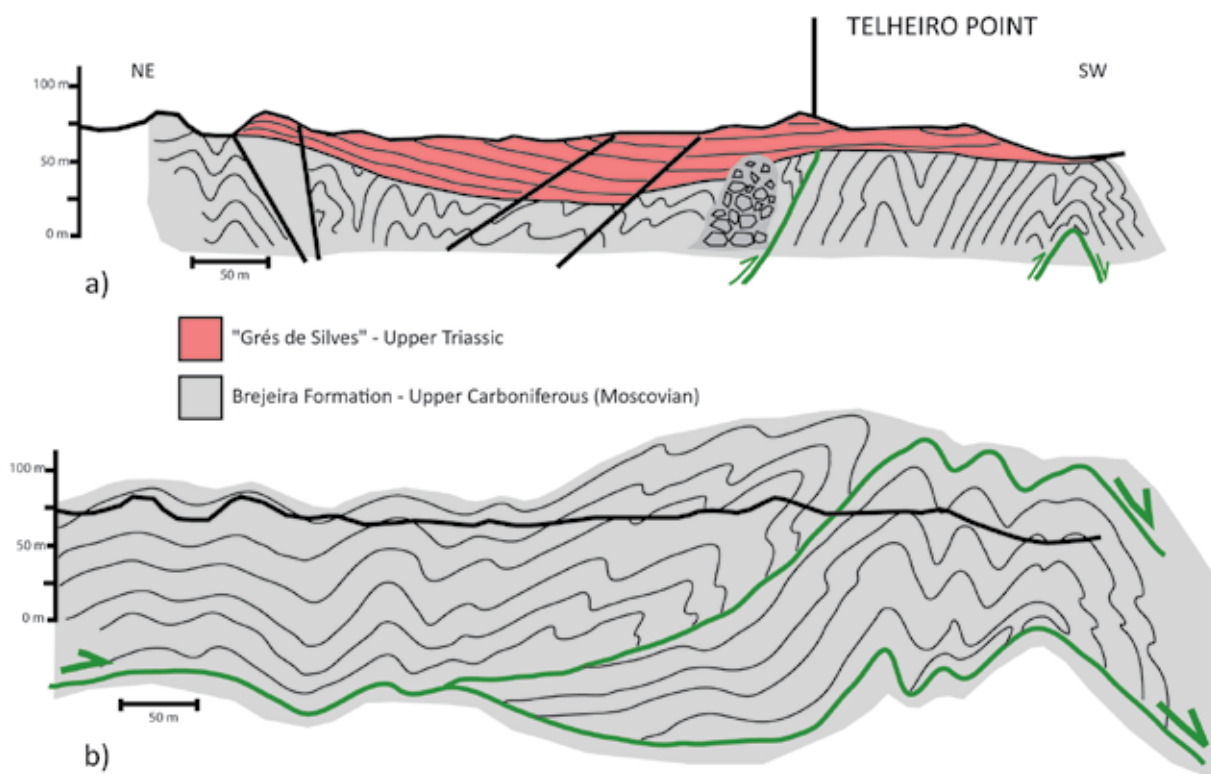


Fig. 14 Schematic geology of the Telheiro beach section (Adapted from Caroça & Dias, 2001).

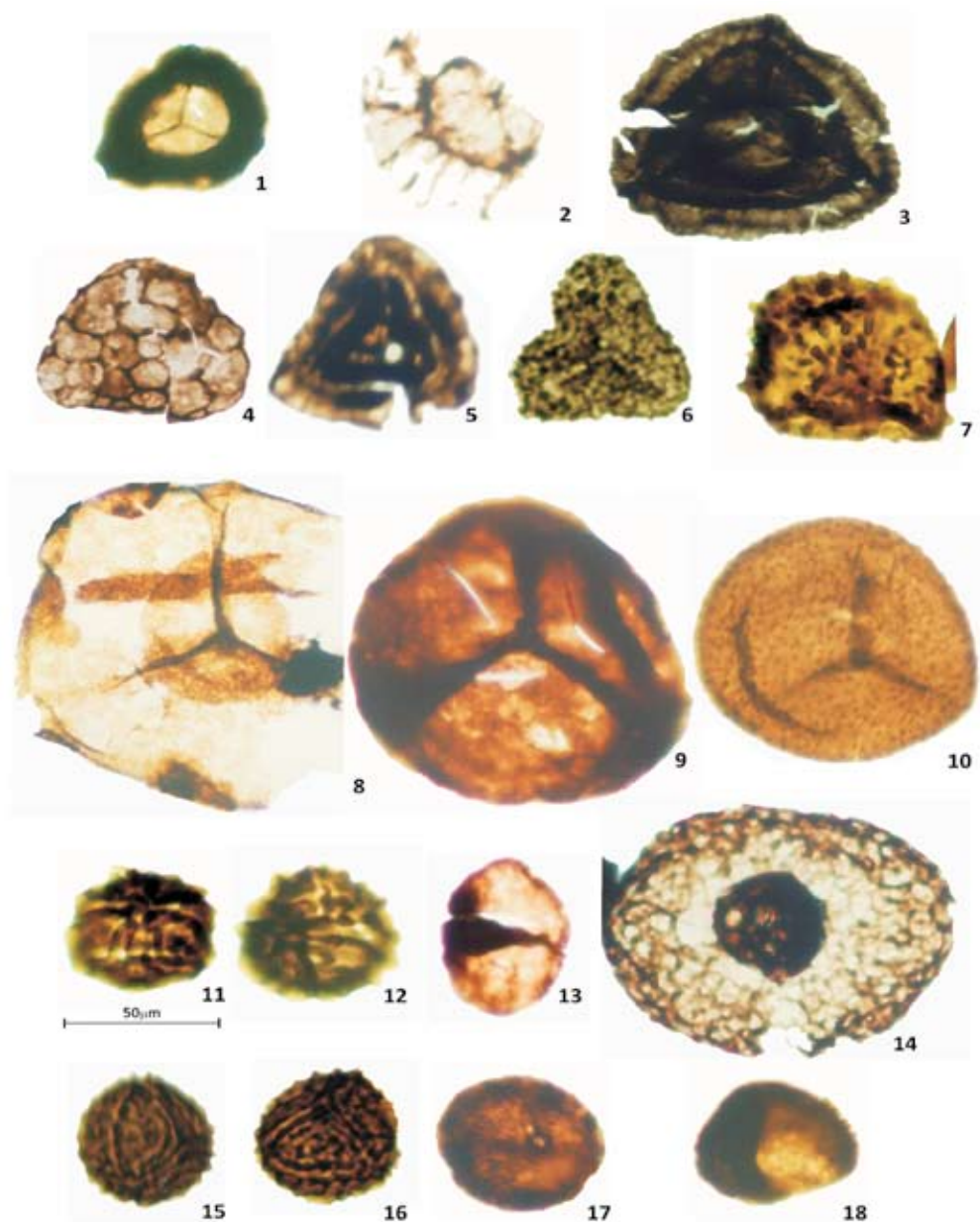


PLATE VII. Miospores of the Brejeira Formation.

1. *Densosporites annulatus* (LOOSE) SMITH & BUTTERWORTH, 1967; Brejeira Formation, sample 229, slide 2, 1340-225.
2. *Radiizonates aligerens* (KNOX) STAPLIN & JANSONIUS 1964; Brejeira Formation, sample 242, slide 5, 1240-210.
3. *Cirratiradites saturni* (IBRAHIM) SCHOPF, WILSON & BENTALL, 1944; Brejeira Formation, sample 266, slide 1, 1260-87.
4. *Dictyotriletes probireticulatus* (IBRAHIM) BUTTERWORTH & MAHDI 1981; Brejeira Formation, sample 238,b,1, 1350-110.
5. *Savitrisorites concavus* MARSHALL & SMITH, 1964; Brejeira Formation, sample 226, slide 2, 1055-188.
6. *Lophotriletes gibbosus* (IBRAHIM) POTONIÉ & KREMP, 1954; Brejeira Formation, sample 372, slide 1, 1150-150.
7. *Raistrickia aculeata* KOSANKE 1950; Brejeira Formation, Sample 63, slide 1, 1385-200.
8. *Endosporites globiformis* (IBRAHIM) SCHOPF, WILSON & BENTALL, 1944; Brejeira Formation, sample 22, slide 4, 1320-137.
9. *Cadiospora magna* KOSANKE 1950; Brejeira Formation, Sample 62, slide 1, 1254-175.
10. *Crassispora maculosa* (KNOX) SULLIVAN, 1964; Brejeira Formation, sample 242, slide 8, 1425-220.
11. *Thymospora pseudothiessenii* (KOSANKE) WILSON & VENKATACHALA 1963; Brejeira Formation, Sample 63, slide 1, 1220-185.
12. *Thymospora pseudothiessenii* (KOSANKE) WILSON & VENKATACHALA 1963; Brejeira Formation, Sample 63, slide 1, 1315-170.
13. *Torispora securis* BALME 1952; Brejeira Formation, sample 63, slide 3, 1215-216.
14. *Florinites junior* (IBRAHIM) SCHOPF, WILSON & BENTALL, 1944; Brejeira Formation, sample 229, slide 3, 1145-100.
15. *Savitrisorites* sp. A; Quebradas Formation, sample 387, slide 2, 1332-150.
16. *Savitrisorites* sp. A; Quebradas Formation, sample 387, slide 2, 1414-145.
17. *Thymospora obscura* (KOSANKE) WILSON & VENKATACHALA 1963; Brejeira Formation, sample 63, slide 4, 1045-65.
18. *Torispora securis* BALME 1952; Brejeira Formation, Sample 63, slide 1, 1135-185.

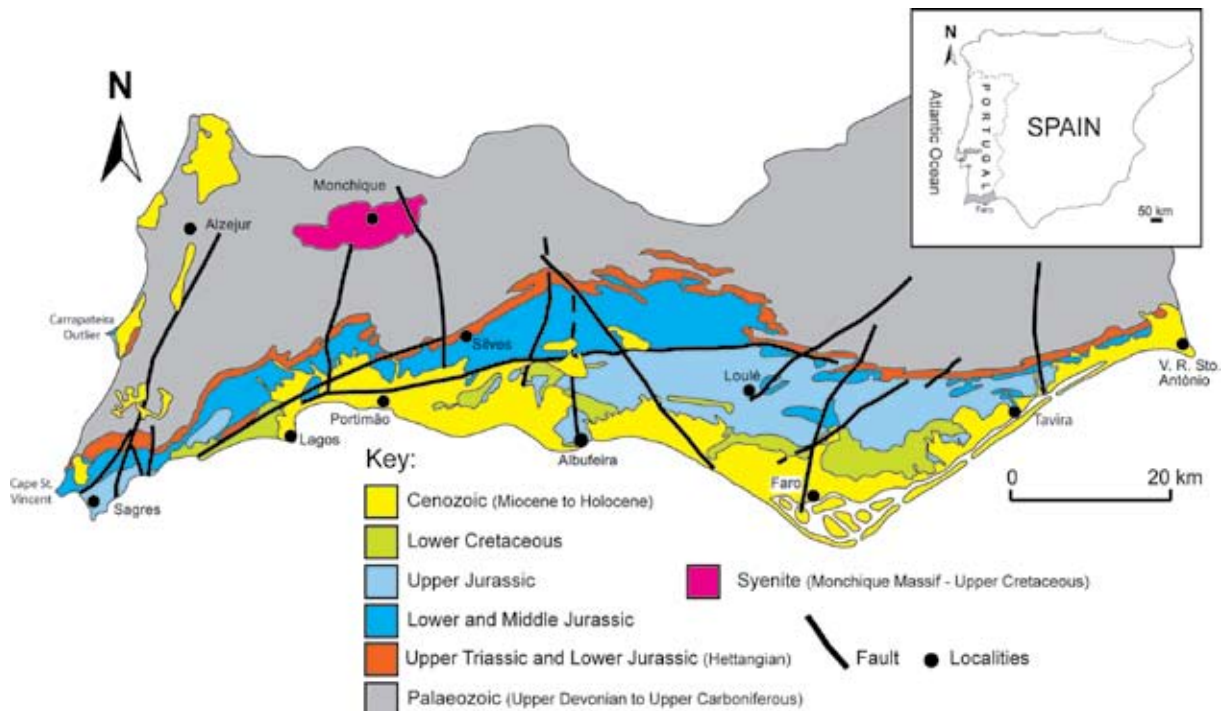


Fig. 15 Geological sketch map of Algarve Basin (Adapt. Geological Map of Portugal, 1:500 000 SGP, 1992).

INTRODUCTION TO THE ALGARVE BASIN GEOLOGY

The Algarve Basin corresponds to the southernmost geological province of mainland Portugal. It has an E-W strike and is represented onshore from Cap Saint Vincent to the Guadiana River on the Portuguese-Spanish border (Fig. 15).

More than 3000 meters of essentially marine sediments accumulated during Mesozoic/Cenozoic times in the Algarve Basin (Manuppella, 1992). Mesozoic strata accumulated on a continental passive margin formed during the successive extensional phases of the North Atlantic Ocean opening that followed the break-up of Pangea, from Upper Triassic to Middle Cretaceous times (Manuppella et al., 1988). Cenozoic rocks were deposited in sedimentary basins controlled by Alpine tectonics that caused the inversion of the Mesozoic strata during Upper Cretaceous and Cenozoic times (Kullberg et al., 1992; Terrinha, 1998). Sedimentary facies changes in the Mesozoic succession reflect the partition of the Algarve Basin into three sub-basins separated by major regional faults, namely: the Sagres sub-basin, the Budens-Lagoa sector and the Faro sub-basin.

The sedimentation in the Algarve Basin started in Late Triassic times with continental red beds and evaporitic deposits which unconformably overlain Late Palaeozoic folded sedimentary rocks. This was followed by an important magmatic event of Early Jurassic age that is correlated to the Central

Atlantic Magmatic Province. From Sinemurian to Late Jurassic marine carbonate sedimentation was well established across the Algarve basin, and dominated by shallow water limestones and pelagic marls/limestones cycles (Manuppella et al., 1987). Lower Cretaceous rocks are represented mainly by clastic and carbonate rocks deposited in near-shore to continental environments. No Upper Cretaceous sedimentary rocks are known in the Algarve Basin; during this time a major episode of basin inversion occurred related to the regional Alpine tectonism and the emplacement of the Late Cretaceous Syenite Massif of Monchique (Rey, 1983; Manuppella, 1992). Sedimentation was only resumed during Miocene times with bioclastic limestone that unconformably overlain the Mesozoic strata. We will briefly describe the general stratigraphy of the Sagres sub-basin since the localities visited in this field trip are all located within this region.

Mesozoic Geology of the Sagres – Lagoa Area

Mesozoic strata in this region start with red sandstones and clays of the Grés de Silves that rest unconformably over the Upper Palaeozoic turbiditic deposits of the Baixo Alentejo Flysch Group (Fig.13). This unconformity is superbly exposed at the sea cliffs of Telheiro. The Grés de Silves

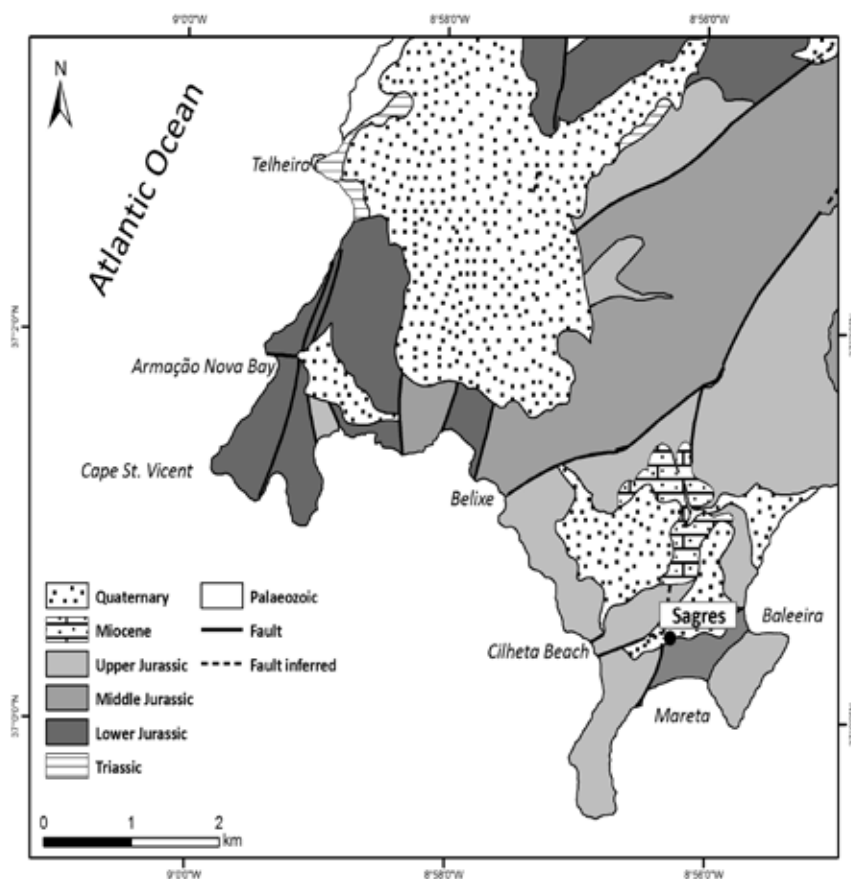


Fig. 16 Schematic map of the Sagres region (adapt. Mannupella, 1972).

sandstones and claystones are continental alluvial deposits deposited in a hot semi-arid environment. Infrequent bone remains of tetrapods (*Labryntodonta*) and brachiopods (*Euestheria minuta*, *Pseudoasmusia destombesi*) indicates an Upper Triassic age for this unit. The Grés de Silves lithologies grade upwards to a rock unit dominated by red/green mudstones intercalated with fine sandstones, siltstones and dolomites. At the top of this unit and south of the Algibre Fault, thick evaporite deposits with anhydrite and gypsum accumulated, whereas north of this fault system the evaporite deposits are rare or absent. The sedimentary structures suggest that this unit was deposited in saline to hypersaline lagoons in tidal to supratidal environments.

A rare spore and pollen association with *Praecirculina* sp. and *Tiradispora* (Doubinger et al., 1970) together with macrofossils (bivalves) indicates an Upper Triassic to Hettangian age for this unit. Unconformable above this last unit are sedimentary and volcanic rocks that are associated with the first phases of rifting of the Central Atlantic (Mannupella et al., 1988; Martins 1991).

The magmatism is represented by basic rocks of

toleitic affinity and consists of effusive volcanic episodes with several lava flows intercalated with more explosive volcanic facies represented by tuffs, volcanic breccias and ashes which accumulated in a submarine setting. The volcanism is of Hettangian age and belongs to the large magmatic province of the Central Atlantic Magmatic Province (CAMP) related to the rifting of the Pangeia (Terrinha et al., 2006).

Above the volcanic rocks are shallow water limestones and dolomites of Sinemurian age that mark the beginning of an important sedimentary cycle that ended in the Lower Cretaceous.

In the Sagres area (Fig. 16) Lower Jurassic sequences are exposed in three localities: Cap St. Vincent, Armação Nova and Belixe. At Cap Saint Vincent (Fig. 17) the base of the section consists of strongly dolomitised limestones conformably overlain by a 30 m thick succession of limestones of Lower Pliensbachian age with abundant chert nodules. This age is given by the presence of ammonoids of the *Jamesoni* and *Ibex* biozones (Rocha, 1976).

The, approximately, 50 m thick succession ob-



Fig. 17 Sagres aerial photo.

served at Belixe spans the Pliensbachian to Lower Toarcian age. Lower Pliensbachian sediments consist of dolomitised limestones rich in chert nodules unconformably overlain by micritic and detrital limestones of Upper Pliensbachian age. According to Ribeiro & Terrinha (2007) the chertification and the dolomitisation were early diagenetic processes that occurred before the deposition of Upper Pliensbachian limestones.

The uppermost part of the section consists of interbedded detrital limestones and marls with ammonites of the *Tenuicostatum* and *Serpentinus* Biozones indicating a Lower Toarcian age for these beds.

A better exposed Lower Toarcian succession occurs at Armação Nova Bay located approximately 1 km to the NE of Cap St. Vincent. The base of the succession consists of strongly dolomitised limestones, probably of Upper Pliensbachian age, passing upwards to marls interbedded with detrital limestones. The bases of the detrital limestone beds show longitudinal scours and flute casts and the tops are bioturbated exhibiting *Zoophycos*. The scour casts and the detrital character of the limestone beds suggest that they were deposited

by the action of turbidity currents. This succession is approximately 35 m thick.

Middle Jurassic strata are well exposed at Mareta Bay, which constitutes a stop in this field trip. The base of the succession consists of coral bioherms showing palaeokarsified tops. There is no direct age of the bioherms, however, the karst cavities are filled and covered by Upper Bajocian detrital limestones and by Middle Bathonian marls. This indicates that the karst event is pre Upper Bajocian and the bioherms are, therefore, older than this age (Aalenian - Lower Bajocian?). Stratigraphically above the bioherm, located at the level of the beach, is a conglomerate bed made up of boulder and cobbles of limestones including clasts of the coral bioherm. This bed is correlated to the palaeokarst surface and shows lateral thickness change. On the top of the conglomerate is a 40 m thick succession of detrital limestones with *Zoophycos* of Upper Bajocian - Bathonian age (Rocha, 1976). The younger sediments consist of an approximately 120 m thick succession, made up of grey marls that pass upward progressively to marly limestones, which are affected by several slump events. The ammonite faunas recovered

from these beds indicates a Callovian age to this part of the succession (Rocha, 1976).

The transition from Middle to Upper Jurassic is marked by an important tectonic episode, observed throughout Iberia that caused the folding of the Lower and Middle Jurassic strata. This situation can be observed at Cilheta beach, where Upper Jurassic limestones rest unconformable over gentle folded Callovian age marly limestones and marls. Above the unconformity plane is a very fossiliferous matrix supported conglomerate bed with ammonoids of the *Plicatilis* Biozone of Middle Oxfordian age. This bed is followed by a 200 m thick Upper Jurassic succession, consisting of interbedded shallow water limestones, marls and dolomites that can be observed along the coast from Martinhal beach to Almadena.

Lower Cretaceous strata are well represented in the Sagres - Lagos region; especially along the sea cliffs between the beaches of Burgau and Porto de Mós. Above the Upper Jurassic limestones several lithostratigraphic units are recognised (Rey, 2006) representing different sedimentary environments that span from Early Berriasian to Late Aptian times. Some of these units are bounded by angular unconformities that indicate tectonic instability related to last phases of rifting (Terrinha, 1998). The thickness of the Cretaceous strata in this region attains a maximum of 500 m.

The Lower Cretaceous deposits of this region, either carbonates or terrigenous, indicate a dominance of marine shallow water and lagoonal environments. Berriasian sediments are represented by lagoonal limestones and marls overlain by oolitic limestones that accumulated in tidal shoals. Upper Berrisian is marked either by an unconformity or fluvial sandstones indicating erosion of continental areas. Fossiliferous limestones of Valanginian age mark a renewed period of deposition and the beginning of a new transgressive cycle. The Hauterivian and Barremian sediments are consist of limestone and marls of lagoonal facies that indicate a regressive cycle.

Aptian strata represent a new transgressive cycle that can be seen without breaks from the beaches of Luz to Porto de Mós. The base of the cycle consists of sandstones with tidal and wave cross stratification. A conspicuous feature of these sandstones is the accumulation of the *Turritella* like gastropods whose long shell axes are current aligned. Conformably above this unit is the Luz Formation that consists of a thick succession of red to green mudstones deposited in littoral lagoons. The Luz mudstones pass upward to the Porto de Mós Formation, a thick succession composed by interbedded limestones and marls deposited in an open carbonate platform.



Fig. 18 Mareta Beach section photo in the middle part of the cliff is visible the trace of the unconformity between the Middle and Upper Jurassic.

GEOLOGICAL STOP 2

The Mareta Beach, Middle Jurassic

Location: Mareta beach (Fig. 16, 18, 19)

Time: 1:30 hours

Breif description on the geology and palynostratigraphy

The coastal exposures at Mareta beach (Praia de Mareta, Fig.19), immediately south of Sagres (Fig. 16) represent an important reference section for the Middle and Upper Jurassic of the Algarve Basin. A composite section is exposed, which is a sporadically fossiliferous mixed carbonate-claystone succession 100 m in thickness. This section has been assigned to the late Bajocian to early Kimmeridgian (Choffat, 1887; Rocha, 1976).

The residues of the samples studied are relatively abundant, including moderately well-preserved palynomorphs and dark woody phytoclasts. Pollen and spores are the dominant palynomorphs, with marine microplankton being subordinate. The miospores include, for example, bisaccate pollen, *Callialasporites dampieri*, *Callialasporites turbatus*, *Classopollis classoides*, *Cyathidites* spp., *Ischyosporites variegatus*, *Leptolepidites* spp. and *Perinopollenites elatoides*. The presence of *Ctenidodinium* spp., the *Ellipsoidictyum/Valensiella* group, *Korystocysta* spp. and *Valensiella ovulum*, present in the samples M3 and M4, is characteristic of the Bathonian Stage (Gocht, 1970; Riding et al., 1985).

Samples M25, M27 and M28 (Fig. 18) are from beds which are all considered to be of Early Callovian age, and are assigned to the *Macrocephalus* (=Herveyi) Zone (Rocha, 1976).

The dinoflagellate cyst floras (Plate VIII) are indicative of the Early Callovian due principally to the occurrence of *Impletosphaeridium varispinosum*. Moreover, the presence of *Ctenidodinium cornigerum*, *Ctenidodinium sellwoodii*, *Gonyaulacysta jurassica* subsp. *adecta*, *Korystocysta gochtii*, *Meiourogoniaulax caytonensis* and *Mendicodinium groenlandicum* is characteristic of this interval (Prauss, 1989; Riding, 2005). The dinoflagellate cyst associations from samples M45 and M47 are indicative of the Callovian Stage. *Gonyaulacysta jurassica* subsp. *adecta*, *Korystocysta gochtii*, *Meiourogoniaulax caytonensis*, *Mendicodinium groenlandicum*, *Tubotuberella dangeardii* and *Wansea acollaris* are all characteristic of the Callovian (Riding, 2005).

The relatively low diversity nature of this dinoflagellate cyst flora was probably influenced by several factors. The Mareta section represented relatively deep water conditions, seaward of reef limestone facies within a highly enclosed basin. Rocha (1976) envisaged an offshore pelagic setting, possibly with stratified water and occasional upwelling within a restricted marine environment. The restricted nature of the marine waters probably prevented the incursion of fully diverse Callovian dinoflagellate populations.

However, the palynostratigraphic research in the Mareta succession is currently still in progress.

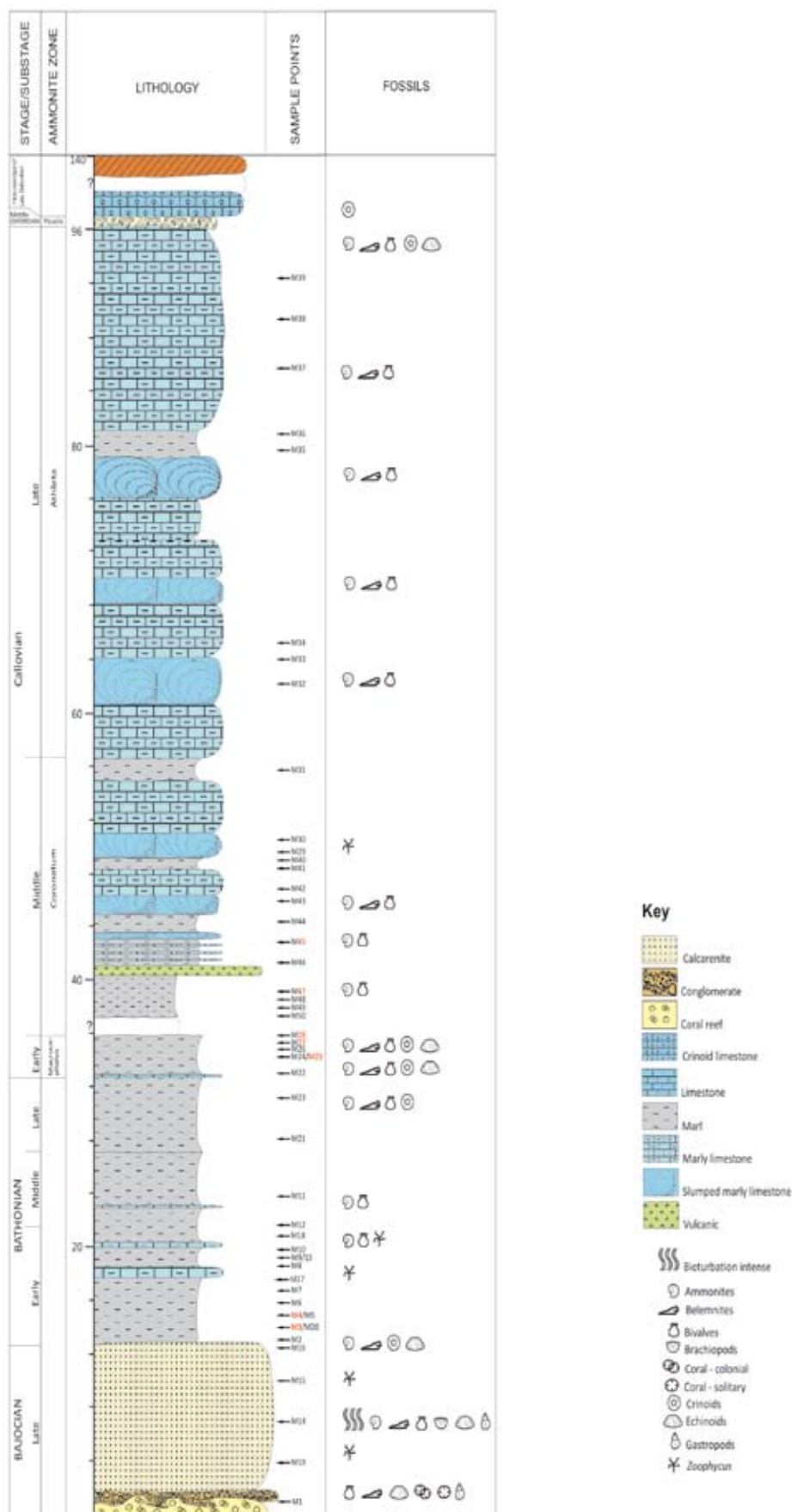


Fig. 18 Log of the Mareta Beach Section with sample location.

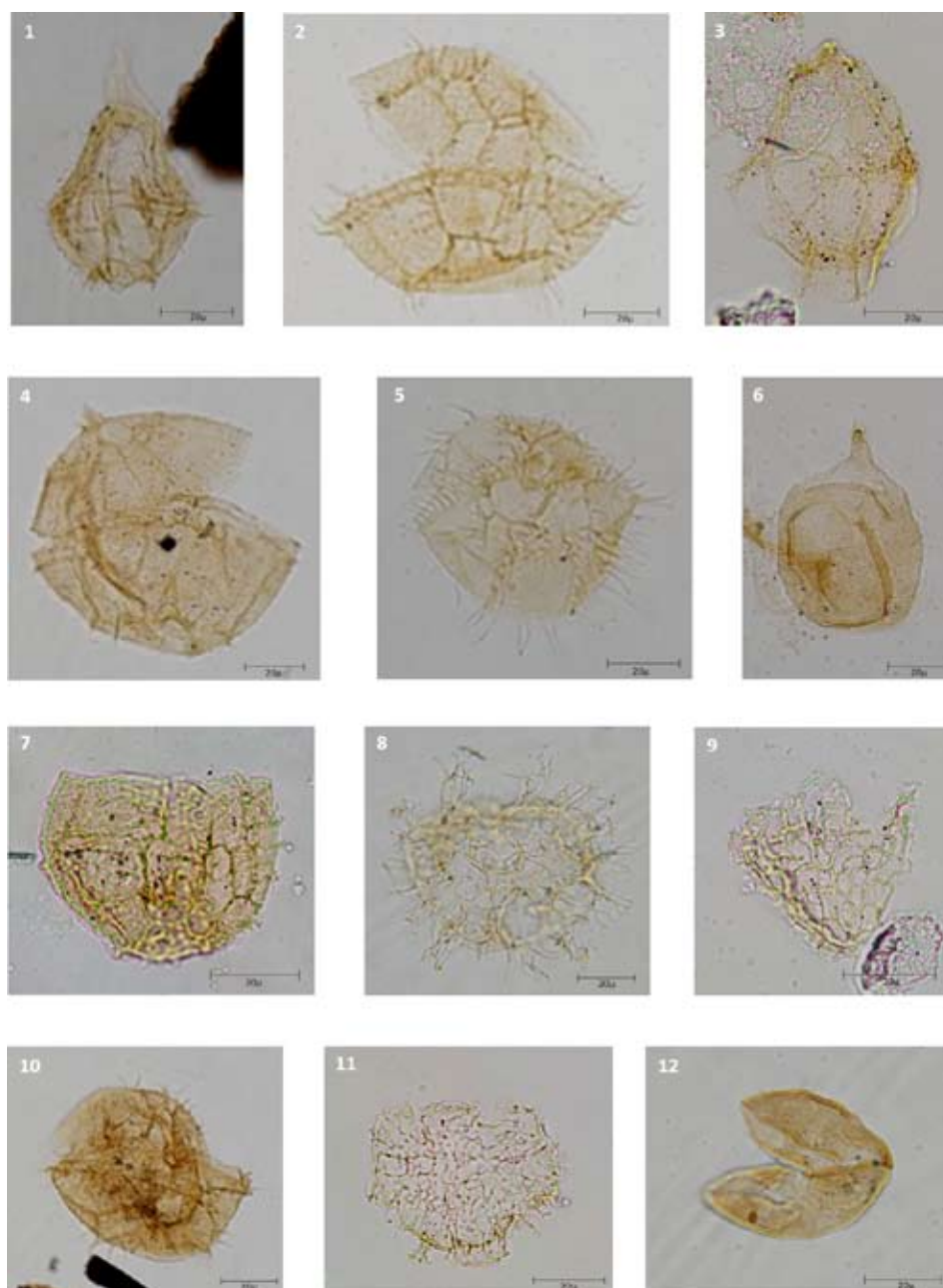


PLATE VIII. Dinoflagellate Cyst assemblage of Mareta Section.

1. *Gonyaulacysta jurassica* (Deflandre 1939) Norris & Sarjeant 1965 subsp. *adecta* Sarjeant 1982; Sample M47-1, R12/3.
2. *Ctenidodinium sellwoodii* (Sarjeant, 1975) Stover & Evitt 1978; Sample M28, 130-4, 2.
3. *Tubotuberella dangeardii* (Sarjeant 1968) Stover & Evitt 1978; Sample M45, P18.
4. *Korystocysta gochtii* (Sarjeant 1976) Woollam 1983; Sample M28, 114-11.
5. *Ctenidodinium cornigerum* (Valensi, 1953) Jan du Chêne et al. 1985; Sample M25, N3.
6. *Pareodinia ceratophora* (Deflandre, 1947) emend. Gocht 1970; Sample M28, 125,9-10,9.
7. *Meiouragonyaulax caytonensis* (Sarjeant 1959) Sarjeant 1969; Sample M3, O18/3.
8. *Systematophora areolata* Klement 1960; Sample M28, 140,9-8.
9. *Valensiella ovulum* (Deflandre 1947) Eisenack 1963; Sample M3, V30/2.
10. *Ctenidodinium* spp.; Sample M28, 138,5-11.
11. *Ellipsoidictyum*/*Valensiella* group; Sample M4, M12/3.
12. *Mendicodinium groenlandicum* (Pocock & Sarjeant 1972) Davey 1979; Sample M27, T23.



Fig. 20 **a.** Luz Beach Section photo; **b.** Detailed of the fine grained sandstones with cross stratification; **c.** Detailed of sandstone bed with *Nerinea algarbiensis*.

GEOLOGICAL STOP 3

The Luz Beach, Lower Cretaceous - Aptian

Location: Luz beach (Fig. 20, 21)

Time: 1:30 hours

Brief description on the geology and palynostratigraphy

In the Praia da Luz and the neighbour Praia de Porto de Mós, outcrops the most complete Aptian sedimentary succession of the Algarve basin (Fig. 15). The succession consists of mudstones interbedded with sandstones and limestones that accumulate, mostly, in lagoonal to littoral environments very susceptible, therefore, to sea-level variations (Rey, 1983; Correia, 1989; Cabral, 1995).

The structure of the succession is very straightforward; beds have dips that vary between 5° to 8° and strike N25° to N30°. Faulting is not complex, only two minor faults are identified, whereas jointing affects strongly the more competent lithologies (sandstones and limestones) in an orthogonal pattern. At Ponta das Ferrarias, marking the limit between the two beaches, the succession was intruded by basic igneous rocks of Upper Cretaceous age and contemporaneous of the Monchique Massif (Martins, 1998).

The succession at Praia da Luz starts at Ponta da Calheta in the west. Here outcrops medium to fine grained sandstones with tidal and wave cross stratification with 15 m thick (Fig. 20b. and 21). Another striking feature of these beds is the presence of very rich levels of practically intact gastropod shells of the genus *Nerinea algarbiensis* (Fig. 20 c.). The long axes of the shells are orientated N105°, suggesting current driven accumulation,

with the long axes parallel to the dominant tidal currents.

After the beach, towards the east, the cliffs exhibit the upper part of the Luz succession, which is composed by two formations, the Luz Formation at the base and the Porto de Mós Formation at the top. The Luz Formation consists of a monotonous succession (150 m in thickness) of red to green mudstones intercalated with marls deposited in restricted lagoonal-brackish environments with few open-marine episodes (Rey, 1983; Heimhofer et al., 2003). Pollens of the *Classopolis* group suggesting arid conditions dominate the palynology of the Luz mudstones (Heimhofer et al., 2003). This part of the succession is interrupted by one marine excursion with coarse to medium grained sandstones with cross and parallel stratification with 15 m thick. The sandstone beds are rich in charcoalised wood fragments. The depositional environment of these beds was of a littoral setting with strong continental influences. This formation is dated of Aptian by foraminifera and ostracods (Rey, 1983, 1986; Correia, 1989; Cabral, 1995).

The Porto de Mós Formation (more than 100 m thickness) is composed of thick-bedded, bioturbated limestones interbedded with calcareous marls. Typical sedimentary structures of the limestones include laminations, bored hardgrounds and fenestrae, indicating a carbonate-dominated

REFERENCES

- AZERÊDO, A. C., MANUPPELLA, G. & RAMALHO, M., 2003. The Late Sinemurian carbonate platform and microfossils with Tethyan affinities of the Algarve Basin (south Portugal). *Facies*, Erlangen, 48, pp. 49-60.
- BERTHOU, P. Y., CORREIA, F., PRATES, S. & TAUGOURDEAU, J., 1983. Essai de synthèse du Crétacé de l'Algarve: biostratigraphie, paléogéographie, sédimentation argileuse. Première étude: Biostratigraphie, Paléogéographie. *Bull. Inf. Géol. Bass. Parisien*, 20(2), pp. 3-24.
- CABRAL, M. C., 1995. Ostracodos do Cretácico inferior do Algarve e da região de Lisboa: Sistemática, bioestratigrafia, aspectos paleoecológicos e paleobiogeográficos. Phd thesis, Univ. Lisboa, 442 p.
- CHOFFAT, P., 1887. Recherches sur les terrains secondaires au sud du Sado. *Com. Comis. Trab. Geol. Portugal*, I, pp. 222-312.
- CLAYTON, G., 1996. Mississippian miospores. In: J. Janzonius & D.C. McGregor, Eds, *Palynology: principles and applications*, American Association of Stratigraphic palynologists Foundation, Vol. 2, pp. 589-596.
- CLAYTON, G., HIGGS, K., KEEGAN, J. B., 1977. Late Devonian and Early Carboniferous occurrences of the miospore genus *Emphanisporites* Mc Gregor in Southern Ireland. *Pollen et Spores*, 19, 3, pp. 415-425.
- CLAYTON, G., MCCLEAN, D., OWENS, B., 2003. Carboniferous palinostratigraphy: recent developments in Europe (Abstract 103). *International Congress on Carboniferous and Permian Stratigraphy*, Utrecht, August 2003.
- CORREIA, F., 1989. Estudo biostratigráfico e microfácies do Cretácico carbonatado da bacia sedimentar meridional portuguesa (Algarve). Ph.D thesis, Universidade de Lisboa, 377 p.
- DIAS, R.P., 2001. Neotectónica da região do Algarve. Phd Thesis. Univ. Lisboa, 369p.
- DOUBINGER, J., ADLOFF, M., PALAIN, C., 1970. Nouvelles précisions stratigraphiques sur la série de base du Mésozoïque portugais. Extr. "Comptes rendus des séances de l'Académie des Sciences de Paris", t. 270, Paris.
- GOCHT, H., 1970. Dinoflagellaten-Zysten aus dem Bathonium des Erdölfeldes Aldorf (NW-Deutschland). *Palaeontographica Abteilung B*, 129 (4-6), pp. 125-165.
- HEIMHOFER, U., HOCHULI, P., BURLA, S., ANDERSEN, N., WEISSERT, H., 2003. Terrestrial carbon-isotope records from coastal deposits (Algarve, Portugal): A tool for chemostratigraphic correlation on an intrabasinal and global scale. *Terra Nova* 15: pp. 8-13.
- HEIMHOFER, U., HOCHULI, P. A., BURLA, S., DINIS, J. M. L., WEISSERT, H., 2005. Timing of the Early Cretaceous angiosperm diversification and possible links to major palaeoenvironmental change. *Geology*, 33(2), pp. 141 - 144.
- HERBIG, H. G., KORN, D., MESTERMANN, 1999. Cresntria Event and Asbian-Brigantian Transition in the South Portuguese Zone -Sea Level Control on a Hemipelagic Late Dinantian Platform. *Facies*, 41, pp. 183-196.
- HIGGS, K., CLAYTON, G., KEEGAN, J.B., 1988. Stratigraphic and Systematic Palynology of the Tournaisian Rocks of Ireland. *Geol. Surv. Ireland, Spec. Paper*, 7: pp. 1-93.
- HIGGS, K., STREEL M., KORN, D., PAPROTH, E., 1992. Palynological data from the Devonian-Carboniferous boundary beds in the new Stockum trench II and the Hasselbachtal borehole, northern Rhenish Massif, Germany. *Ann.Soc. géol. Belgique*, 115, 2: pp. 551-557.
- HIGGS, K.T., AVCHIMOVITCH, S. I., LOBOZIAK, S., MAZIANE, N., STAMPIEN- SALEK, M., STREEL, M., 2000. Systematic study and stratigraphic correlation of the Grandispora complex in the Famennian of northwest and eastern Europe. *Review of Palaeobotany and Palynology*, 112, pp. 207-228.

- JULIVERT, M., FONTBONÉ, J., RIBEIRO, A., CONDE, L., 1972. Memória Explicativa del Mapa Tectónico de la Península Ibérica y Baleares. Inst. Geol. Min. España. Madrid.
- KORN, D. 1997. The Palaeozoic ammonoids of the South Portuguese Zone. *Mem. Serv. Geol. Portugal*, 33 p.
- KULLBERG, J. C., PAIS, J., MANNUPELLA, G., 1992. Aspectos gerais da tectónica alpina no Algarve. *Ciências da Terra*, Universidade Nova de Lisboa, 11, pp. 29-302.
- LOTZE, F. 1945. Zur Gliederung der Varisziden der Iberischen Meseta. *Geotek., Forch*, 6, pp. 78-92.
- MANUPPELLA, G. (coord.), 1992. Carta Geológica da Região do Algarve. escala 1/100 000, 2 folhas, Serviços Geológicos de Portugal, Lisboa.
- MANUPPELLA, G.; MARQUES, B.; RAMALHO, M. M., ROCHA, R. B., 1987. Le jurassique de l' Algarve; stratigraphie et evolución sédimentaire. 2nd InternSymp, Jurassic Stratigraphy, Excursion C, September, 19-21, Lisboa, pp. 3-33.
- MANUPPELLA, G., MARQUES, B., ROCHA, R. B., 1988. Evollution tectono-sédimentaire du basin de l'Algarve pendant le Jurassique. 2nd International Symposium on Jurassic Stratigraphy, Lisboa, pp. 1031-1046.
- MARTINS, L., KERRICH, R., 1998. Magmatismo toleítico continental no Algarve litoral (South Portugal): a Basanite-Lamprophyre Suite. *Geolines* 9, pp. 84-91.
- MARTINS, L. M. N. C. T. S., 1991. Actividade Ígnea Mesozóica em Portugal (Contribuição petrológica e geoquímica). Ph. D thesis, Fac. Ciências, Univ. Lisboa, 418p.
- MAZIANE, N., HIGGS, K.T., STREEL, M., 1999. Revision of late famennian miospore zonation scheme in eastern Belgium. *Journal of Micropalaeontology*, 18, pp. 17-25.
- MORENO C., PEREIRA Z., OLIVEIRA J.T., SIERRA S., 1996. Sediimentación Litoral en el Limite Devónico/Carbonífero del - Suroeste Portuguê (Zona Sur Portuguesa). *Geogaceta* 20 (I).
- OLIVEIRA J.T., 1990. Stratigraphy and Synsedimentary Tectonism. In: Pre-Mesozoic Geology of Iberia. Dailmeyer R.D., Martinez Garcia E., eds, Springer-Verlag Berlin, Heidelberg, pp. 334-347.
- OLIVEIRA J. T., HORN M., PAPROTH E., 1979. Preliminary Note on the Stratigraphy of the Baixo Alentejo Flysch Group, Carboniferous of Portugal and on the Palaeogeographic Development Compared to Corresponding Units in Northwest Germany. *Com. Serv. Geol. Portugal*, 65: pp. 151-168.
- OLIVEIRA, J. T., WAGNER-GENTIS, C., 1983. The Mértola and Mira Formations boundary between Dogueno and Almada de Ouro, Marine Carboniferous of South Portugal. In: M. J. LEMOS DE SOUSA ed., Contributions to the Carboniferous Geology and Palaeontology of the Iberian Península. Universidade do Porto, Faculdade de Ciências, Mineralogia e Geologia, Porto, pp. 1-39.
- OLIVEIRA, J., HORN, M., KULLMANN, J., PAPROTH, E., 1985. The stratigraphy of the Upper devonian and Carboniferous sediments of Southwest Portugal. C.R. 10e, International Congress Stratigraphy Geology Carboniferous, Madrid 1983, 1, pp. 1-17.
- OWENS, B., 1996. Upper Carboniferous Spores and Pollen. In: Palynology: Principles and applications. Janso-nius J., McGregor D.C, (eds.), American Association of Stratigraphic Palynologist, Found, Vol. 2, pp. 597-606.
- OWENS, B., MCLEAN, D., BODMAN, D., 2004. A revised palynozonation of British Namurian deposits and comparisons with eastern Europe. *Micropalaeontology*, vol 50, 1, pp. 89-103.
- PALAIN, C., 1976. Une série détritique terrígène, les "Grés de Silves": Trias et Lias inférieur du Portugal. *Mem. Serv. Geol. Portugal*, N. S., 25, 377p.
- PEREIRA, Z., 1997. Palinologia e petrologia orgânica do

Sector Sudoeste da Zona Sul Portuguesa. Ph.D thesis, Univ. Porto, Portugal.

PEREIRA, Z., 1999. Palinoestratigrafia do Sector Sudoeste da Zona Sul Portuguesa. *Comun. Inst. Geol. Min. Portugal*, 86, 1, pp. 25-57.

PEREIRA, Z., MATOS, J., FERNANDES, P., OLIVEIRA, J.T., 2007. Devonian and Carboniferous palynostratigraphy of the South Portuguese Zone, Portugal. *Comunicações Geológicas*, 94, pp. 53-79.

PEREIRA, Z., MATOS, J., FERNANDES, P., OLIVEIRA, J.T., 2008. New data on the late Famennian miospore assemblage of the Cercal Anticline (westernmost Iberian Pyrite Belt area), Portugal. Abstract Volume, 12th International Palynological Congress (IPC-XII 2008), 8th International Organisation of Palaeobotany Conference (IOPC-VIII 2008). Joint Congress in Bonn, 2008, pp. 219-220.

PEREIRA, Z., CLAYTON, G., OLIVEIRA, J.T., 1994. Palynostratigraphy of the Devonian-Carboniferous Boundary in Southwest Portugal. *Ann. Soc. géol. Belgique*, 117, 1, pp. 189-199.

PEREIRA, Z., CLAYTON, G., OLIVEIRA, J. T., 1995. Palynostratigraphy of the Devonian - Carboniferous succession of Southwest Portugal: preliminary results. Abstract XIII Int. Cong. Carboniferous - Permian, Poland Pol. Geol. Institute.

PRAUSS, M., 1989. Dinozysten-stratigraphie und palynofazies im Oberen Lias und Dogger von NW-Deutschland. [Dinocyst-stratigraphy and palynofacies in the Upper Liassic and Dogger of NW-Germany]. *Palaeontographica Abteilung B*, 214,1-4, pp. 1-124.

RAMALHO, M., 1972-1973. Observações micropaleontológicas sobre o Malm do Algarve occidental (Portugal). *Comun. Serv. Geol. Portugal*, 56, pp. 451-470.

REY, J., 1983. Le Crétacé de l'Algarve: Essai de Synthèse. *Comun. Serv. Geol. Portugal*, 69 (1), pp. 87-101.

REY, J., 1986. Micropalaeontological assemblages, palaeoenvironments and sedimentary evolution of Cretaceous deposits in the Algarve (Southern Portugal). *Palaeogeo., Palaeoclim. Palaeoeco.*, 55, pp. 233 - 246.

REY, J., 2006. Les Formations Crétacées de L'Algarve Occidental et Central. *Comun. Serv. Geol. Portugal*, 93,

pp. 39-80.

RIBEIRO, A., 1983. Structure of the Carrapateira Nappe in the Bordeira Area, SW Portugal, In: The Carboniferous of Portugal. M. J. LEMOS DE SOUSA and J. T. OLIVEIRA, eds. *Memórias Serviços Geológicos Portugal*, 29, pp. 91-93.

RIBEIRO A., OLIVEIRA J. T., RAMALHO M., RIBEIRO L., SILVA C., 1987. Carta Geológica de Portugal. escala 50000, Notícia Explicativa da Folha 48-D, Bordeira. *Serviços Geológicos de Portugal*.

RIBEIRO, A., QUESADA, C., DALLMEYER, R.D., 1990. Geodynamic evolution of the Iberian Massif. In DALLMEYER R.D., MARTINEZ GARCIA, E. (eds), *Pre-Mesozoic Geology of Iberia*. Springer-Verlag, pp. 399-409.

RIBEIRO, C., TERRINHA, P., 2007. Formation, deformation and chertification of systematic clastic dykes in a differentially lithified carbonate multilayer, SW Iberia, Algarve Basin, Lower Jurassic. *Sedimentary Geology* 196, pp. 201-215.

RIDING, J. B., 2005. Middle and Upper Jurassic (Call-

ovian to Kimmeridgian) palynology of the onshore Moray Firth Basin, northeast Scotland. *Palynology* 29, pp. 87-142.

RIDING, J. B., PENN, I. E., WOOLAM, R., 1985. Dinoflagellate cysts from the Type Area of the Bathonian Stage (Middle Jurassic, Southwest England). *Review of Palaeobotany and Palynology* 45, pp. 149-169.

ROCHA, R.B., 1976. Estudo estratigráfico e paleontológico do Jurássico do Algarve ocidental. *Ciências da Terra (UNL)*, Lisboa, 2, 178 p.

RUGET, C., 1973. Inventaire des microfaunes du Bathonien moyen de l'Algarve (Portugal). *Rev. Fac. Ciências Lisboa*, 2ª Série, C, Lisboa, XVII, 2, pp. 515 – 175.

STREEL, M., 1996. Middle and Upper Devonian miospores. In: *Palynology: Principles and applications*. JANSONIUS J., MCGREGOR D.C. (eds.), *American Association of Stratigraphic Palynologist, Found*, Vol. 2, pp. 575-587.

STREEL, M., HIGGS, K., LOBOZIAK, S., RIEGEL, W., STEEMANS, P., 1987. Spore stratigraphy and correlation with faunas and floras in the type marine Devonian of

the Ardenne-Rhenish regions. *Rev. Palaeobot., Palynol.*, 50, pp. 211-229.

TERRINHA, P., 1998. Structural Geology and Tectonic Evolution of the Algarve Basin, South Portugal. Unpublished Ph.D. thesis, Department of Geology, Royal School of Mines, Imperial College, London, 430p.

TERRINHA, P., ROCHA, R., REY, J., CACHÃO, M., MOURA, D., ROQUE, C., MARTINS, L., VALADARES, V., CABRAL, J., AZEVEDO, M.R., BARBERO, L., CLAVIJO, E., DIAS, R.P., GAFEIRA, J., MATIAS, H., MATIAS, L., MADEIRA, J., MARQUES DA SILVA, C., MUNHÁ, J., RE-

BÊLO, L., RIBEIRO, C., VICENTE, J., YOUNI, N., 2006. A Bacia Algarvia: Estratigrafia, paleogeografia e tectónica. In: *Geologia de Portugal no contexto da Ibéria*. DIAS, R., ARAÚJO, A., TERRINHA, P., KULLBERG, J.C. (eds.), Évora, pp. 247-316.

WOOD, G.D., GABRIEL, A.M., LAWSON, J.C., 1996. Palynological techniques - processing and microscopy. In: Jansonius, J., McGregor, D.C. (eds.), *Palynology: Principles and Applications*, American Association of Stratigraphic Palynologists Foundation, 1. Dallas, pp. 29-50.

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