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STRATIGRAPHIC MICROPALAEONTOLOGY OF THE UPPER JURASSIC NERITIC FORMATIONS OF PORTUGAL AND ITS TETHYAN CONTEXT.
I – THE ALGARVE BASIN

Miguel Ramalho *

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Dedicated to the memory of
Prof. Jean Cuvillier and Prof. Madeleine Neumann

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M. Ramalho[1]

Abstract: The revision of the micropalaeontological studies of the neritic formations of the Upper Jurassic (Kimmeridgian - Tithonian) of the Algarve Basin allowed a more detailed stratigraphic dating and a biozonation proposal based on foraminifera and calcareous algae species. Other groups are also identified (coralline sponges, stromatoporoids, charophytes, ostracods, and *incertae sedis*), some cited and illustrated for the first time in both Algarve and Western Portugal. Three new species of foraminifera (*Neokilianina concava, Amijiella? adherens* and *Involutina algarvensis*) and one calcareous alga (*Heteroporella sagresensis*) are described. On the basis of micropalaeontological data, lithology and tectonics, we discuss the evolution of the Algarve Basin during the Late Jurassic and compare it to others Tethyan carbonate platforms.

Keywords: Upper Jurassic, micropalaeontology, stratigraphy, palaeoenvironments, Algarve (Portugal).

Resumo: A revisão dos nossos estudos micropaleontológicos prévios sobre o Jurássico Superior da Bacia Algarvia (Kimeridgiano-Titoniano) permitiu uma atribuição estratigráfica e biozonação mais detalhadas, especialmente baseadas em foraminíferos e algas calcárias. Espécies de outros grupos (espongiários calcários, estromatoporídeos, carófitas, ostracodes e *incertae sedis*) também foram identificadas e figuradas, algumas citadas pela primeira vez para o Algarve e Portugal Ocidental. São descritas três novas espécies de foraminíferos (*Neokilianina concava, Amijiella? adherens* e *Involutina algarvensis*) e uma nova alga calcária (*Heteroporella sagresensis*). Com base nas caraterísticas micropaleontológicas, litológicas e dados tectónicos, são feitas diversas considerações quanto à evolução da Bacia Algarvia no Jurássico Superior, bem como comparações com as outras plataformas carbonatadas tetisianas.

Palavras-chave: Jurássico Superior, micropaleontologia, estratigrafia, paleoambientes, Algarve (Portugal).

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INTRODUCTION

The Mesozoic Algarve Basin occupies the onshore of the southern Portuguese territory and continues into the present continental shelf. The Upper Jurassic outcrops extend E–W and are interrupted only by a gap of about 20 km, between Alvor and Porches, caused by major faults probably related to the emplacement of the igneous Monchique Massif (Late Cretaceous). Some isolated outcrops, such as those at Carrapateira and Bordoal, are also considered in this study.

The present study is a revision and expansion of our preliminary results on the Upper Jurassic neritic formations of the Algarve Basin (Ramalho, 1972–73; 1985) and is based on the study of 24 geological sections (Fig. 1) and micropalaeontological analysis (about 3500 thin-section slides and 54 residues of marly samples).

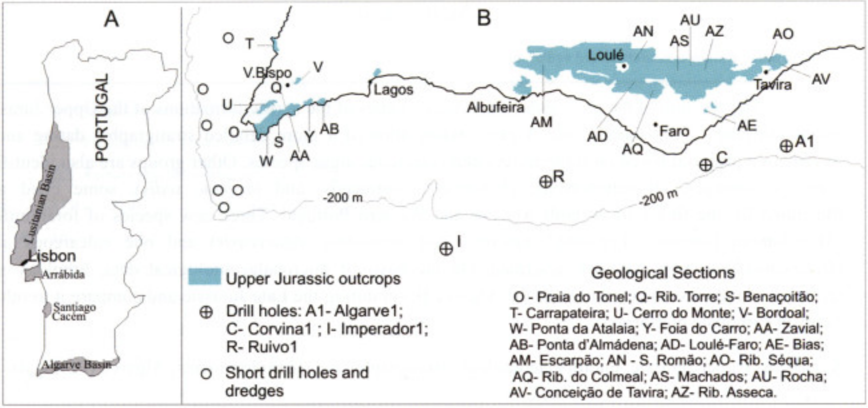

Fig. 1 – A: Location map of the main Portuguese basins and regions recording Upper Jurassic sequences; B: Geological sections and offshore drill holes of the Algarve Basin (-200m: Bathymetic line of the continental shelf).

1. THE EASTERN SECTOR OF THE ALGARVE BASIN

The Eastern Sector extends from Porches to the Guadiana River, and measures about 90 km in length and up to a width of 20 km. Upper Jurassic outcrops are extensively distributed in this sector, attaining a thickness of about 1000 m and representing all the sedimentary series of the Upper Jurassic. In contrast, the Upper Jurassic series of the Western Sector are incomplete because of an important stratigraphic hiatus; their total thickness reaches only about 290 m, and they are directly overlain by Cretaceous deposits.

The lower series with ammonites have been studied by Marques (1983) and Marques *et al.* (1998), who established a good biostratigraphic zonation in which several biozones of the middle Oxfordian–lower Kimmeridgian were recognized. However, in the present study, we are concerned less with the microfacies analysis of the pelagic beds and more with the overlying neritic series.

1.1. The Formations of the Eastern Sector

The formations of the Eastern Algarve sector have been defined and studied by several authors since Choffat (1883-87). The formations and their main characteristics are described in turn below:

The Hydraulic Limestones of Loulé Formation

Defined by Choffat (1883–87), the Hydraulic Limestones of Loulé Formation consists of light-grey compact limestones that are generally argillaceous and which have thin to thick, well-stratified beds separated by thin, marly intercalations. The thickness of the beds increases upwards, locally showing no apparent stratification. The total thickness of the formation reaches about 60 m.

This formation is poorly macrofossiliferous with few and poorly preserved ammonites collected by Choffat, possibly indicating middle Oxfordian age p.p. (Choffat, 1883-87, Marques, 1983). Outcrops of the formation are limited to east and west of Loulé town. The formation passes both laterally and vertically to the Peral Formation, and is considered to be a carbonate equivalent of the lower part of the overlying Peral Formation, described below. The Hydraulic Limestones Formation overlies upper Callovian limestones, separated by an important unconformity from the uppermost Callovian to the lower middle Oxfordian (Marques, 1983).

Peral Formation

Described by Choffat (1883–87) as "Calcaires verdâtres à *Perisphinctes effrenatus*," the ammonitic fauna of this formation was studied in detail by Marques (1983), who named it the Peral Formation. The minimum thickness of the formation is 200 m (Leinfelder *et al.*, 1993).

According to Marques (1983), the Peral Formation is composed of marly limestones and grey to greenish marls that are well stratified in thin to medium beds rich in ammonites, belemnites, siliceous sponges, and some plant remains. This formation presents two important discontinuities, dated as being in the Bimammatum and Planula zones. The base of the Peral Formation belongs to the Plicatilis Zone (middle Oxfordian base), but its upper boundary is diachronous between the Bimammatum Zone (upper Oxfordian) and the Hypselocyclum Zone (lower Kimmeridgian).

We verified in the field that in some places the transition beds of the Peral to Jordana formations show the following facies:

1. Sandstones and conglomeratic intercalations with Palaeozoic basement elements, or
2. Microbial–siliceous sponge bioherms, or
3. Bioclastic limestones.

Jordana Formation

This formation was named by Choffat (1883–87) as "Calcaires à polypiers siliceux" and more recently as the Jordana Formation by Marques (1983). The formation is characterized by silicification in thin, irregular layers or by silicified bioclasts that occur in well-stratified, dark-grey limestones in thin to medium beds. The basal beds also present intercalations of conglomerates, sandstones, dispersed quartz grains, ooids, and coarse bioclats. The thickness of the formation varies from a few metres to about 100 m.

According to several authors, the silicification is due to the increasing alkalinity of the seawater caused by the liberation of ammonia from the decay of organic matter, promoting favourable conditions for silica dissolution of the very abundant siliceous sponges, which seems too implie a calm environement.

The silicified layers can be found in outcrops between Moncarapacho and Foupana, but in other places the silicification is not so evident and may even be absent. Marques (1983) assigned the Jordana Formation to the lower Kimmeridgian. Subsequently, Marques *et al.* (1998) dated the base of the formation more precisely as being from the Platynota Zone (the base of the lower Kimmeridgian).

Cerro da Cabeça Formation

The Cerro da Cabeça Formation was described by Marques (1983) and Ramalho (in Oliveira, coord., 1992). The formation contains thick beds of microbial-coral biohermal/biostromal limestones, and some bioclastic intraformational breccias. These limestones are very fossiliferous, containing coarse bioclasts of bivalves, corals, brachiopods, stromatoporoids, gastropods, echinoderms, and calcareous and siliceous sponges, with microbial structures encrusting or binding these various bioclasts. The limestones may be partially or totally dolomitized. The thickness is variable and can reach 70 m. According to Marques (1983), the upper boundary of this formation is diachronic within the Kimmeridgian.

Escarpão Formation

The Escarpão Formation as described by Ramalho (1985) is composed of a thick succession of fossiliferous limestones and reaches up to 500 m in thickness. These limestones are more or less argillaceous, occur in thick to medium beds, are commonly bioturbated with a nodular structure in the field, and are interbedded with marls. In the eastern part of this sector (Tavira), these limestones show important quartziferous sandy intercalations.

The Escarpão Formation is recognized in both the Eastern and Western sectors, and also in the western Algarve continental shelf (Sagres Sector). The S. Romão Limestones Unit (Ramalho, in Oliveira, 1992) must be considered as being included in this formation based on the unit's lithological and microfacies affinities, as explained further below in Section 1.2.3.

The Escarpão Formation is lower Kimmeridgian-lower Tithonian (Ramalho, 1985).

Limestones with Anchispirocyclina lusitanica Formation

The Upper Jurassic sedimentary series in the Algarve Basin end with this formation, as they also do in the southern Lusitanian Basin (Ramalho, 1971). In the field, this formation is lithologically similar to the Escarpão Formation, consisting of medium to thick beds of fossiliferous compact or nodular clayey limestones, locally with black pebbles and alternating with marls. The thickness of the formation reaches 150 m and is assigned to the upper Tithonian according to Ramalho (1971, 1985) and Durand-Delga & Rey (1982). However, on the basis of magnetostratigraphic data from the geological Section of Bias (Eastern Sector of the Algarve Basin), the same section studied earlier by Durand-Delga & Rey (1982), Galbrun *et al.* (1990) proposed the middle of the ammonite Grandis Zone (lower Berriasian) as the extinction level of *A. lusitanica*.

In the Fóia do Carro section (Western Sector of the Algarve Basin), one of the upper levels containing *Anchispirocyclina lusitanica* shows dinosaur footprints, suggesting a very shallow depositional environment.

In Ponta d'Almádena (Western Sector of the Algarve Basin), this formation terminates with about 20 m of micritic limestones with black pebbles, algal laminites, complex arenaceous foraminifers including the last *Anchispirocyclina lusitanica*, and also dasyclads, interbedded with charophytes, ostracods, and black-pebble levels and overlain by dolomites. This indicates a very shallow lagoonal marine facies, probably with emersion events alternating with brackish-water episodes. We assign these layers to the "Purbeckian" based on their charophyte contents (Ramalho, 1972-73), and they represent the Jurassic-Cretaceous transition.

1.2. Geological Cross Sections

We choose to describe and synthesize only the four most significant geological cross-sections we studied in the Eastern Algarve Sector (Fig. 1). The description of the other geological sections can be found in Ramalho (1972-73; 1985), Rocha *et al.* (1979), Manuppella *et al* (1985a,b) and Ramalho (in Oliveira, coord., 1992). In the descriptions, we mention the ages and biounits established further below in Section 8.2.2. In the descriptions, we use the following abbreviations:

(r) – rare, (ab) – abundant. The ostracods in open nomenclature (e.g., A*sciocythere* sp. 2) are those cited and illustrated in Ramalho (1971).

1.2.1. The Escarpão Section (AM)

This is the most complete and representative geological section of the Eastern Algarve Upper Jurassic. This section starts in Ribeira da Quarteira, about 1 km north of Moinho do Cotovio, and continues to the west, crossing Quinta do Escarpão and its quarries.

Peral Formation (terminal beds) and the transition to the Jordana Formation

a – Medium beds of grey marly limestones with ammonites, some rounded quartz clasts, and shale intercalations. The upper limestone beds contain conical stromatolitic structures (≤30 cm long) with associated siliceous sponges. The limestones are micritic with microbial structures, sponge spicules, and pelagic organisms (>5 m).

b – Thick beds (3–5 m) of yellowish-grey marls, sandstone channelized beds, and lenticular limestones with quartz grains and carbonate pebbles. One limestone bed shows a microbial structure buildup with an irregular thickness of up to 1 m (18 m).

The limestones are composed of micrite with euhedral quartz and glauconite grains, bioclasts (echinoderms, bivalves, corals, and stromatoporoids), microbial structures at the top including siliceous sponges (hexactinellids and lychniskids) and also serpulids (as *Terebella lappilloides), Aeolosaccus* sp., *Bullopora irregularis*, *Placopsilina* sp., *Subdelloidina?* sp., *Tolypammina?* sp., *Nautiloculina* sp., *Tubyphytes morronensis,* and *Mohlerina basiliensis* (top), and hyaline pelagic organisms (including *Pithonella, Cadosina, and Globochaete), Terquemella* sp., and *Corynella* fragments.

Jordana Formation

c – Thin to medium beds of ferruginous sandstones, thick siliciclastic shales and, in the upper part, several coarsening-up conglomeratic levels with imbricated and rounded Palaeozoic constituents, indicating NE–SW-oriented currents. One of the uppermost beds contains silicified coral boulders (≃ 25 m).

d – Ferruginous and silicified sandstones in metre-scale beds, with scattered quartz pebbles passing laterally to quartz and carbonate conglomerate (2–3 m).

e – Dark-grey bioclastic limestones, with silicified coral blocks interbedded with thin silty marls and some lenticular conglomerate beds. In the upper part there is an isolated 2 m-thick coral bioherm (≃ 20 m).

The limestones are dolomitized intramicrites, and contain abundant bioclasts of corals and stromatoporoids, locally with microbial encrustations, gastropods, brachiopods, echinoderms, siliceous sponges (hexactinellids and lithistids), coralline sponges (*Corynella* cf. *quenstedti*, *Neuropora* sp., and *Chaetetidae*), *Terebella lapilloides* and other serpulids, *Tubiphytes morronensis, Nubecularia* sp., *Placopsilina* sp., *Bullopora irregularis, Nautiloculina oolithica* (r), miliolids, *Mohlerina basiliensis*, and *Terquemella* sp.

f – Not visible (30 m?)

Cerro da Cabeça Formation

g – Medium to thick beds of bioclastic limestones, with abundant large blocks of corals and stromatoporoids (<20 cm), although some layers reveal corals in life position. The upper 10 m also show two levels of conglomerates with rounded quartz constituents (≃ 70 m).

The limestones are biomicritic with fine quartz grains and some layers containing microconglomerates, interbedded with layers of microbial structures. The bioclasts, which are generally encrusted by microbial structures, are very abundant and include corals, stromatoporoids, echinoderms, gastropods, bivalves, brachiopods, serpulids, and sponge spicules. We have also identified *Tubiphytes morronensis*, *Nautiloculina oolithica, Troglotella incrustans*, small textularids and miliolids, *Lithocodium aggregatum*, nodules of *Bacinella irregularis*, *Thaumatoporella parvovesiculifera,* *Picnoporidium* aff. *lobatum*, *Solenopora?* sp., *Arabicodium* sp., *Koskinobulina socialis, Chaetetidae, Corynella* cf. *quenstedti, Neuropora* cf. *lusitanica*, *Dehornella choffati*, and *Actinostromaria tokadiensis*.

Escarpão Formation

Biounit A

h – Thick beds of bioclastic limestones, very rich in corals, stromatoporoids blocks, and bivalves (*Ostrea*) (5 m).

i – Medium beds of marly limestones, very rich in large oncoids and bioclasts (corals, stromatoporoids, and bivalves), with black pebbles in the upper part, interbedded with levels covered by soil (≃ 80 m).

j – Thin to medium beds of marly limestones with oncoids, gastropods, bivalves, terrestrial plant remains, and scattered quartz grains, intercalated by marly (?) levels covered by soil (≃ 100 m).

The limestones of these levels (**h**, **i**, and **j**) are micritic and oncolithic and contain abundant microfossils, including: *Alveosepta jaccardi, A. powersi* (r), *Pseudocyclammina* gr. *parvula, Everticyclammina virguliana* (top), *Audienusina fourcadei*, *Kurnubia palastiniensis* (top), *Labyrinthina mirabilis*, *Otaina*(?) sp., *Freixialina planispiralis*, *Nautiloculina oolithica, Mohlerina basiliensis*, *Trocholina elongata*, and *T.* sp.

The algae found are: *Bacinella irregularis, Lithocodium aggregatum*, *Girvanella* sp., *Cayeuxia* gr. *moldavica, Solenopora?* sp., *Picnoporidium* aff. *lobatum*, *Arabicodium* sp., algal nodules, *Lithophylum*(?) *maslovi*, *Permocalculus* sp., *Salpingoporella* gr. *pygmaea, S. annulata*, *Petrascula bursiformis*, *Likanella bartheli, Heteroporella lemmensis, H.* sp., *Clypeina caliciformis?*, *Russoella triangularis, Terquemella* sp., fragments of dasyclads, and *Thaumatoporella parvovesiculifera*. Also present are *Koskinobulina socialis, Terebella lappilloides, Corynella* cf. *quenstedti*, and *Neuropora* cf. *lusitanica.* Charophytes are common and are particularly important in level **j**, where they appear in micrites containing bird's-eye structures and are associated with ostracods, algal nodules, and small gastropods.

Biounit B

k – Medium beds of massive limestones, with very abundant gastropods at the base. The upper part of this level contains several marly (?) interbeds covered by soil (≃ 30 m).

The limestones are micritic and contain foraminifers such as *Nautiloculina oolithica, Alveosepta jaccardi, Pseudocyclammina* gr. *parvula, P. lituus* (?), *Audienusina fourcadei, Rectocyclammina chouberti, Kurnubia palastiniensis*, *Otaina magna, Levantinella egyptiensis*(?), *Parurgonina caelinensis, Charentia atlasica,* "*Valvulina*" gr. *lugeoni,* and *Neotrocholina* sp. *A*.

The algae found are *Cayeuxia* gr. *moldavica*, *Campbeliella striata, Likanella bartheli*, *Salpingoporella annulata, S.*gr. *pygmaea*, and *Thaumatoporella parvovesiculifera.*

l. This level can be subdivided as follows:

- **l.1.** – Compact, medium beds of limestone, but thicker in the upper part, with some reddish fine-grained intraclastic levels with ripple marks and algal laminites (60 m).
- **l.2**. – Medium beds of compact limestone separated by nonvisible soil cover intervals (marly levels?) (≃ 120 m).
- **l.3**. – Limestones, very rich in *Cladocoropsis mirabilis* (4 m).
- **l.4.** – Medium to thick beds of compact limestones, with gastropods (≃ 45 m).

These carbonate levels are micrites with scattered dolomite crystals, and contain the following microfossils:

Foraminifers: *Pseudocyclammina* gr. *parvula, P.* gr. *parvula-muluchensis* (top), *P. lituus*?, *Rectocyclammina chouberti, Freixialina planispiralis*?, *Kurnubia palastiniensis*, *Labyrinthina mirabilis*, *Parurgonina caelinensis*, *Charentia* cf. *atlasica, Nautiloculina oolithica, "Valvulina"* gr. *lugeoni, Trocholina alpina,* and *Eoguttulina* sp., amongst others.

Algae: *Campbeliella striata*, *Clypeina jurassica*, *Salpingoporella annulata*, *Likanella bartheli* (top), *Heteroporella lemmensis* (top), indeterminate dasyclad fragments, *Cayeuxia* sp., *Bacinella irregularis*, *Thaumatoporella parvovesiculifera*, *Picnoporidium* aff. *lobatum*, cyanophycean nodules, *Lithophylum*(?) *maslovi*, and other organisms including *Cladocoropsis mirabilis* (abundant at the top) and *Burgundia trinorchii*.

Biounit C

m – Medium beds of intraclastic limestones that are oolithic and oncolithic at the top, very fossiliferous (echinoids, corals, ostreids, and gastropods resembling *Cryptoplocus pyramidalis*), and interbedded with laminated levels (45 m).

The palaeobiota is less diversified than that of the underlying levels. *Campbeliella striata* is still present but *Clypeina jurassica* and *Kurnubia palastiniensis* are absent. In contrast, some new algal forms appear, including *Clypeina solkani, Permocalculus inopinatus*, *Heteroporella lemmensis, Russoella triangularis*, *Bucurella espichelensis* (r), *Cayeuxia* gr. *piae, C.* gr. *moldavica*, and indeterminate codiaceans. Also found are *Pseudocyclammina muluchensis, P.* gr. *parvula, Charentia atlasica, Freixialina planispiralis, Trocholina alpina, T. elongata*, and *Neotrocholina* sp. A. Several levels with bird's-eye structures and charophytes are observed.

Limestones with Anchispirocyclina lusitanica Formation

Biounit D

n – Medium beds of intraclastic limestones with yellowish zones and containing abundant fossils (including gastropods, ostreids, and echinoids). The uppermost bed is strongly bioturbated and capped by a possible discontinuity surface, covered by *in situ* ostreids. The limestone succession is interrupted by several soil-covered intervals (marls?) (~75 m).

The limestones are micritic, dismicritic, and dolomitic. The most important marker is the first occurrence of *Anchispirocyclina lusitanica*, which is associated with *A. neumannae, Charentia atlasica, Pseudocyclammina* gr. *parvula, P. muluchensis, P. lituus, Nautiloculina oolithica, Freixialina planispiralis, Rectocyclammina chouberti, Amijiella? adherens n. sp., Everticyclammina virguliana, Neotrocholina* sp. A, and *Trocholina* gr. *alpina–elongata*. The algal content includes *Bucurella espichelensis, Salpingoporella annulata, Likanella bartheli, Clypeina solkani, Heteroporella lemmensis, Russoella triangularis, Terquemella* sp., *Permocalculus inopinatus* (ab), *Lithophylum (?) maslovi*, and codiacean algae, amongst others.

o – Intraformational conglomerate of carbonate elements (≤30 cm), with black pebbles and abundant ostreids (0.5 m).

p – Medium beds of limestones, partially covered by soil (marls?) (40 m).

The limestones are micritic with the same microfossils as those of the underlying levels, but also with abnormal forms of *Anchispirocyclina lusitanica, Heteroporella lemmensis*, and abundant charophytes and ostracods.

The geological section ends by a lack of exposure.

1.2.2. The Asseca Section (AZ and AP)

This section starts near Ribeira d'Asseca (2.5 km northwest of Estiramantens) and continues on the eastern flank of Cerro Grande to about 5 km southeast of the village of St^a. Catarina da Fonte do Bispo.

Peral Formation

a – Grey marls (>3m)

Jordana Formation

b – Marly limestones with scattered silicification and silicified coral bioclasts, with abundant fine quartz grains in the upper part and interbedded with thin layers of shales (3 m).

The limestones are micritic with glauconite grains, and contain minor remains of terrestrial plants as well as *Pseudocyclammina* sp., *Nautiloculina oolithica, Rectocyclammina* *chouberti, Freixialina planispiralis(?), Kurnubia palastiniensis, Labyrinthina mirabilis, Textulariidae, Verneuilinidae,* miliolids, *Tubiphythes morronensis, Terquemella* sp., *Arabicodium* sp., indeterminate fragments of dasyclads, siliceous sponges (lithistids), coralline sponges (*Corynella* cf. *quenstedti* and *Neuropora* cf. *lusitanica*), *Chaetetidae*, and serpulids, amongst others.

Cerro da Cabeça Formation and transition to Escarpão Formation

c – Massive limestones with no evident stratification, with coral blocks, oncoids, and eroded bioclasts (17 m).

d – Massive grey bioclastic limestones, rich in quartz pebbles and oncoids, coarsening upwards, with ferruginous zones, interbedded with a small coral bioherm (~ 35 m).

e – Thick, massive limestones with coral blocks (<40 cm) and ferruginous zones (~ 50 m).

f – Thick, massive limestones with no visible stratification and with reddish zones, containing oncoids, coral blocks (<40 cm), and quartz pebbles (<5 cm). The uppermost 10 m are very rich in remains of both corals and stromatoporoids (~50 m).

This succession corresponds generally to alternations of beds of microbial–coral–stromatoporoid bioherms with open-platform microfacies beds.

Level **c** presents microbial structures (stromatolitic and thrombolitic) encrusting and binding bioclasts, showing cavities filled with internal sediment. The palaeobiota includes: siliceous spicules and sponges (lithistids), serpulids, small gastropods, *Keramosphaera* cf. *allobrogensis, Tubiphytes morronensis*, miliolids, small textularids, coral and stromatoporoid fragments encrusted by microbial structures, and one isolated fragment of a dasyclad (*Triploporella*?). Level **d** reveals an internal marine open-platform microfacies: micrites with abundant oncolithized bioclasts (corals, stromatoporoids, molluscs, and serpulids), arenaceous foraminifers, and calcareous algae. The foraminifers include *Pseudocyclammina parvula, P.* sp., *Alveosepta jaccardi, Rectocyclammina* (?) sp., *Labyrinthina mirabilis, Otaina* (?) sp., *Nautiloculina oolithica, Trocholina alpina*, *Mohlerina basiliensis*, and *Troglotella incrustans*.

The algae species include *Bacinella irregularis* (nodules), *Lithocodium aggregatum*, *Cayeuxia* gr. *moldavica*, *Lithophylum* (?) *maslovi*, and some dasyclads such as *Salpingoporella annulata* and *S.* gr. *pygmaea*. Other organisms include *Cladocoropsis mirabilis*, *Corynella* cf. *quenstedti, Neuropora* cf. *lusitanica*, *Helicoenia variabilis*, *Stylosmilia michelini, Blastochaetetes* cf. *bathonicus*, and *Terebella lappilloides*.

Levels **e** and **f** show alternations of the two types of microfacies found in levels **c** and **d**. However, their microbial layers are richer in species than are those of levels **c** and **d** and, in addition, contain *Bullopora tuberculata*, *Placopsilina* sp., *Glomospira* sp., *Koskinobulina socialis,* globigerinids (?), *Bacinella irregularis, Microsolena agariciformis*, *Chaetetopsis crinita*, *Fungiastrea arachnoides, Parachaetetes* sp., and *Placochloenia (?)* sp. Some rare and indeterminate dasyclad fragments are also found.

The internal open-platform microfacies of these levels, in addition to the aforementioned organisms, also show some new organisms, including *Protopeneroplis striata* (r), *Arabicodium* sp., codiaceans (?), *Picnoporidium* aff. *lobatum*, and *Solenopora?* sp.

Escarpão Formation

Biounit A

g – Medium to thick-bedded limestones that are oncolithic and bioclastic (corals, stromatoporoids, gastropods, ostreids, and rudists), with scattered remains of terrestrial plants and some layers of rounded quartz pebbles. A bed with gastropods (*Cryptoplocus*) is found in the middle part of this level (~ 110 m).

These limestones are biomicrites with foraminifers including *Nautiloculina oolithica, Pseudocyclammina* gr. *parvula, Alveosepta jaccardi, Charentia atlasica, Neokilianina? lata, Labyrinthina mirabilis, Kurnubia palastiniensis*, *Mohlerina basiliensis, Trocholina alpina,* and *Troglotella incrustans.*

The calcareous algae found are *Salpingoporella annulata, S.* gr. *pygmaea, Likanella* sp., *Terquemella* sp., *Marinella lugeoni* (top), *Solenopora?* sp., *Picnoporidium* aff. *lobatum, Arabicodium* sp., *Lithophylum(?) maslovi, Cayeuxia* sp., and *Bacinella irregularis.* Several corals and stromatoporoids were identified, including *Cladocoropsis mirabilis, Burgundia trinorchii, Thamnasteria* sp., *Fungiastrea* sp., *Stromatoporina* sp., *Chaetetopsis koltzi, C. crinita, Helicoenia variabilis,* and *Stylosmilia michelini.*

Biounit B

h – Thick beds of oncolithic limestones with a continuous level of a branched coral bioherm *in situ* which is truncated at the top by a regular surface overlaid by a gastropod-rich layer (>15 m).

i – Medium to thick beds of grey bioclastic limestones with oncolithic levels and interbedded with nodular bioturbated marly limestones (~ 180 m).

Levels **h** and **i** are characterized by the presence of *Campbeliella striata* and the uppermost occurrence of *Clypeina jurassica* (top), and are associated with the same foraminifers as found in level **g** but contain in addition *Everticyclammina virguliana, Involutina algarvensis* n.sp., *Rectocyclammina chouberti, Otaina magna, Neotrocholina* sp. *A*, and *Freixialina planispiralis.*

The new algal forms are *Heteroporella anici, Likanella bartheli, Clypeina jurassica* (top), and *Permocalculus inopinatus.*

The marly residues contain *Cytherella* gr. *suprajurassica, Asciocythere* sp. 2, *Schuleridea* sp. 1, *Cytheropteron* sp. 1, and also *Alveosepta jaccardi* and *Ammobaculites* sp.

j – Nodular and bioturbated dark-grey marly limestones, thin to medium bedded, with gastropods, bivalves, and isolated corals (20 m).

Microfossils are scarce. This level corresponds to the uppermost occurrence of *Alveosepta jaccardi,* which is associated with rare *Salpingoporella annulata.*

Biounit C

k - This level has the same lithology as that of the underlying level and is relatively poor in microfossils, showing rare sections of *Rectocyclammina chouberti, Kurnubia palastiniensis, Everticyclammina virguliana, Trocholina* sp., codiacean algae, *Lithocodium aggregatum, Thaumatoporella parvovesiculifera, Heteroporella lemmensis,* and *Salpingoporella annulata.* We also registered numerous sections of isolated corals and intercalations of charophytes (220 m).

Overlying soil interrupts the geological section.

1.2.3. The S. Romão Section (AN)

This is the type section of the "S. Romão Limestones Unity" described by Ramalho (in Oliveira coord., 1992). Jonischkeith (1993) subsequently studied the same section and considered this Unity as an isolated carbonate platform belonging to the Peral Formation, although we do not concur with that opinion, as explained at the end of this Section 1.2.3.

The S. Romão Section starts from the road barrier west of Malhão village, crosses the V. G. Rocha quarry, which is a different place relatively to the Rocha (AU) microbial build-up geological Section (see Fig. 1) and continues to the north along the road, until soil cover prevents observation.

Peral Formation (terminal beds)

a – Thin to medium beds of yellowish-grey marly limestones with ammonites alternating with marls. The ammonites belong to the upper Oxfordian (personal information from Marques, 1984) (>10 m).

The limestones are micrites with pelagic microfossils such as small miliolids, textularids, "filaments" (ab), spicules (ab), echinoderm fragments, thin ostracods, *Aeolosaccus* sp., and *Pithonella (?)* sp.

Jordana Formation

b – Oolithic limestones with quartz grains, black pebbles, and bioclasts (including crinoids and belemnites). Some levels present low-angle oblique stratification (8 m).

The limestones are oopelbiosparites, with quartz grains. The bioclasts, which are oolitized and eroded, are from echinoids, corals, coralline sponges (*Neuropora* cf. *lusitanica* and *Corynella* cf. *quenstedti*), and siliceous sponges (spicules and hexactinellids). A few microfossils are present, such as *Nautiloculina oolithica*, isolated *Tubiphytes morronensis, Nubecularia* sp., and *Terquemella* sp.

Cerro da Cabeça Formation

c – Thick beds of massive light-coloured limestones, with a large number of coral and stromatoporoid blocks, crinoids, and other macrofossils (35 m).

This level contains microbial–coral bioherms, interbedded with bioclastic levels, with fragments of these bioherms being encrusted by microbial structures, and also containing *Tubiphytes morronensis*, hexactinellids, coralline sponges, brachiopods, bivalves, echinoids, crinoids, bryozoa, and serpulids. We have also identified: *Nautiloculina oolithica*, *Pseudocyclammina sp.*, *Alveosepta jaccardi*, textularids, miliolids, lituolids, *Koskinobulina socialis*, *Bacinella irregularis*, *Solenopora*? sp. *Cayeuxia* sp., *Arabicodium* sp., and *Girvanella* sp., and also coralline sponges (*Neuropora* cf. *lusitanica* and *Corynella* cf. *quenstedti)*, *Aeolosaccus* sp., and "filaments".

d – Massive dolomites, with coral sections in some places (30–40 m).

Escarpão Formation

Biounit A

e - Thick beds of fossiliferous (corals, stromatoporoids, bivalves, and crinoids) grey limestones, overlain by thick beds of oncolithic limestones (15 m).

f – Medium to thick beds of limestones containing some coral and stromatoporoid fragments, with several oncolithic levels in the upper part (~ 135 m).

g – Thin beds of marly and nodular limestones interbedded with thick grey marls containing corals and ostreids (18 m).

h – Medium to thick beds of whitish limestones containing corals and stromatoporoids, overlain by medium to thin beds of marly limestones containing corals and ostreids. The uppermost bed contains the ammonite *Idoceras balderum* from the Divisum Zone, which represents the top of the lower Kimmeridgian (Schmid & Jonischkeit, 1995) (~ 15 m).

i – Thick beds of fossiliferous limestones containing corals, stromatoporoids, and gastropods, amongst others, with some oncolithic levels, interbedded with thin and medium irregular layers of marly limestones and marls containing corals (~ 90 m).

The geological section ends by soil cover.

This succession of levels **e** to **i**, totalling about 270 m thick, presents from the base to the top the same type of microfacies: micrites with abundant oncoids and rich microfossiliferous content, as follows.

Foraminifers: small textularids, verneuilinids, miliolids, lituolids, *Lenticulina* sp., *Nautiloculina oolithica, Freixialina planispiralis, Charentia (?)* sp., *Pseudocyclammina* gr. *parvula*, *Everticyclammina virguliana, Rectocyclammina(?)* sp., *Otaina magna*, *Alveosepta jaccardi*, *Labyrinthina mirabilis*, *Levantinella egyptiensis* (?), *Bullopora tuberculata*, *Trocholina* sp., *Mohlerina basiliensis*, and *Tubiphytes morronensis.*

Calcareous algae: microbial structures, *Cayeuxia* sp., *Bacinella irregularis*, indeterminate *Codiaceae*, *Lithophylum* (?) *maslovi, Picnoporidimm* aff. *lobatum, Solenopora?* sp., *Russoella triangularis, Arabicodium* (?) sp., *Thaumatoporella parvovesiculifera*, *Salpingoporella* gr. *pygmaea*, *S. annulata*, *Likanella* *bartheli,* dasyclad fragments, and *Marinella lugeoni.*

Other organisms: *Cladocoropsis mirabilis* (very abundant about 150 m below the top of the section), *Dehornella choffati, Corynella* cf. *quenstedti, Burgundia trinorchii, Terebella lappilloides*, and other serpulids, stromatoporoids, bryozoa, and corals, amongst others.

Ostracods: *Schuleridea* sp. 1, *Cytherella* gr. *suprajurassica*, and *Asciocythere* sp. 2.

The stratigraphic position of S. Romão Unity

The main part of this section should belong to the Escarpão Formation because of its lithological succession, facies and microfacies, and the age of the ammonitic level. This contrasts with the proposal of Schmid & Jonishkeit (1995), who considered S. Romão Unity as part of the Peral Formation.

1.2.4. The Machados Section (AS)

This section is interesting because the Jordana Formation presents a great thickness in this locality. The section can be readily sampled along the road from Faro to S. Brás de Alportel, starting about 0.7 km south of this village and finishing near Machados. The transition of the Peral Formation to the Jordana Formation is not able to be observed.

Jordana Formation (*pro pars*)

a – Compact grey limestones in medium to thick beds, with siliceous nodules and silicified fossil fragments (~ 50m).

b – Very thick beds of compact grey limestones with silicified bioclasts (corals, stromatoporoids, crinoids, sponges, and ostreids) (20 m).

The limestones of these two levels are composed of micrites with very abundant tuberoids and silicified bioclasts, *Tubiphytes morronensis, Nautiloculina* sp., small lituolids, textularids and miliolids, *Nubecularia* sp., *Placopsilina* sp., *Neotrocholina* sp. A, *Spirillina* sp., *Lenticulina* sp., *Bullopora tuberculata*, siliceous sponge spicules (ab), coralline sponges such as *Corynella* cf. *quenstedti* and *Thalamopora lusitanica*, *Terebella lappiloides* and other serpulids, "filaments", ostracods, *Aeolosaccus* sp., *Lithocodium aggregatum* and *Bacinella irregularis*, *Salpingoporella* gr. *pygmaea*, *Terquemella* sp., indeterminate codiacean algae, *Solenopora?* sp., *Thaumatoporella parvovesiculifera*, *Marinella lugeoni,* and *Koskinobulina socialis*, amongst others.

Some beds show well-developed microbial thrombolitic structures associated with siliceous sponges and spicules (*Lychniscosa* and *Hexactinosa), Terebella lapilloides*, and other serpulids, *Tubiphytes morronensis*, *Solenopora?*, sp., and bioclasts of stromatoporoids, corals, brachiopods, and crinoids with microbial encrustations.

Transition levels

c – Thick beds (<2 m) of compact grey limestones with reddish zones, fossiliferous (blocks of corals and stromatoporoids, crinoids, gastropods, rudists (?), and ostreids), and containing some oncolithic levels (65 m).

These beds are micritic with abundant tuberoids. The microfossil content is similar to that of the underlying beds but also containing abundant coral and echinoderm remains, siliceous and coralline sponges, *Otaina* aff. *magna*, *Nautiloculina oolithica, Picnoporidium* aff. *lobatum, Bacinella irregularis,* codiaceans, *Marinella lugeoni, Salpingoporella* gr. *pygmaea*, and *Terquemella* sp. Some levels also reveal well-developed thrombolitic structures similar to those in the underlying beds.

Cabeça Formation

d – Dolomitic limestones containing coral blocks, crinoids, and brachiopods, amongst others, overlain by thick dolomites (>10 m).

The thin-sections also reveal, in addition to the microfossil content of the underlying beds, *Kurnubia* sp. and *Salpingoporella annulata.*

The Machados section is interrupted by a fault.

This section reveals some interesting characteristics, as follows:

1 – There is an essentially continuous transition from the silicified levels of the Jordana Formation to the dolomitised Cabeça Formation, in which the microfossil content maintains the same forms but with a progressive enrichment in reefal organisms and an increasing degree of dolomitization.

2 – However scarce some microfossils are found in these two formations, namely, *Salpingoporella* gr. *pygmaea, S. annulata, Terquemella* sp., *Picnoporidium* aff. *lobatum, Kurnubia palastiniensis*, *Labyrinthina mirabilis* and *Otaina* aff. *magna*, all of which are commonly present in the Escarpão Formation, showing a micropalaeontological affinity between these three formations (see Sections 8.2.2 and 9.1.2 further below).

2. THE WESTERN SECTOR OF THE ALGARVE BASIN

The Upper Jurassic series of this sector are well exposed along the coast and also comprises two isolated outcrops overlying the Palaeozoic basement (Carrapateira and Bordoal) (Fig. 1). This series is also well exposed in some stream margins.

2.1. Geological cross sections

2.1.1. The Sagres area Section

The following synthetic succession is based on several geological sections previously described by Ramalho (1972–73), Rocha *et al*. (1979) and Ramalho (in Oliveira, coord., 1984).

Upper Callovian

According to Rocha *et al.,* (1979) the last levels of this stage are represented by thin to medium argillaceous limestones interbedded with thin shale interstratifications dated from the Athleta Zone. The last bed of the Callovian presents a wavy ferruginous and karstified surface. This Callovian series is tilted what corresponds to an angular unconformity that separates the Middle to the Upper Jurassic.

Those limestones are pelagic argillaceous pelmicrites with abundant fragments of echinoderms, sponge spicules and "filaments". They also contain small benthic foraminifers as *Glomospira* sp., *Ophthalmiidae*, textularids, and *Spirillina* sp.

Tonel Unity

At Tonel beach, overlying the Callovian series are observed:

a – Intraformational conglomerate containing ferruginous and phosphatized fossiliferous nodules with numerous fossils as ammonites from the upper Callovian (Coronatum Zone) to the middle Oxfordian (Plicatilis Zone), as described by Rocha (1976) (0.3 m).

b – Thick beds of massive whitish bioclastic limestone, microconglomeratic at the top, with eroded and oolitized fragments of crinoids (ab), corals, codiaceans, *Arabicodium* sp., *Terquemella* sp., and small arenaceous foraminifers (~15 m).

Escarpão Formation

Biounit A

The following layers may be observed in several locations along the coast, namely between Baleeira and Ponta da Atalaia (East and Southeast of Sagres, respectively), where the following are found:

– Oolitic-limestones, more or less dolomitized, with eroded fragments of crinoids (ab), corals, *Arabicodium* sp., and other bioclasts, and thick dolomitic layers (20–30 m?).

This level is equivalent to the level **b** and probably to its upper parts, which are not seen at Tonel beach.

c – Micritic marly limestones, locally containing black pebbles, very rich in charophytes and ostracods, and interbedded with marls containing *Dictyoclavator ramalhoi* and *Porochara* sp. (15 m).

The cross-section continues at Tonel beach, where the base of the series is cut by faults.

d – Nodular, bioturbated clayey limestones, interbedded with carbonate conglomerates, black-pebble levels, and dark bituminous marls. The limestones are rich in fossils, including bivalves, gastropods, crinoids, corals, and stromatoporoids, such as *Dehornella choffati* (≤80 m).

The limestones are micritic with rich microfossiliferous content, as follows.

Foraminifers: *Nautiloculina oolithica, Pseudocyclammina* gr. *parvula, P. lituus, Alveosepta jaccardi, A. powersi, Everticyclammina virguliana, Kurnubia palastiniensis, Neokilianina* gr. *rahonensis, N. concava* n. sp., *Parurgonina caelinensis, Otaina magna, Levantinella egyptiensis* (?), "*Valvulina*" gr. *lugeoni, Paravalvulina* aff. *complicata, Neotrocholina* sp. A, and *Trocholina alpina*.

Algae: *Salpingoporella annulata, Likanella bartheli* (ab), *Heteroporella lemmensis, Russoella triangularis, Terquemella* sp., indeterminate fragments of dasyclads, *Cayeuxia* gr. *piae, C.* gr. *moldavica, Picnoporidium* aff. *lobatum, Thaumatoporella parvovesiculifera, T.* sp., *Bacinella irregularis, Lithocodium aggregatum*, and *Bacinella* nodules (ab).

Coralline sponges: *Corynella* cf. *quenstedti* and *Thalamopora lusitanica*.

Stromatoporoids: *Burgundia trinorchii, Dehornella choffati*, and *Siringostromaria pruvosti*.

A deposit corresponding to a short episode with pelagic influence containing *Protopeneroplis striata*, calcispheres, and *Pithonella* sp. occurs at the base of level **d**.

Some layers with a subaerial influence are also present in this succession, showing black pebbles, *fenestrae*, and shrinkage structures, along with abundant ostracods and charophytes. The marls were studied by Helmdach & Ramalho (1976), and the ostracod composition of these marls is: *Cytherella* gr. *suprajurassica, Asciocythere* sp. 2., *Schuleridea* sp. 1, *Cytheropteron* sp., *Monoceratina* sp., *Leiria striata, Bisulcocypris* gr. *fluxans, B. algarbiensis*, and *Timiriasevia mackerowi*, which are associated with the charophytes *Dictyoclavator ramalhoi, Echinochara* n. sp., *Porochara fusca*, and *P. raskyae*.

Biounit B

e – Polygenic conglomerate (1 m thick) overlain by nodular, bioturbated argillaceous limestones, with black-pebble levels and terrestrial plant remains (>35 m).

The limestones are micrites and contain, in addition to the microfossils reported for levels **c** and **d**, *Freixialina planispiralis, Orbitolinopsis? sp.* and some important new algal forms, including *Campbelliella striata* and *Clypeina jurassica*, which are associated with *Salpingoporella* gr. *pygmaea, Heteroporella sagresensis* n. sp., *Russoella triangularis, Permocalculus*? sp., and *Solenopora*? sp. We also note the abundance of *Cladocoropsis mirabilis* in the lower part of this level.

Biounit C

f – Massive limestones, partially covered by soil, containing gastropods and abundant *Cladocoropsis mirabilis*, bioturbated in their upper parts, and interbedded with thick dolomitic layers (40–80 m).

The limestones are micritic, with the following foraminifers: *Pseudocyclammina* gr. *parvula, P. muluchensis, Audienusina fourcadei, Freixialina planispiralis*, and *Kurnubia palastiniensis* (?), and algae such as *Likanella bartheli, Heteroporella lemmensis, Salpingoporella annulata, Campbeliella striata, Bucurella espichelensis* (r), and *Thaumatoporella parvo-vesiculifera*.

Limestones with Anchispirocyclina lusitanica Formation

Biounit D

g – Massive limestone beds, partially dolomitized, and interbedded with yellowish to rose dolomites (40–60 m?).

The limestones are micritic with the following microfossils. Foraminifers: *Anchispirocyclina lusitanica, A. neumannae, Levantinella egyptiensis(?), Feurtillia frequens, Pseudocy-*

clammina gr. *parvula, P. muluchensis, Rectocyclammina chouberti*, *Freixialina planispiralis*, *Charentia atlasica(?)*, *Nautiloculina oolithica, Trocholina alpina, T. elongata*, *Neotrocholina* sp. A, and miliolids (ab) associated with the algae *Bucurella espichelensis, Likanella bartheli, Heteroporella lemmensis, Russoella triangularis, Salpingoporella annulata, Terquemella* sp., *Campbeliella striata* (rare at the base), *Clypeina jurassica, Permocalculus inopinatus, Picnoporidium* aff. *lobatum,* and *Bacinella irregularis*, amongst others.

h – Medium to thin beds of marly limestones with irregular boundaries and erosion surfaces, interbedded with black-pebble levels and intraformational conglomerates. The upper part contains thick beds of marls with black pebbles and thin dolomitic layers (25 m).

In the Fóia do Carro Section one of the uppermost layers of this formation contains several dinosaur footprints.

The limestones are oolitic intramicrites, with black pebbles and *fenestrae*. The microfossil content is similar to that of the underlying layer **h**, but is scarcer and also contains algal laminites and some abnormal forms of *Anchispirocyclina lusitanica.*

The marls reveal ostracods, such as *Timiriasevia mackerowi* and *Fabanella polita ornata*, and charophytes, such as *Dictyoclavator fieri, Nodosoclavator bradleyi*, *Globator maillardi*, *Perimneste horrida*, and *Porochara* sp.

This level is overlain by Cretaceous rock series.

2.1.2. Isolated outcrops

The Carrapateira Section (T)

This outcrop has been studied by several authors since Choffat (1883–87), including investigations of its coral macrofauna by Koby (1904–05), Geyer (1956), Rosendhal (1985) and Beauvais (in Ribeiro *et al.*, 1987). Its dinoflagellates have been studied by Borges (2012) and the micropalaeontology by Ramalho (1972–73, and in Ribeiro *et al.,* 1987*).*

Limestones and dolomites of Zimbreirinha (cf. Ribeiro et al., 1987)

a – Dolomites and micritic limestones interbedded with greyish marls with carbonate elements (>13 m).

b – Compact greyish limestones, locally showing thick beds, and containing black pebbles and gastropods (20 m).

These two levels correspond to bioturbated pelmicrites, with *fenestrae*, gastropods, bivalves, sponge spicules, ostracods, and codiacean algae. These levels have no correspondence to the Tonel Section and we infer them to be lower Kimmeridgian.

Tonel Unity

c – Thick beds of compact whitish limestones, intrabiosparites with abundant eroded crinoid elements, bivalves, and *Trocholina alpina.* These beds are comparable to level **b** of Tonel Unity (see Section 2.1.1) (~ 10 m).

d – Reddish pelites (3–5 m).

Escarpão Formation

Biounit A

e – Thick grey marls with black pebbles interbedded with some carbonate levels. These marls contain numerous charophytes (*Dictyoclavator ramalhoi* and *Porochara* sp.), ostracods (*Bisulcocypris algarbiensis*, *B.* gr. *fluxans*, and *Leiria striata*), and foraminifers (*Alveosepta jaccardi* and *Everticyclammina virguliana*) (10 m).

f – Grey marly fossiliferous limestones, commonly bioturbated, and interbedded with marls (~ 40 m).

The limestones are micrites, locally with quartziferous silt and bioclasts of corals (ab), stromatoporoids, crinoids, sponge spicules, brachiopods, bivalves, and ostracods.

Foraminifers: *Alveosepta jaccardi* (ab), *Pseudocyclammina* gr. *parvula*, *Everticyclammina virguliana*, *Parurgonina caelinensis*, and *Nautiloculina oolithica.* Algae: *Cayeuxia* gr.

moldavica, Salpingoporella annulata, Likanella bartheli, Terquemella sp., and charophytes (oogonia and stems). Other organisms: *Burgundia trinorchii* and *Corynella* cf. *quenstedti.*

The marls contain *Alveosepta jacardi, Everticyclammina virguliana, Cytherella* gr. *suprajurassica, Asciocythere* sp. 2, *Porochara* sp., and charophyte stems.

g – Thick beds of greenish marls, yellowish where altered, interbedded with marly limestones that have medium layers containing silicified corals[2] (ab) in life position and also gastropods, bivalves, and echinoids (~ 20 m).

The microfossils are richer in content compared with the underlying level, and additionally include *Spirillina* sp., lagenids, and some *Alveosepta jaccardi* with incipient unrolling morphology.

The algae content is *Heteroporella lemmensis* and *Thaumatoporella parvovesiculifera*. The content of ostracods is *Schuleridea* sp. 1, *Cytheropteron* sp., *Monoceratina* sp., and *Paracypris* sp.

h – Interruption by sand dune cover and a possible fault.

The following series is described in Ramalho & Ribeiro (1985):

i – Dolomitic limestones (<2 m).

j – Coarse and polygenic conglomerates, with Mesozoic and Palaeozoic elements, poorly rounded, with a reddish marly matrix (~ 20 m).

k – Yellowish limestones, partially dolomitized, with small gastropods, *Alveosepta jaccardi*, and *Kurnubia palastinensis* (1–2 m).

l – Volcanic agglomerates and tuffs (20–30 m).

The Carrapateira Section shows close affinity to the Sagres sections, and has been assigned to the lower Kimmeridgian based on the age of its microfossils (Ramalho, 1985), as confirmed by results for the dinoflagellates (Borges, 2012) and by the stratigraphic conclusions obtained from the investigation of corals, mentioned at the beginning of this Section 2.1.2.

We consider that levels **e** to **k** belong to the Escarpão Formation, based on their lithology and microfacies.

According to Ribeiro (in Ramalho & Ribeiro, 1985) these lower Kimmeridgian volcanic rocks of level **l** were genetically related to flexural movements recorded in western Algarve. This alkaline magmatic activity was related to the beginning of the rifting phase that led to the opening of the Atlantic Ocean.

The Bordoal Section (V)

Biounit D

This outcrop was discovered by our colleague G. Manuppella, described and dated by us in Rocha *et al*., (1979). This Upper Jurassic outcrop located about 4 km east-northeast of Vila do Bispo is assigned to the uppermost Tithonian. It belongs to the Limestones with *Anchispirocyclina lusitanica* Formation and is the northernmost outcrop of this age in the Western Sector, and probably represents a short transgressive event (see Section 7.2.1).

The outcrop comprises about 10 m of micritic limestones interbedded with marls, with a carbonate conglomerate at the base, which overlies the slates and greywackes of the Carboniferous basement.

The limestones are micrites, with *Anchispirocyclina lusitanica*, some of which are abnormal specimens, and also including *Nautiloculina oolithica,* as well as miliolids (ab), *Heteroporella lemmensis, Terquemella* sp., *Russoella triangularis*, *Bucurella espichelensis, Salpingoporella annulata*, and *Permocalculus(?)* sp.

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[2] The coral species are listed in Ribeiro *et al*. (1987, p. 87) and Rosendhal (1985).

3. THE UPPER JURASSIC OF THE ALGARVE CONTINENTAL SHELF

Data on the facies and microfossils of the Upper Jurassic continental shelf of Western Algarve have been obtained since the 1970's by collecting and analysing sea-bed surface samples or sediments of short drill holes taken during oceanographic missions (Lusitanie 73, 74, and 75; Hesperides 75) conducted in the offshore area of Sagres.

According to Terrinha *et al.* (2013), the Algarve offshore is cut by several major faults that are oriented approximately N–S and which define different blocks. It is important to note that each well is located in a different tectonic block (Fig. 2).

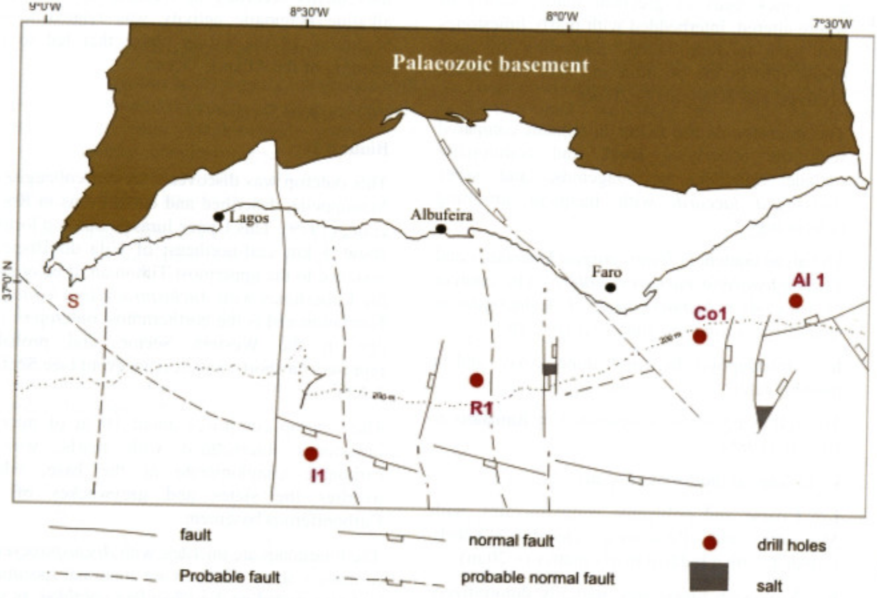

Fig. 2 – Mesozoic tectonic structures of the Algarve offshore and the locations of the tectonic blocks of: S – Sagres; I – Imperador1; R – Ruivo1; Co – Corvina1; Al – Algarve1 (adapted from Terrinha *et al.*, 2013). — fault; ----- probable fault; ⊓ normal fault.

3.1. Western Sector offshore

According to Baldy *et al.* (1977), samples from the Sagres offshore revealed shallow-water, gravelly limestones, locally dolomitized or oncolithic and oolithic, and containing bivalves, gastropods, *Alveosepta jaccardi*, *Pseudocyclammina* gr. *parvula-muluchensis, P. lituus, Nautiloculina* sp., *Everticyclammina virguliana, Anchispirocyclina lusitanica, Clypeina jurassica, Salpingoporella annulata*, and *Thaumatoporella parvovesiculifera.*

This microfossil association is identical to those of the onshore Escarpão and *A. lusitanica* formations.

In the offshore, these two formations extend at least to the −200 m bathymetric line (Fig. 1), which demarcates the Portuguese continental shelf. The same situation occurs in the offshore of western Portugal (the Lusitanian Basin).

3.2. Eastern Sector offshore

We had access only to incomplete oil drill hole technical reports, which contain the systematic determinations used in this Section.

3.2.1. Algarve 1

This well was drilled about 20 km south of the onshore outcrops (Fig. 1). The drill-hole report (ESSO, 1982) includes a micropalaeontological study by R. Lehmann and N.S. Ioannides, who determined the planktonic organisms and benthic foraminifers from about 30 ditch and sidewall core samples of the Upper Jurassic sediments.

Middle Jurassic

Callovian (the top at 2862 m)

The uppermost Callovian is represented by grey silty shales and marls interbedded with some layers of micritic limestones. This series is interrupted by an unconformity that is considered to extend from the upper Callovian to the middle Oxfordian (see Section 2.1.1).

The microfossils found are: *Protoglobigerina oxfordiana, Epistomina* sp., *Lenticulina dictyoides, Spirillina elongata, Textularia agglutinans, Trochaminoides* sp., *Verneuilinoides mauritii, Ophthalmidium* sp., and the ostracod *Bairdia* aff. *hilda*.

Upper Jurassic (2862–2332 m)

Middle (?) to upper Oxfordian (2862–2775 m)

1 – Marls and siltstones (87 m)

The microfossils found are: *Spirillina* sp., *Triplasia* sp., *Lenticulina* sp., *Haplophragmoides* sp., and *Epistomina parasteligera*.

Upper (?) Oxfordian to upper (?) Kimmeridgian (2775–2565 m)

2 – Marls, siltstones, and thin limestone beds (245 m)

The microfossils found are: *Protoglobigerina oxfordiana* (present through the entire level and disappearing essentially at its top), *Epistomina mosquensis, E. parasteligera, Lenticulina muensteri, Dorothia kummi, Haplophragmoides sp., Verneuilinoides sp., Triplasia sp., Nodosaria sp., Spirillina sp.*, and *Ophthalmidium sp.*

Upper Kimmeridgian (2565–2530 m)

3 – Siltstones interbedded with minor limestone beds (35 m).

The microfossils found are quite scarce: *Calcisphaerulidae, Globochaete alpina, Radiolaria,* and *Saccocoma* sp., and benthic foraminifers such as *Epistomina mosquensis, Lenticulina muensteri, L. quenstedti,* and *Dorothia kummi.*

“Lower” Tithonian (2530–2475 m)

4 – Thick limestones with dispersed biotite interbedded with marls and siltstones (55 m).

The microfossils are: *Globochaete alpina, Calcisphaerulidae, Saccocoma sp.*, and radiolaria. Benthic forms are much less common compared with the underlying levels (*Lenticulina sp.*).

“Upper” Tithonian (2475–2332 m)

5 – Massive micritic limestones containing dispersed biotite, with thin interbeds of siltstones and minor shales locally. Glauconite grains occurring at the top and pyrite are minor constituents (143 m).

Planktonic organisms dominate: *Globochaete alpina, Calcisphaerulidae,* and the important occurrence of calpionellids, including *Calpionella alpina, Crassicolaria brevis, Cr. parvula, Cr. sp.,* and *Tintinopsella carpathica.* Benthic foraminifers remain scarce.

Berriasian (?) to Valanginian (2332–2286 m)

6a – Limestones and marls identical to those of the underlying level (28 m).

The microfossil assemblage contains planktonic forms of underlying layers, including the same *Calcisphaerulidae, Globochaete alpina, Cal-*

pionella alpina, *Tintinopsella carpathica*, *Calpionellites darderi*, *Lorenziella hungarica*, *Remaniella cadishi,* some indeterminated calpionellids, and benthic foraminifers, such as *Lenticulina* sp., *Spirillina* sp., and *Tritaxia pyramidalis*.

6b – Shalestones and marls interbedded with limestones and sandstones, with pyritized ammonites (>20 m).

The microfossils include *Epistomina spinulifera*, *E. caracolla, Lenticulina eichenbergeri, L. ouachensis*, and *L. guttata*.

We consider the Upper Jurassic series of Algarve 1 to be important because, to our knowledge, it is the only significant succession in Portugal that contains planktonic microfossils, including calpionellids, as well as benthic foraminifers, and therefore it may be considered to be a stratigraphic reference.

On the basis of the species determined by Lehmann and Loannides, referred to above, we revised the stratigraphic divisions of Algarve 1 (Fig. 3) using the following criteria based on Ascoli (1976), Jansa *et al*, (1980), Stam, 1986 and Remane (1986):

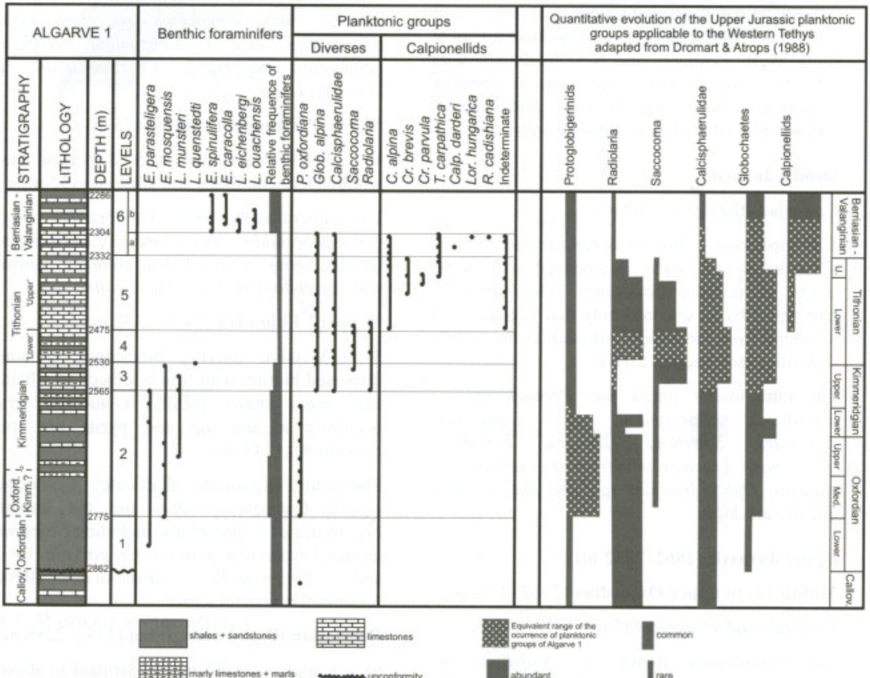

Fig. 3 – Stratigraphic, lithological, and micropalaeontological log of Algarve 1 drill hole (adapted from ESSO, 1982) compared with the quantitative evolution of the Late Jurassic planktonic groups applicable to the western Tethys (adapted from Dromart & Atrops, 1988). (*C. – Calpionella; Calp. – Calpionellites; Cr. – Crassicolaria; E. – Epistomina; Glob. – Globochaete; L. – Lenticulina; P. – Protoglobigerina; T. – Tintinopsella; Lor. – Lorenziella; R. - Remaniella*).

- The higher stratigraphic ranges of *Epistomina mosquensis*, *Lenticulina muensteri,* and *L. quenstedti* do not go beyond the Kimmeridgian
- The appearance of the first calpionellids in the Tethys Ocean is recorded in the lower Tithonian and their disappearance is recorded in the lower Valanginian. The range of *Crassicolaria brevis* is within the upper part of the upper Tithonian, *Lorenziella hungarica* ranges from the upper Berriasian to the lower Valanginian, and *Calpionellites darderi* is a Valanginan species.
- *Epistomina caracolla. E. spinulifera, Lenticulina eichenbergeri,* and *L. ouachensis* appear in the lowermost Cretaceous, namely, the Berriasian.

Finally, we note the good correlation between the vertical distribution of the Algarve 1 planktonic groups and the quantitative scheme proposed by Dromart & Atrops (1988), which is applicable to the Western Tethys and included in Fig. 3.

The Upper Jurassic sediments of Algarve 1 correspond to deposition in a deep and calm marine environment. The presence of abundant planktonic groups shows that the surface waters were open to the influence of Tethys, suggesting good oceanic circulation in some areas of the Eastern Algarve offshore. The sea-bottom waters had a different evolution. The benthic foraminifers almost disappeared during the Tithonian and the transition to the Cretaceous (levels 4, 5, and 6a), probably caused by a lack of oxygenation. Interestingly, these levels correspond to the period of the greatest development of planktonic organisms.

The lower levels (1 and 2) are dominated by argillaceous sedimentation, but the overlying levels (3, 4, and 5) are essentially carbonates. The lowermost Cretaceous starts with carbonate facies (level 6a) but changes upwards to marls (level 6b).

3.2.2. Corvina 1

This well was drilled about 20 km south of the Upper Jurassic outcrops (Fig. 1).

The technical report of CHALLENGER (1976) includes a micropalaeontological study of the well's foraminifers, palynomorphs, and nannofossils. However, the lack of good stratigraphic markers and non-optimum sampling did not allow precise stratigraphic interpretations to be made.

We present the following succession:

Middle Jurassic

Callovian (and Oxfordian?) (top at 2100 m)

This stage ends (?) with grey to dark-grey, locally reddish-brown marls interbedded with light-grey or whitish sparitic limestones. The interval from 2170 to 2120 m shows nannofossils such as *Discorhabdus patulus*, *Stephanolithion bigoti*, *S. haxum*, and *Tubirhabdus patulus*, which, according to the CHALLENGER report, indicate a Callovian age.

Between 2185 and 2095 m, a foraminiferal assemblage is found, containing *Epistomina mosquensis*, *Glomospira jurassica*, *G. variabilis*, *Lenticulina* cf. *muensteri*, *L. quenstedti*, *Planularia tricarinella*, *Ramulina nodosarioides*, and *Globigerina* cf. *helvetojurassica*; the assemblage is attributed to a possible Callovian–Oxfordian age.

Although the unconformity between the Callovian and Oxfordian was not detected, we consider this boundary to be defined at -2100 m depth, based on lithological differences.

The environmental conditions under which the upper part of the Callovian levels was deposited are considered to be outer neritic to upper bathyal.

Upper Jurassic (2100–1915 m)

1- Grey to green or brown sparitic limestones (25 m);
2- Grey silty or sandy marls (20 m);
3- Whitish sparitic limestones interbedded with calcareous claystones (25 m);
4- Blueish to greenish-grey claystones with calcareous to dolomitic cement, commonly silty, locally with chert nodules interbedded with sandstones (70 m);

5- – Limestones to dolomitic limestones, grey to greenish, with chert nodules (20 m);

6- – Blueish-grey silty claystone with calcareous cement (25 m).

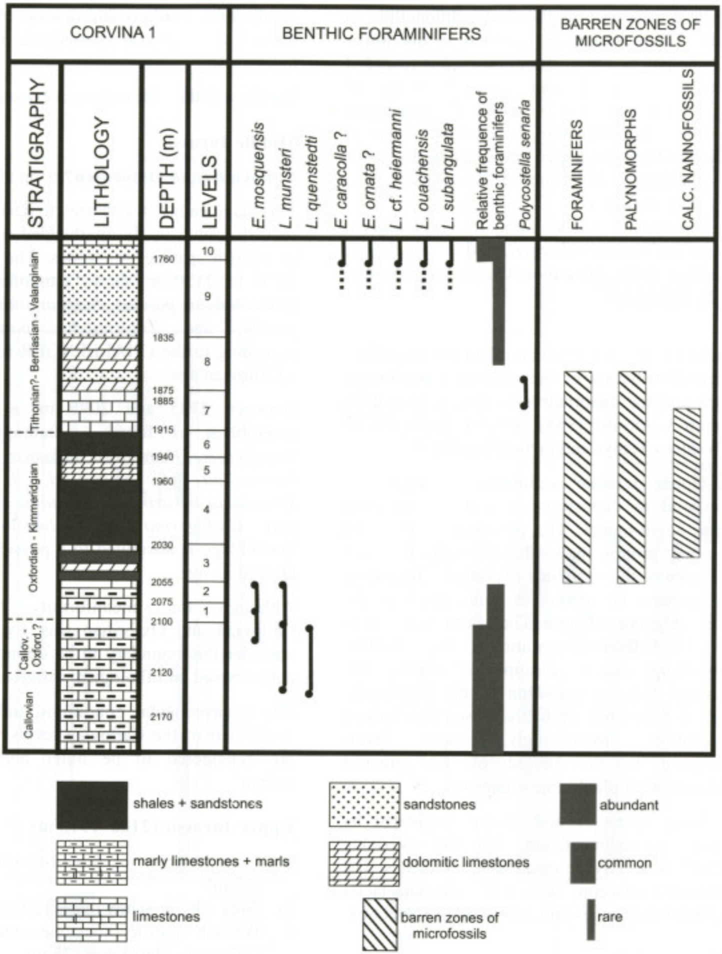

Fig. 4 – Stratigraphic, lithological, and micropalaeontological log of Corvina 1 drill hole (adapted from CHALLENGER, 1976).

The CHALLENGER report gives the following microstratigraphic data:

a. The foraminiferal assemblage found between 2095 and 2050 m (levels 1 and 2) contains *Epistomina* cf. *mosquensis*, *Glomospira variabilis*, *Lenticulina* cf. *muensteri*, *Planularia* cf. *tricarinata*, and *Ramulina nodosarioides*, and is attributed to the Upper Jurassic.

b. The interval 2090 to 2030 m (levels 1, 2, and 3) contains several nannofossil species that point to a possible Kimmeridgian age (cf. CHALLENGER, 1976).

c. The remaining series (2030–1855 m) does not contain foraminifers, palynomorphs, or nannofossils.

Tithonian(?) to Berriasian(?) (1915–1875 m)

7- Light-grey to yellowish micritic limestones with rare chert nodules and thin marl beds (40 m).

The uppermost few metres of this level contain *Polycostella senaria*, a nannofossil that suggests a Berriasian age (cf. CHALLENGER, 1976).

Berriasian(?) to Valanginian(?) (1875–1760 m)

8- Pink, pale-yellowish to white crystalline dolomites grading into dolomitic limestones, interbedded with cherty, coarse to granular sandstones (40 m).

The basal layers contain *Polycostella senaria*.

9- Well-sorted light-grey sandstones with some rare foraminifers as cited in the overlying level (70 m).

10- Well-sorted, medium light-grey sandstones interbedded with thin beds of yellowish limestones (>20 m).

This level contains some benthic foraminifers, including *Epistomina caracolla*(?), *E. ornata*(?), *Lenticulina hermanni*, *L. ouachensis,* and *L. subangulata*.

Borges (2012) studied the dinoflagellates of the Corvina 1 well and proposed that the interval 2450–1800 m represented the lower to middle Oxfordian, which corresponds in part to the upper Callovian–Berriasian series described in the CHALLENGER (1976) report. Without more reliable data, it seems impossible to reconcile these two studies.

The biostratigraphic markers in Corvina 1 are not as distinct as those in Algarve 1 because of the absence of planktonic groups and the weak presence of benthic foraminifers. The most important stratigraphic microfossils are as follows:

The species *Epistomina mosquensis*, *Lenticulina muensteri*, and *L. quenstedti* are common in the Upper Jurassic, but not above the Kimmeridgian;

The species *Epistomina caracolla*, *E. ornata*, and *Lenticulina ouachensis* belong to the Lower Cretaceous and also appear in the Berriasian–Valanginian of Algarve 1.

- According to the CHALLENGER (1976) report, the calcareous nannofossils are the most important source of stratigraphic information, particularly with regard to the presence of *Polycostella senaria*, which suggests the Berriasian.

The Upper Jurassic of Corvina 1 was most likely deposited under calm, deep-marine conditions, firstly characterized by the continuous deposition of silty clay and then changing upwards to carbonates, similarly to the pattern observed in Algarve 1.

In Corvina 1 there is an almost 200 m thick interval of sediments (2050–1853 m) that lacks foraminifers, palynomorphs, and calcareous nannofossils, probably corresponding to the Kimmeridgian to the base of Cretaceous (Fig. 4). This interval seems to be contemporaneous with levels 4, 5, and 6a of Algarve 1, in which benthic foraminifers show a marked decline in abundance (Fig. 3). This event was probably related to a significant change in the environmental conditions of the sea-bottom waters that affected circulation in the eastern area of the Algarve offshore.

During that same interval, the presence of planktonic organisms differed substantially between the two wells. Corvina 1 does not contain planktonic microfossils, whereas Algarve 1 shows a rich and varied content that includes Protoglobigerina *oxfordiana*, *Calcisphaerulidae*, *Globochaete alpina*, *Saccocoma,* radiolarians, and calpionellids. This difference can be explained by the existence of a palaeoecological barrier that affected surface water circulation in the area between the two well locations.

3.2.3. Ruivo 1

This well was drilled about 25 km south of the actual Upper Jurassic outcrops (Fig. 1). According to the report of CHEVRON (1975b), the Jurassic series is about 877 m thick (2025–1198 m) and is represented by thick limestones interbedded with claystones and, in the upper part, with dolomite levels.

Micropalaeontological analyses (foraminifers, palynomorphs, and calcareous nannofossils) suggest the possible existence of the Lower and Middle Jurassic, overlain directly by Upper Cretaceous terrigenous sediments.

Borges (2012) dated these Jurassic levels from the middle to upper Callovian using dinoflagellates, and found evidence of subaerial exposure and erosion of the Lower Jurassic rocks during the Callovian.

3.2.4. Imperador 1

This well was drilled about 50 km south of the Upper Jurassic outcrops (Fig. 1). According to the report of CHEVRON (1975a), the possible Callovian and Upper Jurassic are completely dolomitized and are overlain by dolomites and limestones of the Lower Cretaceous, which contain some foraminifers, suggesting a Neocomian age.

3.3. Conclusions

3.3.1. The geological record of the Algarve Basin offshore

1- The Sagres offshore is the only area where the onshore neritic facies of the Escarpão and *A. lusitanica* formations occur.

2- The Jurassic sediments cut by the Imperador 1 and Ruivo 1 wells show different facies that are impossible to correlate. The Imperador 1 well shows the Jurassic series as completely dolomitized. In Ruivo 1, the Jurassic is composed mainly of limestones interbedded with claystones, marls, and dolomites dated from the Callovian.

3- The Corvina 1 and Algarve 1 wells may be compared. In both wells, and also in Ruivo 1, the Callovian is represented by shales, marls, and limestones with pelagic facies, which is the same as observed in the Algarve onshore. The Upper Jurassic series of Corvina 1 and Algarve 1 also present pelagic facies and both are represented by shales interbedded with marls and limestones, overlain by massive carbonates (limestones or dolomitic beds). The thickness of these series differs between the two wells, with the Upper Jurassic of Algarve 1 being about twice as thick as that of Corvina 1.

4- The Upper Jurassic series of Corvina 1 and Algarve 1 were both deposited in a marine environment. The Algarve 1 record shows the well-recognized succession of planktonic organisms as described from other locations in the Tethyan domain, accompanied by the usual array of Jurassic deep-benthic foraminifers, including several species of *Epistomina*, *Lenticulina*, and agglutinated forms. According to Stam (1986), based on Portuguese data, *Epistomina mosquensis* preferred deep water (200–250 m or more). This inference presupposes a deep-marine environment freely open to the ocean currents emanating from the Mediterranean Tethys and maintaining sufficient oxygenation at the sea bottom. In contrast, the Corvina 1 geological record does not show these planktonic forms. However, the record shows that benthic organisms were well developed until the early Kimmeridgian (?), in a pattern similar to that recorded in Algarve 1. After this time, an important environmental modification must have occurred, as reflected in the disappearance of foraminifers, palynomorphs, and calcareous nannofossils in a 200 m thick body of sediments overlying the lower Kimmeridgian deposits. These groups reappeared only at the beginning of the Early Cretaceous (Fig. 4). It would seem that the water column of the Corvina 1 tectonic block was temporarily isolated from open-ocean influences, causing the sea bottom to be deprived of oxygen. It is interesting to note that in Algarve 1, the sedimentary record shows that planktonic forms experienced a remarkable development during the Upper Jurassic, while the benthic foraminifers underwent a drastic decrease (Fig. 3). This event corresponds to levels 4, 5, and 6a, which belong to the Tithonian and to the base of the Berriasian. This interval seems to correspond more or less to levels 3 to 7 and the base of 8, where as in Corvina 1 the benthic foraminifers, palynomorphs, and calcareous nannofossils disappear from the sedimentary record. It is noted that the thickness of the Algarve 1 Upper Jurassic series is about double that of Corvina 1.

5- The sedimentary record of the Upper Jurassic–Cretaceous transition is different in the four wells:

- In Imperador 1 those transitional levels, are dolomitised but the lowermost Cretaceous seems to be present, as dated by benthic foraminifers;

- In Ruivo 1, an important unconformity exists between the Callovian and the Upper Cretaceous;

- In Corvina 1, the transition is marked by the appearance of coarse sandstones and by the occurrence of dolomitic beds, which suggest very shallow marine conditions;

- In Algarve 1, both the Tithonian and Berriasian show outer-neritic to pelagic facies, with calpionellids and deep-water benthic foraminifers, whose stratigraphic distribution is the same as that of the Tethyan realm;

6- The Upper Jurassic geological record of the four offshore wells shows that sedimentation was probably affected by the different tectonic behaviours of the blocks in which the wells were drilled (see Section 9.1).

3.3.2. Comparison between the onshore and offshore geological records

a) In both the onshore and offshore of the Algarve Basin, the Callovian is composed of pelagic marly carbonates and shales. This stage, especially in its upper part, records tectono-sedimentary events, including tilting and erosion to produce local angular unconformities (e.g., Sagres onshore) and an important erosional hiatus that is best expressed in the Ruivo 1 well.

b) In the Algarve Basin, during the Upper Jurassic, tectonic processes had a much greater influence on offshore sedimentation compared with the onshore, as confirmed by the rapid lateral facies changes in the offshore record.

c) The facies of the offshore series are different from those of the onshore, with the exception of the Sagres area (see Section 3.3.1). The onshore series of the Kimmeridgian–Tithonian interval are composed of limestones and marls, with abundant foraminifers, calcareous algae, and reefal organisms, typical of the Tethyan carbonate platforms. In contrast, the eastern Upper Jurassic offshore, represented by the Algarve 1 and Corvina 1 wells, shows silty claystones interbedded with some limestone and overlain by thick limestone levels. The microfossil assemblages of the offshore are composed of deep-benthic foraminifers and, in Algarve 1, by a rich and varied succession of planktonic groups. The four drill hole reports do not mention the occurrence of shallow-water fossils or even their fragments eventually transported by allodapic sediments. This seems to point to deposition at a considerable distance from the slope base of the onshore carbonate platform and its area of influence, and from the locations where the wells were drilled.

d) With the exception of the Algarve 1 well, the sedimentation of the Jurassic–Cretaceous transition in the Algarve Basin was dominated by regressive facies, corresponding to the final phase of the Late Jurassic sedimentary cycle (see Section 7.2.1.).

4. MICROFACIES AND PALAEOENVIRONMENTS

4.1. Pelagic and hemipelagic microfacies

Both pelagic and hemipelagic microfacies are common in the Peral Formation, in which ammonites and other pelagic macrofossils are abundant. However, other formations may show deposits from relatively short pelagic events, interbedded within bioclastic successions. The more common example is the alternation of pelagic and allodapic sediments containing neritic biohermal debris.

The typical pelagic microfacies in the Algarve are micrites or pelmicrites, locally presenting silty quartz and glauconite grains. Generally, the microfossils of these microfacies have small dimensions, and include sponge spicules, "filaments" (broken, thin shells of the pelagic bivalve *Bositra buchi*), thin-shelled ostracods, *Globuligerina oxfordiana, Pithonella* sp., *Globochaete* sp., and radiolarians. Less common are small benthic arenaceous foraminifers (lituolids, textularids, verneuilinids, and *Placopsilina* sp.) or organisms with calcite shells, such as miliolids, ophthalmiids, lagenids, spirillinids, *Trocholina* sp., *Glomospira* sp., and epistominids.

In the Algarve Basin onshore, the only known occurrence of calpionellids is in a level at the top of the Limestones with *Anchispirocyclina lusitanica* Formation, from the Bias Section (Eastern Sector of the Algarve Basin), and they include the following species identified by Durand-Delga & Rey (1982) and D. Delga (written personal communication, 1986): *Calpionella alpina*, *Calpionella "undeloides"(?)*, *Crassicolaria parvula*, and *Tintinopsella* gr. *carpathica.* The Algarve offshore reveals a rich planktonic association, occurring from the Oxfordian to the Berriasian of the Algarve 1 drill hole in successive "zones", and including from bottom to top: 1) - "*Protoglobigerina*" (*Globuligerina*) *oxfordiana*; 2) - *Globochaete alpina*, *Calcisphaerulidae*, *Saccocoma,* and radiolaria; and 3) - Calpionellids (see Section 3.2.1). This succession is the same as that verified in the Eastern Tethys domain (Dromart & Atrops, 1988).

The sediments of the offshore drill holes of Algarve 1 and Corvina 1 also contain several benthic foraminifers (e.g., species of the genera *Epistomina* and *Lenticulina)*, which are well known from the Tethys deep-sea environment (Fig. 3).

4.2. Biohermal microfacies

4.2.1. Microfacies of microbial–sponge bioherms

This type of bioherm is well known in the Upper Jurassic of the Tethyan margins, and is found from the Gulf of Mexico to Poland and even in Japan (Shiraishi & Kano, 2004) in the Oxfordian–Kimmeridgian (Gwinner, 1976; Gaillard, 1983; Crevello & Harris, 1984). In Portugal, a good example from the lower Kimmeridgian of Algarve has been described by Ramalho (1988 a) from the Rocha outcrop (South of S. Brás de Alportel).

The Rocha bioherm is about 30 m thick but thins markedly to 1 or 2 m in the parts surrounding the main buildup, and covers an area of about 7 km^2. This bioherm started its development during the deposition of the final few metres of the Peral Formation, and is overlain and flanked on both sides by well-stratified limestones with abundant cherty levels of the Jordana Formation.

The Rocha bioherm is the most important example of its type in Algarve, but we also identified other levels with this type of microbial structure (although much less well developed) in various facies. Its microbial mass may be stromatolitic (laminated, conical, mammilate, and columnar) or thrombolitic, and may include glauconite grains. The microbial structures show stromatactis and burrows of lithophags, whose cavities may be totally or partially filled by internal sediment (see Ramalho, 1988 a, pl. IV–VII), which suggests rapid lithification.

The macroinvertebrates found in thin-sections are: small ammonites, siliceous sponges (hexactinellids, lithistids, and lychniskids), and, also in the upper part, small brachiopods, isolated small corals, bryozoan (?), and "filaments".

The microfossils we have found are as follows: Sessile foraminifers: *Tubiphytes morronensis*, *Troglotella incrustans*, *Bullopora tuberculata, Placopsilina* sp., *Subdelloidina?* sp., and *Nubeculinella?* sp. Vagile foraminifers: *Spirillina* sp., *Valvulina* sp., *Nodosaria* sp., lagenids, miliolids, small arenaceous forms (textularids and lituolids), and globigerinids. Other organisms: *Terebella lappilloides* and other serpulids, A*eolosaccus* sp., pelagic crinoids, and thin-shelled ostracods.

It should be noted that these features, namely the microfossils, are similar to those of all other microbial bioherms along the Western Atlantic and Mediterranean Tethyan margins.

For the Rocha bioherm, we infer a normal marine environment situated in the deep euphotic zone (50–150 m in depth) with low energy and depleted of oxygen, and also infer that the superficial water was warm, based on the palaeontological features presented in equivalent levels of the entire Eastern Algarve (Ramalho, 1985). However, the presence of hexactinellid sponges, small isolated corals, and glauconite grains presumes deeper, colder water for the emplacement of the Rocha bioherm (Schmid *et al*., 2001).

These conclusions are reasonably similar to those of other authors, namely Crevello and Harris (1984), Leinfelder *et al.* (1993) and Mancini *et al.* (2004). According to those authors, the sedimentation rate would needed to have been very low to allow the development of the microbial structures described above. This low rate of sedimentation contrasts with that of equivalent levels near outcrops, but these microbial structures appear in different facies, and locally even under an argillaceous influence. However, it is possible that the abnormal development of the Rocha bioherm was a consequence of a local palaeohigh. Several levels containing these microbial sponge structures, although not forming true biohermal buildups, were found in limestone layers, generally encrusting bioclasts. A good synthesis of these Portuguese sponge microbialites (in the Algarve and Lusitanian basins) can be found in Leinfelder *et al.* (1993).

4.2.2. Microfacies of coral–stromatoporoid–microbial bioherms

Despite the difficulty in typifying true bioherms, we acknowledge that in certain cases they are present, with corals and stromatoporoids *in situ*, and encrusted and/or stabilized by microbial structures (both stromatolitic and thrombolitic types) associated with a diverse assemblage of both macro- and microfossils.

These bioherms include predominantly reefal invertebrates, where hexacorals, stromatoporoids, and coralline and siliceous sponges dominate, accompanied by some brachiopods, bivalves, and gastropods that are generally small, and bound or encrusted by both microfossils (foraminifers and algae) and microbial structures. These bioherm levels generally correspond to thick and massive limestone beds, in which clayey sediments are rare or absent. The main components of the bioherms are as follows:

a – Microbial structures: these are the main support for the aforementioned reefal elements, and include stromatolitic, thrombolitic, and algal crust structures. Their interiors show *stromatactis*, burrows, and other cavities, as well as internal sediments with geopetal disposition in some places.

Since 1971, we have pointed out the importance of "stromatolitic" structures encrusting reefal bioclasts in the Upper Jurassic of the Lusitanian Basin, which at the time we termed "microfaciès récifal à organismes encrôutants". Subsequently, we also referred to the occurrence of "encroûtements stromatolithiques" associated with corals, stromatoporoids, and other invertebrates of the Cerro da Cabeça Formation in Eastern Algarve (Ramalho, 1985).

b – Sessile organisms: siliceous sponge spicules and coralline sponges: *Neuropora* cf. *lusitanica*, *Thalamopora lusitanica*, and *Corynella* cf. *quenstedti*. Stromatoporoids: *Actinostromaria tokadiensis* and *Dehornella choffati*. Foraminifers: *Tubiphytes morronensis* (ab), *Placopsilina* sp., and *Bullopora tuberculata*. Algae: *Arabicodium* sp., *Picnoporidium* aff. *lobatum*, *Solenopora*? sp., *Cayeuxia* spp., *Bacinella irregularis* / *Lithocodium aggregatum*, and rare *Salpingoporella* gr. *pygmaea*.

Other organisms: *Terebella lappiloides* (ab), other serpulids, and *Koskinobulina socialis*.

c – Vagile organisms: foraminifers such as *Reophax* sp., textularids, verneuilinids, miliolids, lagenids, *Nautiloculina oolithica*, and *Mohlerina basiliensis*.

Shiraishi & Kano (2004) described an Upper Jurassic–Lower Cretaceous reef limestone from Japan rich in corals, stromatoporoids, molluscs, brachiopods, echinoderms, microbial crusts, and some algae microencrusters (*Bacinella irregularis, Lithocodium aggregatum, Troglotella incrustans, Thaumatoporella parvovesiculifera, Koskinobulina socialis, Tubiphytes morronensis*, and *Girvanella* sp.). Interestingly, these macro- and microfossil assemblages are practically identical to those found in Portugal and in other Tethyan carbonate platforms for the same type of reef.

4.2.3. Bioclastic piles

In accordance with Crevello & Harris (1984) and more recently Leinfelder *et al.* (2002), we consider the following situations for the biohermal debris piles:

- The bioclast accumulations may not present characteristics suggesting transportation, and are in some places assumed to be reefal debris halos of unknown reefs.
- The majority of these piles represent the normal type of Jurassic high-energy reef relics.
- The debris piles may show microbial structures inherited from the initial developing stage of the reef, because it is unlikely for microbial encrusters to settle on and stabilize large amounts of reefal debris in high-energy waters owing to their vulnerability to abrasion, except when deposited in still-water environments (back-reef and fore-reef).

In the Algarve Basin, the bioclastic piles have levels containing bioclasts that are conspicuously broken, including abundant microbialite fragments, interbedded with micrites or pelmicrites with no microbial structures *in situ*, or in other cases with levels of large oncoids or ooids.

We consider two types of bioclastic piles:

a) Proximal bioclastic piles

Several authors refer to the reduced area of the true biohermal reefs compared with the very large areas occupied by their debris. However, the debris may form rigid substrates that promote the growth of new bioherms (Wilson, 1973).

Despite the similarity between the two microfacies discussed in Sections 4.2.2.1. and 4.2.2.2., the bioclastic pile microfacies are richer and more diverse, showing new forms such as *Neotrocholina* sp. B, *Marinella lugeoni, Terquemella* sp., S*olenopora?* sp., and indeterminate debris of dasyclads, along with coarse fragments of microbial structures, stromatoporoids, coralline sponges, and other organisms found in bioherms.

b) Distal bioclastic piles

Here, we consider the allodapic bioclastic accumulations located far from the original bioherms. The bioclasts are smaller and more abraded, and are interbedded with micritic limestones devoid of microfossils and locally with pelagic organisms described above in Section 4.1.

4.3. Internal open-marine platform microfacies

This is the most widespread microfacies type, occurring in both sectors of the Algarve Basin in a large number of levels of the Escarpão Formation and with lesser importance in the *A. lusitanica* Formation. Its general matrix characteristics are: bioclastic micrites with abundant intraclasts, peloids, abundant oncoids, and some oolite levels.

A rich benthic microfossiliferous content is dominated by complex arenaceous foraminifers and dasyclads. Other organisms, such as siliceous or coralline sponges, stromatoporoids and microbial structures are scarce but a net increase in gastropods and bivalves is observed.

The transition of the Cabeça Formation (biohermal microfacies) to the Escarpão Formation (internal open-marine platform) generally corresponds to the appearance of rich oncolithic levels followed by an increase in clay sedimentation, represented by clayey limestones and marly levels.

Flügel (1979) proposed a model of sedimentary environment based on the distribution of algae in Upper Jurassic deposits of the northern Alps, where the open-marine platform environment was characterized by the occurrence of almost all the presented algal genera and by very high palaeobiodiversity values. Similar results were presented by Peybernès (1979) from the Pyrenees Upper Jurassic, where the majority of dasyclads originated in protected, calm infralittoral environments with normal salinity levels. *Clypeina jurassica* is recognized as the only dasyclad able to tolerate higher values of salinity.

As noted in the Upper Jurassic deposits, the southwestern Portuguese marine platform (Sagres sector) can reach more than 20 km wide, occupying the actual continental shelf. Given the absence of reefal structures from the offshore record, it seems that the greater part of the onshore outcrops of the Escarpão and *A. lusitanica* formations represents the inner area of an open-marine platform of the Algarve, which was protected by its width (≥20 km) and also certainly subjected to fluctuations in both salinity and depth.

4.4. Restricted platform microfacies

In the two formations referred to above, we have observed several levels where ostracods and charophytes were abundant but accompanied by a marked decrease in palaeobiodiversity. This is particularly evident in the *A. lusitanica* Formation of the Western Sector, where these levels may be interbedded with intraconglomerates, erosional surfaces, black-pebble levels, and dolomitic limestones.

We infer that, particularly during the deposition of the upper part of the *Anchispirocyclina* Formation, water depth shallowed and water circulation became calmer, probably corresponding to a restricted area of the platform environment. Microfacies rich in charophytes and ostracods, usually with *A. lusitanica*, have been found in beds of the Lusitanian Basin with dinosaur footprints, verifying deposition in very shallow water depths (Ramalho, 1988). More recently, dinosaur footprints have been discovered in one of the uppermost levels of the *A. lusitanica* Formation in the Western Sector (Fóia do Carro), which confirms its deposition in very shallow water levels.

As discussed above, these events represent a slow and intermittent decrease in the degree of marine influence, as was already occurring during the deposition of the Escarpão Formation; the shallowing represents the transition to a subaerial environment, which is better expressed in the lowermost Cretaceous deposits (Rey, 1983).

5. COMMENTS ON THE LATE JURASSIC SEDIMENTARY PALAEOENVIRONMENT OF SOUTHWESTERN IBERIA

The Late Jurassic was a turning-point epoch between the old Pangaean closed world and a new open world in which inter-oceanic communications were established. The opening of seaways by rifting and seafloor spreading that divided Pangaea into three important domains (North America, Eurasia, and Gondwana) was reinforced by the trend of sea-level rise during the Late Jurassic, which reached its peak during the Kimmeridgian. The communication between the Tethys and Pantalassa Ocean was completed during the early Tithonian (Moore *et al.*, 1992).

The palaeoclimatic models tested by Moore *et al.* (1992), using 1120 ppm $C0_2$ for the atmospheric composition (i.e., a strong greenhouse effect situation), fit well with the observed geological record, namely, the Tethys coral facies distribution (including Iberia) falling within the 20–30 °C domain of seawater temperatures for both summer and winter seasons. The conclusions of those authors also confirm several other opinions about the general climatic conditions during the Late Jurassic: warm with a zonal and expanded tropical zone, and ice-free continents with arid interiors.

For this epoch, the climate of the Tethyan domain is generally considered to have been warm, subsequently evolving to increased aridity. Dercourt *et al.* (1986) state that this would have been due to the effect of the southward drift of continents. On the basis of an analysis of clay minerals, Hallam *et al.* (1991) verified for Europe and North America a drastic reduction in the production of kaolinite during the Kimmeridgian and Tithonian compared with that during the Callovian and Neocomian, and indicating a pronounced aridity.

According to Weissert & Erba (2004), the Late Jurassic was an epoch characterized by a strong greenhouse effect, but was also marked by important temperature fluctuations, having cool episodes during the Callovian–Oxfordian transition, early and late Oxfordian, and early Kimmeridgian, but warm conditions during the middle Oxfordian. Those authors also cite "palynological results that indicate a long-term warming trend lasting from the Kimmeridgian into the earliest Cretaceous".

The palaeoclimatic models of Valdes & Sellwood (1992) for the Late Jurassic show a Mediterranean semi-arid climate for Iberia, with a wet winter and a very dry summer, both seasons having a mean temperature of 24–25 °C. At equivalent latitudes of North American territories, the mean temperature was lower and the storm regime much stronger than in Iberia. Dromart *et al.* (2003) argued for much lower temperatures in the northernmost latitudes, even proposing persistent ice sheets in polar regions, but this a somewhat controversial proposal.

In Portugal, during the Early and Middle Jurassic, the boundary between the Boreal and Mesogean domains oscillated between the Lusitanian and the Algarve basins (Rocha, 1976). According to that author, the Algarve Basin belonged to the Submediterranean Province of the Mesogean domain between the Lias and the middle Oxfordian. At the end of the Callovian (corresponding to the Lamberti Zone), an invasion of boreal *Kosmoceratidae* ammonites occurred in the Algarve Basin, occupying about 20% of its total cephalopod macrofauna. In the Algarve Basin, the boreal influence disappeared progressively and by the late Oxfordian the entire territory of modern-day Portugal was included in the Submediterranean Province (Rocha, 1976*)*. Rocha (1976) proposed that the ammonites arrived by the sea-way linking the Paris Basin to the Portuguese territory, passing between northern Iberia and the Armorican Massif and reaching the Lusitanian and Algarve basins. It seems reasonable to link the appearance of boreal ammonites in the Algarve Basin during the late Callovian–early Oxfordian to the low-temperature event referred to by Weissert & Erba (2004).

Late Jurassic eustatic movements were characterized by a general tendency of sea-level rise that reached a maximum during the Kimmeridgian (Eudoxus Zone) and which was associated with the deposition of a vast area of black shales (Hallam, 2001). During the late Callovian–earliest Oxfordian, a significant fall in sea level occurred in association with a global condensation phenomenon (the Athleta and Cordatum Zones). The middle Oxfordian represented a transgressive peak after which the sea level fell again and then rose during the Kimmeridgian. The Tithonian was characterized by a high sea level that slowly fell during the late Tithonian and Early Cretaceous. According to Vail *et al.* (1977), the sea level during the Late Jurassic was 200 m higher than during the Early Jurassic, but fell about 100 m during the Berriasian. The regressive facies of the Jurassic–Cretaceous boundary is well documented in

Europe (the Purbeckian facies) but not in the rest of the world (Hallam, 2001).

Hallam (2001) also proposed a tectonoeustatic mechanism to explain the Jurassic sea-level oscillations related to the newly created ocean ridges of the central Atlantic and Indian oceans. The initial breakup of Eastern Gondwana during the Late Jurassic is proposed as the origin of these sea-level oscillations, because the seafloor spreading of the central Atlantic is considered to have been more or less uniform during those times (Hallam, 2001).

In Portugal, the late Callovian–early Oxfordian interval corresponds to an important hiatus, associated with a eustatic sea-level fall of 40–80 m (Dromart *et al.*, 2003), forming karstification phenomena in the Lusitanian Basin. That hiatus is also linked to local tectonic movements, the reactivation of terrestrial erosion, and the deposition of conglomerates and condensed horizons that are rich in phosphatized or ferruginous nodules and which contain ammonites belonging to the late Callovian–middle Oxfordian interval as recorded in the Algarve Basin (Rocha, 1976). Similar events were also registered in Europe and South America (Hallam, 2001).

In Portugal, the middle and late Oxfordian and the early Kimmeridgian were times of a rich ammonitic record, as observed in eastern Algarve. These periods correspond quite well to the high-sea-level situation referred to above. The late Kimmeridgian transgressive peak was not recorded in the Algarve onshore, as shown by the shallow-marine deposition of the Escarpão Formation.

We consider that in the Algarve Basin, the sea level during the sedimentation of the Escarpão and *Anchispirocyclina lusitanica* formations did not undergo important oscillations until the end of the Jurassic but that the lowermost Cretaceous deposits present significant regressive facies. During the Kimmeridgian–Tithonian, the persistence of the sea-level values may explain the thickness of those formations, especially in the Eastern Sector, as well as the homogeneous microfacies and their widespread distribution in the onshore area of the Algarve and Lusitanian basins, and as also observed in the Portuguese continental shelf. This situation seems to be correlated with the very slow sea-level fall that occurred during the Tithonian (Hallam, 2001), possibly associated with local tectonic subsidence (see Section 9.1). However, the Algarve Basin also underwent tectonic inversion during the Jurassic–Cretaceous transition, which could have reinforced the emersion tendency during those times, especially during the Early Cretaceous (Terrinha *et al.*, 2013).

The Algarve Basin belonged to the southwestern part of the Iberian margin, and was freely open to the "Atlantic" and the "Mediterranean" parts of the Tethys Ocean. On the basis of its palaeolatitude (~20-25°N), the Algarve Basin was situated in a warm intertropical zone, and we infer from the lithological sections (both onshore and offshore), which are almost free of siliciclastic sediments, that this was an ideal situation for the development of the Portuguese carbonate platforms, which had symmetric counterparts in the North African margin. Both margins were separated by the pelagic domain of the Rif–Iberia seaway (500–600 km wide), and the alignment of its rift fractures was related to the opening of the central Atlantic Ocean (Jansa, 1986).

The palaeoceanographic model of Dercourt *et al.* (1994) shows strong E–W directed surface currents, which would have promoted the dissemination of microbiota from the "Mediterranean" domain (in which southern Iberia and northwestern Africa were the "last stop") to the "Atlantic" domain.

6. A SHORT SYNTHESIS OF THE UPPER JURASSIC NERITIC MICROFOSSILS OF THE TETHYAN REALM

This section presents a synthesis of the distribution of neritic microfossils in the Tethyan margins.

6.1. The Tethyan Atlantic margins

Separated during the Late Jurassic by a distance of about 1300–1500 km (Jansa, 1986), the Eastern and Western Atlantic margins were occupied by an almost continuous carbonate platform rim. The results of studies based on numerous oil exploration wells in the offshore regions of both of these margins allow to compare its microfossils with the Mediterranean ones.

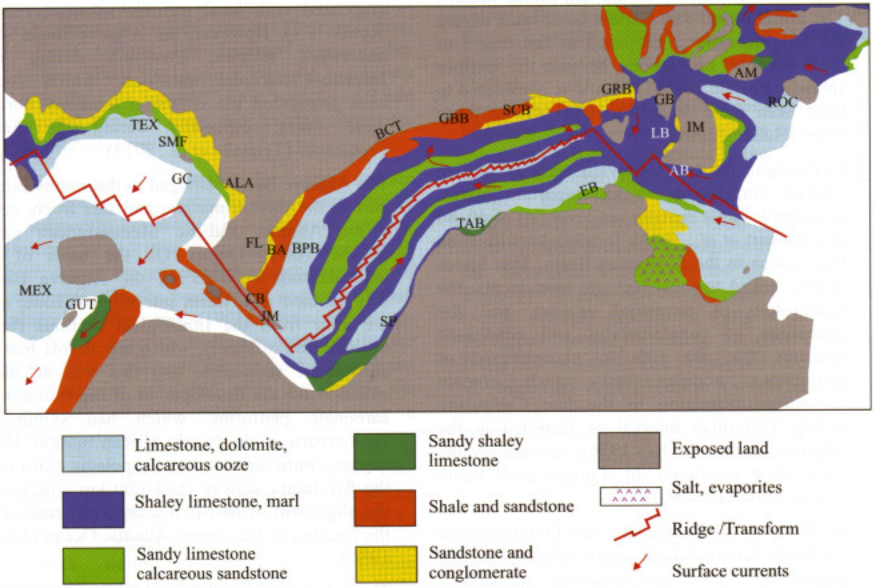

Fig. 5 – Late Jurassic (Late Oxfordian) palaeogeography of the Western Atlantic Tethys (adapted from Tucholke & Jansa, comp., 1986). AB – Algarve Basin; GB - Galicia Banks; LB - Lusitanian Basin; ALA – Alabama; BCT – Baltimore Canyon Trough; GBB - George Bank Basin; MEX – Mexico; AM – Armorican Massif; GC – Gulf Coast; ROC – La Rochelle; BA – Bahamas; GRB – Grand Banks; SB – Senegal Basin; BPB – Blake Plateau; GUT – Guatemala; SCB – Scotian Basin; CB – Cuba; IM – Iberian Massif; TAB - Tarfaya Basin; EB – Essaouyra Basin; JM – Jamaica; TEX – Texas; FL – Florida.

6.1.1. The Western Atlantic margin (from Mexico to Canada)

From south to north along the western Atlantic coastal region (Fig. 5), we have registered the following:

a – In Mexico, a rich "Mediterranean" microfauna has been identified by Johnson (1964), Fourcade & Michaud (1987), Ornelas–Sanchez & Hottinger (2006), and Omãna & Arreola (2008). For the Oxfordian and Kimmeridgian, those authors found: *Nautiloculina oolithica, Freixialina planispiralis, Audienusina fourcadei, Pseudocyclammina lituus, Choffatella* cf. *tingitana, Alveosepta jaccardi, Mesoendothyra croatica, Everticyclammina virguliana, Rectocyclammina chouberti, Labyrinthina mirabilis, Kurnubia* gr. *palastiniensis*, and *Trocholina* sp.

The calcareous algae genera cited by those authors were *Clypeina, Cylindroporella, Zergabriella, Actinoporella, Apinella, Heteroporella, Deloffirella, Salpingoporella*, *Radoiciciella, Likanella,* and *Permocalculus* and species as *Pseudoepimastopora jurassic*a and *Marinella lugeoni*.

For the Tithonian and the Berriasian, the following foraminifera species were cited: *Timidonella* (?) sp., *Pseudospirocyclina* sp., *P. maynci*, *Pseudocyclammina lituus,* and *Anchispirocyclina lusitanica,* as well as *Linoporella capriotica, Draconisella genotii, Likanella* sp., and *Radoiciciella* sp.

Ornelas–Sanchez & Hottinger (2006) also stressed the resemblance between the Tithonian facies of Mexico and Portugal.

b – From Guatemala, Johnson & Kaska (1965) reported the following algae species from the Upper Jurassic–Lower Cretaceous: *Girvanella minuta, Lithothamnium(?) primitiva* n. sp. (aff. *Lithophyllum shebae*), *Permocalculus ellioti* n. sp. *(*aff. *P. irenae), Picnoporidium lobatum, Marinella lugeoni, Cayeuxia piae, Actinoporella* cf. *podolica*, *Anchispirocyclina henbesti (= A. lusitanica)*, and *Aulotortus sinuosus*.

c – The Gulf Coast Smackover Formation (Oxfordian) contains an important reef complex, with sponge–coral–algal buildups with abundant *Tubiphytes*, stromatolite mounds, and bioclastic piles (Crevello & Harris, 1984) that are quite similar to the Algarve examples.

Anchispirocyclina lusitanica is recorded from the Tithonian of Florida, Jamaica(?), Guatemala, and Cuba (Fourcade & Michaud, 1987).

From the Upper Jurassic of Texas and Alabama, Johnson (1961) listed *Acicularia jurassica* n. sp., *Cylindroporella texana* n. sp., *Cayeuxia americana*, and *Marinella lugeoni*.

d – The central North American coast has revealed *Alveosepta jaccardi* and *Kurnubia palastiniensis* in the Oxfordian–Kimmeridgian and *Anchispirocyclina lusitanica* in the Tithonian (Fourcade & Michaud, 1987).

e – The Canadian Scotian Basin and the Grand Banks are of particular interest because they were located at the same palaeolatitude, and not far, from Iberia during the Late Jurassic. However, there were significant differences with respect to palaeoceanographic conditions (wind and sea regimes) between the Canadian margin and Iberia. According to Hiscott *et al*. (1990), the Canadian margin was under the influence of a strong, even storm-dominated, wave energy regime during the Neocomian. In contrast, the Lusitanian Basin experienced low-energy winds and waves, which allowed only a minor redistribution of the deltaic terrestrial sediments. We consider that the conditions in the Algarve Basin during the Late Jurassic would have been similar to those described for the Lusitanian Basin, given the very consistent palaeogeographic position of Iberia during this time interval, the proximity of the two basins (300 km apart), and the resemblance in microfacies.

According to Gradstein (1979), the Oxfordian–Kimmeridgian of that region is characterized by an association of several species of calcareous benthic foraminifer genera, such as *Epistomina, Gaudryina, Lenticulina*, and others commonly found in deep-water facies. Only the uppermost Jurassic shows neritic microfacies of the *Alveosepta jaccardi* Zone, which is overlain by the *Anchispirocyclina lusitanica* Zone, dated as Tithonian by calpionellid species (e.g., in the Algarve Basin).

According to Stam (1986) during the Upper Jurassic there was a good affinity between the deep benthic and planktonic foraminifers of the Great Banks of Newfoundland and the Portuguese basins.

In the onshore of both Lusitanian and Algarve basins those foraminifers are almost exclusive of the deep marine levels of midle Oxfordian to Lower Kimmeridgian. As we have seen before (see Section 3.2), in the Algarve Basin, those microfossils where also identified along the Upper Jurassic and lowermost Cretaceous series of Corvina 1 and Algarve 1 offshore wells.

The calpionellid assemblages found in the offshore of the Canadian Atlantic Shelf (Jansa *et al.*, 1980) allow correlations to be made with the Tethyan zonation and the dating of associated complex foraminifers and ostracod faunas. *Anchispirocyclina lusitanica* and *Alveosepta jaccardi* occur respectively in Tithonian and upper Oxfordian–lower Kimmeridgian clastic–carbonate intervals. Other cited Tethyan species include *Pseudocyclammina lituus, Buccicrenata italica, Trocholina alpina, T. elongata, Epistomina madagascariensis*, and *Lenticulina busnardoi*. Jansa *et al.* (1980) surmised that these species lived in the warm near-surface waters brought from Tethys to the North Atlantic. In contrast, the boreal foraminifera species also inhabiting the Canadian Shelf would have been associated with cold deep-neritic waters derived from the Boreal realm. The presence of calpionellids, dispersed as far as the Grand Banks, indicates that a well-established circulation between Tethys and the North Atlantic Basin was operating during the Late Jurassic (Jansa *et al.*, 1980).

Ascoli *et al.* (1984) provide interesting stratigraphic data from the study of complex arenaceous and calcitic foraminifers, also reported in Algarve: *Alveosepta jaccardi* (Oxfordian–Lower Kimmeridgian), *Trocholina alpina* and *T. elongata* (Kimmeridgian–Tithonian), *Anchispirocyclina lusitanica* (Tithonian), *Everticyclammina virguliana* (Kimmeridgian–Valanginian), and *Trocholina valdensis* (Tithonian–Valanginian).

Furthermore, Ascoli *et al.* (1984) also identified a diverse assemblage of calcareous benthic foraminifer species of various genera including *Epistomina* spp. and *Lenticulina* spp., as well as calpionellids, with the following stratigraphic distribution: middle–upper Tithonian (*Crassicolaria brevis*, *C. intermedia*, C. *massutiniana*, C. *parvula*, *Calpionella alpina*, and *Tintinopsella carpathica*); and uppermost Tithonian–Berriasian (*Calpionella alpina* (Acme Zone), *Crassicolaria parvula*, and *Tintinopsella carpathica*).

The Scotian Shelf reveals the occurrence of bioherms (stromatolites, siliceous sponges, corals, chaetetids, and stromatoporoids) from the Oxfordian to Berriasian, which, according to seismic data, appear to extend to the Bahamas (Jansa *et al.*, 1982). These bioherms also contain *Tubiphytes morronensis*, red algae, and calcareous sponges. Several species of *Epistomina* and *Lenticulina* are also found. The affinity between these bioherms and those from the Algarve Basin is clear.

6.1.2. The Eastern Atlantic margin (from Senegal to Western France)

The Senegal coast seems to be the southernmost tethyan African region where complex arenaceous foraminifers occur in the Upper Jurassic, with the following species being found (Castelain, 1965): *Alveosepta jaccardi, Everticyclammina virguliana, Pseudocyclammina* aff. *lituus, Anchispirocyclina lusitanica*, and *Trocholina* cf. *alpina.* Further north, in the offshore and onshore areas of Morocco, a rich Mediterranean Tethys micropalaeontological association (foraminifers and algae) that is quite similar to those of Algarve is found (e.g., Hottinger, 1967; Steiger & Cousin, 1984; Bouaouda *et al.*, 2004). These typical "Mediterranean" microfacies are also found in Portugal, as we have recorded since 1971.

The northernmost limit of these microfacies is situated at the latitude of La Rochelle (France), where *Alveosepta jaccardi, Kurnubia palastiniensis, Parurgonina caelinensis, Pseudocyclammina lituus*, and *Anchispirocyclina lusitanica* still appear (Fourcade & Michaud, 1987). North of this latitude, the typical Tethyan neritic carbonate microfacies give way to shales, marls, and sandstones of shallow- to deep-marine environments, with a large number of benthic foraminifers (including *Epistomina, Lenticulina, Ammobaculites,* and *Ophthalmiidae*) and also planktonic forms, such as *Globuligerina* and pelagic ostracods.

6.2. The Tethys Mediterranean domain

6.2.1. The neritic microfossils record

The Late Jurassic was an extraordinary epoch for the development of carbonate platforms around the Mediterranean Tethyan margins, where rich marine microfauna and microflora assemblages grew and evolved in warm, shallow epicontinental waters.

The major part of this micropalaeobiotic record belongs to Tethyan carbonate platforms. There are now hundreds of foraminifers and calcareous algal species described in a profuse literature, in which the arenaceous complex foraminifers and dasyclads are very important groups for both stratigraphic and palaeoenvironmental research purposes. Other organisms associated, as microproblematica, sponges, corals, and stromatoporoids, have also been studied.

At times, the Tethyan carbonate platform environment was invaded by pelagic organisms, such as ammonites, calpionellids, globigerinids, dinoflagellates and radiolaria, providing good stratigraphic markers and supporting the neritic microfossil biozonations.

Although there is a significant correspondence between the Tethyan margin microfacies and their biozonation scales, there are some differences between the Algarve Basin and other Mediterranean areas, as examined further below, in Sections 7.2.2 and 7.2.3.

6.2.2. The pelagic microfossils record

In the open Tethys Ocean, far from its margins where shallow-water carbonate platforms prevailed, a deep-water pelagic environment dominated and the sea-bottom accumulated radiolarites, limestones (*Ammonitico Rosso* facies), and calcareous turbidite sediments that were generated in the distal areas of carbonate platforms. The geographic distribution of siliceous and carbonate sediments was controlled mainly by the carbonate compensation depth (CCD), which in those times was abnormally shallow (Dercourt *et al.,* 1994).

The pelagic palaeobiota of the Tethys Mediterranean domain is composed mainly of:

1. **Planktonic groups**: dinoflagellates, radiolarians and ostracods, *Globochaetae, Saccocoma, Cadosinidae, Stomiosphaeridae, Calcisphaerulidae, Nannoconus*, Protoglobigerinids, and typical Tethyan calpionellids.
2. **Benthic groups**: calcitic foraminifers belonging to various genera, including *Epistomina, Lenticulina, Spirilina, Ophtalmidium,* and *Nubeculinella*, and arenaceous foraminifers such as *Ammobaculites* and *Reophax*.
3. **Macrofossils**: ammonites and *Aptycus,* pelagic bivalves ("filaments") such as *Bositra buchi* (Röemer), *Saccocoma* and holuthurian's sclerites, amongst others.

As noted above, some forms of these groups could have invaded the Late Jurassic carbonate platforms of the Algarve and Lusitanian basins for short periods.

6.3. Conclusions

Overall the Tethyan neritic microfossil assemblages may be characterized as follows:

a - The high palaeobiodiversity characterizes both the northern and southern margins of the "Mediterranean" Tethys basin. Although some species occur only with a restricted regional distribution, a greater number are common to both margins.

b - In most parts of the Atlantic Tethys, the palaeobiodiversity was lower, but the majority of its species are common to the Mediterranean region. According to the literature, the southern Atlantic region seems to have been characterized by a higher biodiversity (Guatemala, Mexico, and Morocco offshore), but this biodiversity appears to decrease to the north of the western Atlantic margin (Central American and Canadian coasts). However, the palaeobiodiversity was high in the central zone of the eastern Atlantic margin (Morocco, Iberia, and the southwest of France), probably because of the direct influence of the Tethys Mediterranean outflow currents.

7. MICROPALAEONTOLOGY

7.1. Micropalaeontological remarks

The most interesting groups studied are foraminifers, calcareous algae, corals and stromatoporoids, coralline sponges, ostracods, and charophytes. Several of these species have already been described and illustrated by us in previous studies (e.g., Ramalho, 1971). Therefore, here we make some remarks about new or interesting species.

7.1.1. Foraminifers

Globuligerina oxfordiana (Grigelis)

(Pl. 10, Figs 8-10)

Identified in the uppermost layers of the Peral Formation (upper Oxfordian), of the Ribeira do Colmeal Section (Fig. 1) this species also appears in the Rocha microbial buildup levels (lowermost Kimmeridgian) and in the Algarve 1 drill hole (Kimmeridgian).

Tubiphytes morronensis Crescenti

(Pl. 12, Figs 3-5)

This species has been widely identified in the Upper Jurassic biohermal facies of Portugal (Lusitanian and Algarve basins), and was initially termed "association *Nodophthalmidium* et Cyanophycées" (Ramalho, 1971). In the Algarve Basin, this species is common in the Jordana (in "deep" water microfacies) and Cabeça formations, where it is associated with microbial structures or encrusting bioclasts, and also in Biounit A of the Escarpão Formation, generally as a free form.

This species is ubiquitous in the Tethyan realm, from the eastern margin of the North American continent (e.g., the Smackover Formation) to Japan, and is associated with siliceous sponges and stromatolitic bioherms; it is dated from Oxfordian to Early Cretaceous (Jansa *et al.*, 1982).

Coarsely agglutinated Lituolids

(Pl. 1, Figs 1- 4)

Several different forms of these foraminifers occur in our sections. The most of them possess relatively large dimensions, reaching about 4.5 mm in length.

Haplophragmoides cf. ***joukowski*** Charollais, Bronnimann & Zaninneti

(Pl. 3, Figs. 9, 11 and12)

This is a small planispiral lituolid with a finelly micritic test, a rounded periphery, and the aperture at the base of the last septum. Its dimensions are as follows with the values of the type-species being contained in parenthesis:

- test diameter = 0.18-0.36 mm (0.12-0.20 mm)
- number of turns = 2-3 (2-2.5)
- number of chambers (last turn) = 7-11 (8-10)
- height of the last chamber = 0.040-0.072 mm
- proloculus diameter = 0.036-0.072 mm (0.024-0.032 mm).

With the exception of the proloculus diameter, the other values are clearly compatible with those of the type -species.

H. cf. *joukowski* occurs in all the biounits of the Kimmeridgian-Tithonian of Algarve Basin.

***Levantinella egyptiensis*?** (Fourcade, Arafa & Sigal)

(Pl. 7., Figs 7-8)

Although a small number of thin-sections from Biounit A and B (Kimmeridgian) were available, they were insufficient for precise identification. A form from the Kimmeridgian of the Lusitanian Basin has been cited as "Lituolidé, gen. et sp. (?)" by Ramalho (1971, Pl. XVIII, figs. 7 and 8), and probably belongs to this species.

Otaina magna Ramalho

(Pl. 5, Figs 1-7)

Originally described in the upper Kimmeridgian of the Lusitanian and Algarve basins (Ramalho, 1990), this species was subsequently identified in several parts of the Tethyan domain (Spain, Sardinia, Middle East, Arabia, and Mexico). More recently, Schlagintweit (2011) described a new species, *Spiralonoculus suprajurensis,* from the Kimmeridgian–Berriasian of Austria, which seems identical to our species. *O. magna* is commonly found in Biounits A and B (Kimmeridgian), but is only rarely found in Biounit D (upper Tithonian) of the Algarve Basin.

Several specimens show a less conspicuous internal structure and a more massive upper part of the septa. The internal structure may be more or less coarse as can be seen in Pl. 5, Figs. 1 – 7. For now, we consider that these forms may represent the B generation of *Otaina magna*, as referred too by us in a previous study (Ramalho, 1990).

Neokilianina gr. rahonensis (Foury & Vincent)

(Pl. 3, Figs 1-6)

These forms have been observed in just a single layer of level **d** from the lower Kimmeridgian of the Sagres Section, where it is abundant and associated with *N. concava* n. sp.. Its dimensions are given in Fig 6:

	N. rahonensis (adapted from Foury & Vincent, 1967)	***N.*****gr.** ***rahonensis*** (from Algarve)
basal diameter (d) (mm)	0.30-1.25	0.47-1.26 (070-0.90)
height (h) (mm)	0.50-1.80	0.45-1.30 (0.69-0.75)
h/d	1.44 -1.67	0.96- 1.08
apical angle	45°-55° (approx)	55° (approx)

Fig 6 – A comparison of the dimensions of *N. rahonensis* from France and *N.* gr. *rahonensis* from Algarve. The most common values are contained in parenthesis.

The comparaison of these two forms allows the following conclusions to be drawn:

Specimens of *N.*gr. *rahonensis*, from Algarve, have greater basal diameters than the French specimens but are not as high. The h/d ratio of the Algarve forms presents lower values and its apical angle is more open compared with that of the French forms.

These several differences may represent a morphological transition to *N. concava* n. sp.

The embryonary stage is composed of about five trochospiral chambers conically disposed, with an apical angle of approximately 5°. The adult stage lateral walls present a greater angle (around 55°) compared with the French forms and a conical disposition with a convex profile.

Neokilianina concava **n. sp.**

(Pl. 2, Figs 1-18)

Associated with *N.* gr. *rahonensis*, we found sections of another morphological type of *Neokilianina*, whose axial sections show a pronounced concavity in the middle part of the basal side, and a wider angle between the lateral walls.

Name origin: Related to the pronounced concavity on its basal side.

Holotype: One thin-section 0-9 HOLOT.

Paratypes: Two thin-sections 0-9 PARAT.

Studied material: 97 thin-sections (axial, transverse, tangential and oblique sections) all from sample 0-9

Holotype, paratypes, and all other sections and samples, are kept in the LNEG collections.

Local type: Level **d** of the Escarpão Formation (Biounit A) of the Tonel Unity.

Diagnose: Species belonging to the genera *Neokilianina* Stepfontaine, 1988, with an internal structure similar to that of *N.* gr. *rahonensis* (Foury & Vincent, 1967).

The new species presents externally a convex profile with two major differences in its angular value, with an apical angle greater than that of *N. rahonensis*. The adult test is much more open than *N. rahonensis* and has a pronounced concavity along the basal side.

Dimensions:

- Basal side length (d) = 0.90–1.98 mm (0.90–1.40 mm);
- Test height (h) = 0.54–0.97 mm (0.90–0.95 mm);
- h/d = 0.61–1.43;
- Apical angle= 60º-120º;

The most common values are contained in parenthesis.

Environment: The environment corresponds to an internal marine platform with rich micropalaeontological content. The level with *Neokilianina* is essentially micritic with very few clasts indicating a calm deposition event.

Age: Lower Kimmeridgian (Biounit A of Escarpão Formation)

Discussion: *N. concava* n. sp. occurs associated with *Neokilianina* gr. *rahonensis*. Both species exhibit the same type of internal structure, described by Foury & Vincent (1969) for *K. rahonensis*, but their external morphologies are different. The new species has a greater apical angle and presents a conspicuous basal concavity.

Two sections designated as *Kilianina* sp. have previously been illustrated by Ramalho (1971, Pl.XX, fig 7), from the upper Oxfordian–Kimmeridgian of the Arrábida region (Lusitanian Basin), one of which has the characteristics of *N. concava* n. sp.

It is interesting to notice that Arnaud-Vanneau (publication year unknown), illustrates two sections of *Kilianina blancheti* (Pfender) with a concavity in the basal side of the test, but its internal structure cannot be attributed to the genus *Neokilianina*, according to the definition of Septfontaine (1988), and Boudagher-Fadel (2008).

Neokilianina ? lata (Oberhauser)

(Pl. 3, Fig. 7)

This species was described and illustrated by Oberhauser (1956), who considered it as a *Kilianina,* from the Malm of Turkey and by Fourcade (1970), from the Kimmeridgian of southeastern Spain. Its test is very platy, reaching a diameter of 6.5 mm and a heigt of 0.5 mm according to Arnaud- Vanneau (publication year unknown).

The form attributed to this species was found in the lower Kimmeridgian of the Asseca Section (level **g**, Biounit A of the Escarpão Formation).

Orbitolinopsis ? sp.

(Pl. 4, Figs. 12-15)

This is a small Orbitolinid with the following dimensions (in mm), with the median values in parenthesis:

- Height (h) = 0.450-–0.990 (0.692);
- Base diameter (b) = 0.360–0.612 (0.522);
- h/b = 0.55– 0.96 (0.75);
- Apical angle = 30°–50° (40°);
- Adult chambers height = 0.070–0.090 (0.080);
- Number of chambers = 8–10.

The test is commonly conical, but some specimens present an asymmetrical twisting although with opposite directions for the juvenile and adult stages (Pl. 4, Figs. 12 and 15). The internal structure of our specimens shows close affinity with the genus *Orbitolinopsis* (Loeblich & Tappan, 1988). The thin-sections of *Orbitolinopsis*? sp. resemble the figures of O. *capuensis* (De Castro) presented in Macoin *et al.* (1970), Velic (1977) and in L. Sinni & Masse (1984). It is also possible to occur transition forms to *Parurgonina caelinensis.*

According to the available literature, this genus is found in the Lower Cretaceous. In Algarve, our form is present in the upper Kimmeridgian (Escarpão Formation).

Because of this stratigraphic difference, we prefer to wait for more material before deciding a more appropriate designation.

Feurtillia frequens Maync

(Pl. 3, Figs. 13–14)

This is not a common form, appearing in Biounit D (upper Tithonian) in association with *Anchispirocyclina lusitanica*.

Charentia atlasica Fares
(Pl. 7, Fig. 12)

This species occurs in the Kimmeridgian – Tithonian from the Escarpão and *A. lusitanica* formations. Its dimensions are: external diameter = 0.27–0.72 mm; number of chambers in last coil = 10–13. In some sections, we noticed an initial stage composed of two small chambers of unequal size.

Anchispirocyclina lusitanica (Egger)
(Pl. 5, Figs. 11–15; Pl. 6, Fig. 1)

In Portugal, the appearance of this species marks the upper part of the Tithonian and its higher stratigraphic occurrence is found in the lowermost Berriasian. In both the Lusitanian and Algarve basins, the uppermost levels containing this species usually show some abnormal specimens.

The occurrence of *A. lusitanica* in the eastern Canadian margin is a good stratigraphic marker because it not only allows a correlation with the Tithonian Mediterranean microfacies but also is integrated in series with deep-water assemblages (e.g., benthic foraminifers and calpionellids), allowing a comparison between the two Atlantic domains to be more easily made, as was the case for Algarve 1.

Anchispirocyclina neumannae Bernier, Fleury & Ramalho
(Pl. 6, Figs. 2–5)

From our previous studies, we originally reported this species as *A.* cf. *maynci* (Hottinger) found in the upper Tithonian of Portugal. This species also occurs in the Kimmeridgian–Portlandian of Greece and probably in other regions although identified there as *A. lusitanica*.

In Algarve, *A. neumannae* occurs associated with *A. lusitanica*, in Biounit D (upper Tithonian) of several of our geological sections.

Some comments about *A. lusitanica* and *A. neumannae*

According to the authors who defined and redefined these two species, Maync (1959a) and Bernier *et al.* (1979), the main differences are:

a) *A. lusitanica* has a very small or no free spaces along the marginal interior of its test as compared with *A. neumannae*, where the pillars zone is concentrated in the central third of the test. However, in *A. lusitanica,* irregular marginal interruptions may appear (Pl. 5, Fig. 14 and Pl. 6, Fig. 1).

b) The microsphaeric B generation of *A. lusitanica* shows a much larger test diameter (4–15 mm) compared with *A. neumannae* (2.4 mm).

c) The number of chambers of the last turn of the macrospheric A generations of *A. lusitanica* and *A. neumannae* is 10–26 and 23–25, respectively, and for the microspheric B generation is 34–130 and 25–30, respectively.

d) The proloculus presents a more restricted range in its dimensions for *A. neumannae* (0.160–0.270 mm) compared with *A. lusitanica* (0.050–0.450 mm).

e) According to our observations of axial or subaxial thin-sections, the edge of *A. neumannae* tests presents an angular or blunt contour while in *A. lusitanica* it is subrounded.

Torinosuella peneropliformis (Yabe & Hanzawa)

(Pl. 5, Fig. 10)

This species occurs in the Limestones with *A. lusitanica* Formation in the Escarpão and Loulé-Faro sections (upper Tithonian).

T. peneropliformis was cited from the upper Tithonian of Cape Espichel (southern Lusitanian Basin) by Ramalho, (1961, 1971), and was previously studied by Maync (1959b) and Hottinger (1957) This species is cited from the Kimmeridgian – Neocomian, in the literature.

The proloculus of this species is not circular, and has diameters varying from 0.126 to 0.218 mm. The tests are peneropliform with a length of 0.540–1.440 mm, and have about 17 chambers in the last turn.

Valvulinidae "plexus" Septfontaine, 1988
(Pl. 6, Figs. 8–15)

Septfontaine (1981) presents a phyllogenetic interpretation for several Mesozoic Lituolid assemblages ("plexus").

One such "plexus" comprehends some *Valvulinidae* genera, particularly with respect to the evolution of the aperture. The primary species of this assemblage is "*Valvulina*" *lugeoni*, which appears from the Middle Jurassic to the Cretaceous. According to Septfontaine (1981), the morphology of the aperture of this "plexus" changes with time according to successive genera: *Paravalvulina* (Dogger), *Parurgonina* and *Kilianina* (Malm), and, finally, *Chrysalidina* (Upper Cretaceous) (see Fig. 7).

Belonging to this "plexus"[3], we have identified "*Valvulina*" *lugeoni* (Pl. 6, Figs. 8–9), *Paravalvulina* aff. *complicata* (Pl. 7, Figs. 11-15) *Parurgonina caelinensis* (Pl. 7, Figs 1 and 2) and *Neokilianina* gr. *rahonensis* (Pl. 3, Figs 1 - 6). This means that in the lower Kimmeridgian of the Algarve Basin all these forms may coexist.

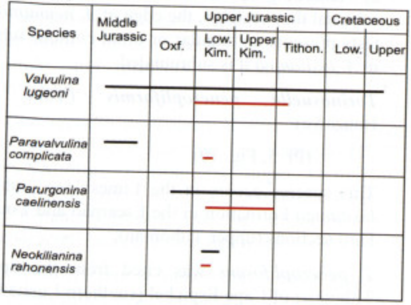

Fig. 7 – Stratigraphic distribution of the *Valvulinidae* "plexus" after Septfontaine (1981), in black, and Algarve, in red.

***Amijiella? adherens* n.sp.**

(Pl. 4, Figs. 1 – 11)

This unusual Lituolid has an internal structure quite similar to that of the genus *Amijiella* (see subsection entitled "Diagnose" below). However several forms show an initial stage characterized by adherence of the test to a rigid support, generally one or more rounded micritic clasts, followed by an adult uniserial stage in which the first chambers may be also adhered.

Name origin: From the latin word *adherens* (adherent).

Holotype: Thin-section HOLOT. AM – 466d. (Pl. 4, Fig. 1).

Paratypes: Two thin-sections PARAT. AM-466d and PARAT. AM- 466c. (Pl. 4, Figs. 2 and 3).

Studied material: About 40 thin-sections from the level that revealed this species (AM-466), deposited in the LNEG collections.

Local type: Base of level ***n*** of Biounit D of Limestones with *A. lusitanica* Formation, in the outcrop at the Escarpão Section.

Diagnose: Test finely agglutinated with a short planispiral initial stage free or adherent, followed by an unrolled, rectilinear and uniserial adult stage that may be either free or adherent. The aperture is multiple.

The free adult test is subcylindrical, with straight sutures. The walls present a coarse and irregular subepidermal network of beams and rafters. The chambers central zone does not present pillars.

This species presents two morphologic types.

a) Free test: with the initial and the adult stages free;

b) Adherent test: with the initial stage or even the entire adult stage adhering to a clast.

Dimensions (The most commun values are in parenthesis in mm)

Rectilinear adult stage:

- Test diameter = 0.27–0.54 (0.31–0.36).
- Length = 0.63–1.80 (1.00-1.40).
- Number of chambers = 5–12 (7-12).
- Chambers height = 0.11–0.20 (0.11-0.14).

Environment: Shallow internal marine platform with moderate to high hydrodynamic energy confirmed by the occurrence of microsparite, oolites, and rounded clasts.

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[3] This plexus comprises various homeomorphic genera which hinders their classification. Our specimens presenting trematophore ouverture, pillars and canaliculate walls, seems quite similar to Paravalvulina complicata Septfontaine, 1988.

Age: This form occurs at the extreme base of Biounit D of the Escarpão Section, considered by us to be part of the upper Tithonian.

Discussion: Notwithstanding its common adherent behaviour, this species appears to belong to the genus *Amijiella* (see Diagnose). It is interesting to note the similarity of the internal characteristics of *A.? adherens* and those shown in the sections illustrated by Hottinger (1967, pl. 8, figs. 1–6, 20, and 21) for the free forms of *Haurania amiji* Henson (Lias of Morocco). However this African forms have larger dimensions than our new species.

Weynschenk (1951) illustrated two forms attributed to *Labyrinthina mirabilis* (figs. 5 and 8) attached to rounded clasts, similar to our Pl. 4 Fig. 6, but they are considered to belong to a different genus.

Neotrocholina spp. A, B and C

(Pl. 9, Fig. 1–10)

Neotrocholina sp. A is common in our sections from the Jordana Formation to the *A. lusitanica* Formation (lower Kimmeridgian–upper Tithonian). Its dimensions are: basal diameter (d) = 0.27–0.47 mm; height (h) = 0.14–0.27 mm; d/h = 1.6–3.0; apical angle = 80°–90°.

This form resembles *Neotrocholina* sp. 1 from the Kimmeridgian–Tithonian of the Lusitanian Basin (Ramalho, 1971), specimens of which have the following dimensions: d = 0.44–0.68 mm; h = 0.25–0.50 mm; and d/h = 1.1–1.7. However, they are clearly bigger than *Neotrocholina* sp. from the Algarve Basin.

We have also observed two more forms of *Neotrocholina* (sp. B and sp. C), but the reduced number of specimens did not allow a specific classification to be made.

Mironovella granulosa Bielecka & Pozaryski

(Pl. 9, Fig. 11)

This species was identified in the Jordana Formation (Colmeal Section) and is identical to the original figures and sections of *Parinvolutina aquitanica* Pelissié & Peybernès presented by Bernier (1984) from the upper Oxfordian–upper Kimmeridgian of France. Görög & Wernli (2013) considered this species to be a junior synonym of *M. granulosa*, which ranges from the upper Oxfordian to the lower Tithonian of the northern margin of Tethys.

Involutina algarvensis n. sp.

(Pl. 8, Figs. 1–16)

Name origin: From the name of Algarve.

Holotype: One thin-section HOLOT. AP-72 (Pl. 8, Fig. 3).

Paratypes: Two thin-sections, PARAT. AP-137 and PARAT. AP-173a (Pl. 8, Figs. 2 and 9).

Studied material: About 40 axial and 5 subequatorial sections, deposited in the LNEG collections.

Local type: Asseca Section

Diagnose: The test is free, recrystallized, and lenticular to subglobular with a rounded periphery, planispiral, with an undivided chamber of rounded section, with several coils that tend to enlarge laterally. The proloculus is not observed. Both sides of the test are thickened by crystalline masses. These prominent zones present equidimensional papillae or pillars in axial view, giving a crenulated profile, but not affecting the last coil. The aperture is simple at the end of the last coil and is larger rather than high.

Our forms present two types: (Dimensions in mm and the most common values in parenthesis)

Type 1: Subglobular with a diameter (d) of 0.36–0.68 (0.49-0.58), thickness (t) of 0.25-0.45 (0.34-0.40), and a ratio t/d: 0.60-0.80 (0.62-0.73). The ouverture reaches 0.09-0.25 (0.11-0,13) of width and 0.05-0.11 (0.05-0.07) of height.

Type 2: Less common than Type 1. Sublenticular and with the dimensions of: diameter (d) = 0.25–0.56 (0.34-0.43); thickness (t) = 0.16–0.27 (0.18-0.23); t/d = 0.40-0.60 (0.53-0.57). Ouverture width = 0.07-0.11 (0.07-0.09); Ouverture height = 0.05-0.07 (0.07-0.09). We think that specimens of Type 2 belong to a different species but we have not yet sufficient material to decide.

Environment: This species occurs in micrites, commonly associated with small bioclasts, siliceous spicules (ab), *Alveosepta jaccardi* and *Kurnubia palastiniensis* and probably living in deeper environements of internal platforms.

Age: *I. algarvensis* occurs in the upper Kimmeridgian (Biounit B). This species accompanies *Alveosepta jaccardi*, both disappearing at the same stratigraphic level in the Asseca Section. To our knowledge, it is the only *Involutina* species described from the Upper Jurassic.

Discussion: Although the recrystallization of the tests does not allow the internal wall characteristics, to be observed the genus description corresponds rather well to our thin-sections. Rigaud *et al.* (2013), considered as valid only *Involutina liasica* (Jones *in* Brodie, 1853) from the Rethian–lower Middle Jurassic and *I. hungarica* (Sido, 1952) from the Aptian–Albian. The first of these species is predominantly lenticular with uneven papillae, differing from *I. algarvensis*. *I. hungarica* presents larger dimensions (d = 0.80–1.70 mm) and a dense network of numerous large pores (Consorti *et al.*, 2014). *I. lacunosa* (Rugieri & Giunta), from the Italian Dogger, presents almost rectangular axial sections, with both sides parallel and not inflated.

Keramosphaera cf. ***allobrogensis*** Steinhauser *et al.*
(Pl. 9, Fig. 14)

This porcellaneous foraminifer have been found in the upper Berriasian of France and Switzerland. However, in Algarve, this species has been found in the transition of Cerro da Cabeça to Biounit A (lower Kimmeridgian) of the Asseca Section (level ***c***). Unfortunately, we have one incomplete specimen only, although this is sufficient to characterise it. The diameter of the specimen is about 3.2 mm. *K.* cf. *allobrogensis* occurs in microbial facies associated with *Tubiphytes morronensis*, *Corynella* cf. *quenstedti*, sponges, and serpulids.

Coscinophragma cribrosum (Reuss)
(Pl. 6, Figs. 6–7 and Pl. 12, Fig. 8)

This species occurs in the Jordana Formation of the Machados Section and at the base of Biounit A of the Conceição de Tavira Section (lower Kimmeridgian). In other countries, *C. cribrosum* appears in the Tithonian–Lower Cretaceous.

7.1.2. Calcareous algae

Salpingorella **gr.** ***pygmaea*** Gümbel
(Pl. 13, Figs. 6, 7, and 9)

In our samples, it is difficult to separate this species, which is prevalent, from some sections that include *S. enayi, S. johnsoni* and some smaller specimens of *S. gigantea.* For this reason, we consider a group that includes all of these forms. The great majority of the sections have an external diameter D = 0.324–0.720 mm, central canal diameter dc = 0.144–0.290 mm, dc/D = 0.30–0.40, and a diameter of the base of the branches = 0.036–0.054 mm.

"*Salpingoporella*" *gigantea* (Carozzi)
(Pl. 14, Figs. 3 and 4)

According to Bassoulet *et al*. (1978) this form corresponds to *Linoporella capriotica* (Openheim), but we prefer to use the old designation that is generally adopted in the literature, waiting for a more complete revision of this species.

"S." gigantea occurs in the lower Kimmeridgian (Escarpão Formation) of the Algarve Basin.

Their dimensions are:

- Maximum lenght (L)= 2.90 mm
- External diameter (D) = 0.72–1.15 mm
- Central canal diameter (dc) = 0.270–0.396 mm
- dc/D =0.30–0.40
- Branches basal diameter = 0.036–0.072 mm
- Branches length = 0.216–0.360 mm

In the Tethyan Mediterranean region *"S." gigantea* occurs in the Kimmeridgian–Portlandian (Bassoulet *et al.*, 1978)

Macroporella aff. ***praturloni*** Dragastan
(Pl. 14, Figs. 9 and 10)

We found some rare sections of this form, that resembles *M. praturloni,* in the lower

Kimmeridgian (Escarpão Formation) with the following dimensions:

- Thallus lenght = 3.45 mm
- External diameter = 1.08 mm
- Branches diameter = 0.09 mm

In the Tethyan region *M. praturloni* appears in the Tithonian to Valanginian

Griphoporella minima? Nickler & Sokac
(Pl. 14, Fig. 6)

Some bad sections resembling this species were found in the upper Kimmeridgian and in the upper Tithonian of the Algarve Basin. *G. minima* occurs from the Oxfordian to the lower Kimmeridgian of the Tethyan Mediterranean region.

Griphoporella piae? Dragastan
(Pl.14, Figs. 7 and 8)

This form occurs in the Kimmeridgian of the Algarve Basin, and their dimensions are as follows:

- Maximum lenght = 4.32 mm
- Maximum external diameter = 1.80 mm
- Central canal diameter = 0.14–0.72 mm
- Branches diameter = 0.055–0.070 mm

In the Tethyan region *G. piae* occurs from the Tithonian to Valanginian .

Alga AD-75
(Pl. 17, Figs. 9 - 14)

This alga occurs in the upper Kimmeridgian of the Loulé – Faro Section.
Until now we have not found in the literature any species with such characteristics. It is an alga with numerous tubular branches, very irregularly disposed and commonly curved and pointing down, strongly oblique to the thallus and with the following dimensions:

- Thallus lenght = 2.520–8.640 mm
- External diameter = 0.900–2.340 mm
- Central canal diameter = 0.360–0.900 mm
- Branches lenght 0.450–0.540 mm
- Branches diameter = 0.035 – 0.090 mm

Clypeina jurassica Favre
(Pl. 13, Fig. 8)

In our previous studies, we have always considered two species, *Clypeina jurassica* and *C. inopinata,* with the former occurring before and the latter being contemporaneous with *Anchispirocyclina lusitanica*. This specific separation was based on the presence of a dark band around the proximal portion of the branches and in its smaller dimensions observed on *C. inopinata* sections of the Lusitanian Basin (Ramalho, 1971).

The present study shows that considering the Algarve Basin specimens, this specific separation is impossible to maintain, as is recommended by Bassoulet *et al.* (1978). Therefore, a slight tendency towards greater dimensions prevails in the older Algarve forms (Biounit B).

In both the Algarve (Biounit C) and Lusitanian basins, we notice a significant interruption of the vertical distribution of *Clypeina jurassica* below the first appearance of *Anchispirocyclina*.

Clypeina? solkani Conrad & Radoicic
(Pl. 14, Fig. 1 and 2.)

This dasyclad has been identified in Biounits B, C, and D of the Escarpão Section, in Biounit C of the Loulé–Faro Section, and also appears in the Berriasian (Rey, 1982, 1983).

Actinoporella podolica (Alth)
(Pl. 13, Figs. 3–4)

This species was found in Biounit D of the Bias Section, but continues into Berriasian levels (Rey, 1982, 1983).

Campbeliella striata (Carozzi)
(Pl. 15, Fig. 11)

This species is typically Tethyan and is important for the biostratigraphy of the Algarve and Lusitanian basins. C. striata occurs commonly in the upper Kimmeridgian levels (Biounit B) in most geological sections of Algarve Basin. This species is less common in the lower Tithonian (Biounit C). Some rare specimens *C. striata* may occur at the base of upper Tithonian.

Petrascula bursiformis (Etallon)

(Pl. 14, Fig. 11 and 12)

Fragments of this species were detected in one layer of Biounit B (upper Kimmeridgian) of the Escarpão Section.

Coniporella valfinensis Bernier

(Pl. 14, Fig. 5)

Our sections present the same characteristics of the type species. They are found mainly in Biounit A (lower Kimmeridgian) of the Conceição de Tavira Section (Eastern Sector.

Bucurella espichelensis (Deloffre & Ramalho)

(Pl. 15, Fig. 11)

This species was first reported from the Portlandian B (upper Portlandian) of the southern Lusitanian Basin as *Zergatella* sp. 1 (Ramalho, 1971). Deloffre & Ramalho (1971) defined the species as *Macroporella espichelensis*, and this was included by Granier (2010) in the new genus *Bucurella*. This species seems to be a good marker for the upper Tithonian of Portugal[4].

Heteroporella[5] ***anici*** (Nikler & Sokac)

(Pl. 15, Figs. 1–3)

This species was firstly described by Nikler & Sokac (1965) in the Malm of Yugoslavia, which probably corresponds to the Kimmeridgian stage.

In Algarve, this species is dectected at the base of Biounit B (Kimmeridgian) of the Asseca Section. In some thin-sections can be observed sterile branches of about 0.018 mm diameter alternating with the fertile ones.

Heteroporella lemmensis (Bernier)

(Pl. 15, Figs. 4–6)

This alga is common from the lower Kimmeridgian to the upper Tithonian of the Algarve, where its dimensions are as follows:

- Length = 0.360–1.440 mm
- External diameter = 0.350–1.440 mm
- Central canal diameter = 0.020–0.060 mm
- Sporange dimensions = 0.126–0.216 mm (length); 0.072–0.126 mm (height)
- Number of sporanges per verticil = 8–9

	Yugoslavian forms	Algarve forms
Length (mm)	1.5	1.130 -1.620
External diameter (mm)	0.29-0,40	0.540
Central canal diameter (mm)	0,080-0,130	0.126-0,180
Sporange diameter (mm)	0.05-0.09	0.108-0.125
Number of sporanges per verticil	12-16	12
Angle of branches with the thallus	80°-90°	90°
Distance between verticiles (mm)	0.070-0.100	0.126-0.144
Age	Malm (Kimmeridgian)	Kimmeridgian

Fig.8 - Comparative dimensions and age of Yugoslavian and Algarve forms of *Heteroporella anici*.

***Heteroporella sagresensis* n. sp.**

(Pl. 15, Figs. 7–10)

Name origin: From Sagres, the main locality situated nearby the local type.

Local type: Benaçoitão Section found in the coastal zone at a beach situated about 5 km northeast of Sagres (see Fig. 1).

Holotype: Two thin-sections HOLOT. S-128 and HOLOT. S-103.

Paratypes: Two thin-sections PARAT. S-128.

Studied material: Six thin-sections of the Benaçoitão Section.

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[4] Some forms with two coalescente thallus have been designated by us as "siamese specimens" (Pl. 15, Fig. 11).

[5] For now we prefer to employ the genus designation *Heteroporella* instead *Otternstella* Granier *et al.*

Diagnose This species resembles *Heteroporella lemmensis*, with which it is associated, but its greater dimensions and the number of fertile sporanges by verticil easily distinguish the two species

The characteristics observed are:

- Maximum length (thallus) >1.800 mm
- External diameter = 0.850–1.620 mm
- Central canal diameter = 0.115–0.216 mm
- Number of sporanges by verticil = 23–26
- Fertile sporange dimensions:
  Length = 0.320–0.430 mm
  Height = 0.126–0.180 mm
- Diameter of sterile branches = 0.054 mm

Discussion The range of *H. sagresensis* values is incompatible with those of any other *Heteroporella* spp. presented in the inventories of Bassoulet *et al.* (1978), Peybernès (1976), and Bernier (1984). This new species have a central canal diameter narrower than the others species (with exception of *H. lemmensis*) and the number of its fertile sporanges is significantly higher, with the exception of *H. morillonensis* Bernier, which have 18 – 20 sporanges. However *H. morillonensis* also differs by the dimensions of its central canal diameter (0.255–0.357 mm), fertile sporanges length (0.229–0.280 mm) and sterile branches diameter (0.02–0.08 mm).

Age The levels containing *H. sagresensis* belong to Biounit B (upper Kimmeridgian) of the Benaçoitão section.

Association This new species always occurs in micritic limestones, and is associated with *H. lemmensis, Salpingoporella annulata, Campbeliella striata, Clypeina jurassica, Russoella triangularis, Permocalculus inopinatus, Kurnubia palastiniensis, Freixialina planispiralis, Pseudocyclammina* gr. *parvula, "Valvulina" lugeoni,* charophytes, and other microfossils.

Environment The exclusive presence of micrite, the absence of clastic or terrigenous elements, and the common presence of dasyclads together point to a shallow and calm environment of an internal open-marine carbonate platform.

Russoella triangularis (Ramalho)
(Pl. 16, Fig. 4)

Defined as *Terquemella(?) triangularis* in the Lusitanian Basin (Ramalho, 1971), this species occurs commonly in the Kimmeridgian–Tithonian of the Algarve Basin, especially in Biounit D.

Terquemella spp.
(Pl. 16, Figs. 1–3.)

These dasyclad corpuscles are quite common, particularly in Biounit A. They have circular, oblong, or irregular sections, identical to those generally attributed to the genus *Acicularia*. However, the elongate sections characterizing this genus have not been found, and therefore we prefer to use the genus *Terquemella,* as we have done in our previous studies.

Three morphological types were recognized, with the more common value ranges being indicated in parentheses, as follows:

Terquemella type A: Specimens show circular sections with a diameter of 0.090–0.450 mm (0.120–0.360 mm); diameter of internal cavities = 0.018–0.054 mm (0.038 mm); number of cavities = 5–25 (7–8).

Terquemella type B: Specimens show oblong sections with a maximum external diameter D = 0.540 mm; minimum external diameter d = 0.108 mm; number of internal cavities = 8–22 (13–14); diameter of cavities = 0.020–0.070 mm (0.036 mm); d/D = 0.5–0.8.

Terquemella type C: Specimens show irregular sections with no stable morphology

The morphologies and dimensions of *Terquemella* types A and B are similar to those of the published sections of *Acicularia elongata* Carozzi. In our sections, we did not discriminate between the morphological types because they do not show stratigraphic differentiation, appearing in all formations.

Permocalculus inopinatus Elliot
(Pl. 16, Figs. 5–6)

The *Permocalculus* genus is quite common in the higher Upper Jurassic levels of Portugal, in both the Lusitanian and Algarve basins, where the genus is apparently monospecific. Although these forms appear generally fragmented, the morphology seems identical to that of *P. inopinatus*, according to the genus revision of Deloffre (1992).

Lithophyllum (?) maslovi Dragastan

(Pl. 16, Figs. 9 and11)

This species occurs usually as small rounded (eroded) bioclasts with an amberine colour, composed of straight, tubular radially disposed cells, presenting circular sections with diameters around 0.020 mm. The cells are divided by thin walls and the thalus characterized by concentric growth zones, with different intervals between them. *Ethelia alba* Praturlon and *Diversocallis moesicus* Dragastan & Bucur are forms that resemble this species.

Cayeuxia spp.

(Pl. 17, Figs. 1–6)

Forms belonging to this algal genus are very abundant in our sections, composed by tubular cells of which present variable diameters. For practical reasons, we have considered only two groups: *Cayeuxia* gr. *moldavica* Frollo and *C.* gr. *piae* Frollo, based on a diameter of less than or greater than 0.060 mm, respectively. Both groups are common in Biounits A, B, and D, particularly in oncolithic facies. *C.* gr. *moldavica* also occurs as isolated nodules or encrusting bioclasts, although *C.* gr. *piae* is more abundant than *C.* gr. *moldavica* in Biounit D.

Picnoporidium* aff. *lobatum Yabe & Toyana

(Pl. 17, Figs. 7–8)

This species has sections resembling the general aspects of *Cayeuxia*, but presents tubular cells divided by sparse thin walls. The tubes have an irregular disposition, with circular sections measuring 0.040–0.090 mm in diameter. The dimensions of the thallus are shorter than in the type species, the cellular tubes more irregular, and with concentric structures referred to in the original description. These forms are common in Biounit A, but they also occur in other biounits, and in the Jordana and Cabeça formations.

7.1.3. Other organisms

Serpulids

(Pl. 11, Fig. 1 and Pl. 12, Fig.9)

These organisms are commonly found free or encrusting bioclasts (e.g. bivalves, gastropods, corals, microbialitic structures), especially in the Jordana and Cabeça formations.

Terebella lapilloides Munster

(Pl. 12, Figs. 6–7 and 10)

This serpulid is commonly associated with *Tubiphytes morronensis* and with microbial structures in the Jordana and Cabeça formations. The same association has been identified in the Upper Jurassic of the Lusitanian Basin (Ramalho, 1971), where *Terebella lapilloides* was designated by *Prethocoprolithus* sp.

Calpionellids

According to Durand-Delga & Rey (1982) and Durand-Delga (personal written communication, 1986) several species of this pelagic group occur at the top of the Tithonian in the Bias Section, in association with *Anchispirocyclina lusitanica*: *Calpionella alpina, C. "undelloides"(?), Crassiocolaria parvula*, and *C.* gr. *carpathica*.

In the northwestern Portuguese onshore, calpionellids are rare. However, in some of our samples from the Lusitanian Basin, Durand-Delga (written communication, 1986) identified *Calpionella alpina* and *Tintinopsella* gr. *carpathica* from the Tithonian–Lower Cretaceous transition (Sintra–Cascais region).

In contrast, calpionellids are common in the Portuguese offshore. The Algarve 1 drill hole cuts through a Tithonian series containing *Calpionella alpina, Crassicolaria brevis, C. parvula*, and *Tintinopsella carpathica*, as well as the lower levels of the Berriasian(?) containing *Calpionelites darderi*, *Calpionella alpina*, *Lorenziella hungarica*, *Remaniella cadischiana*, and *Tintinopsella carpathica*. Several offshore dredges of northwestern Portugal have revealed calpionellids also associated with neritic foraminifers, such as *Anchispirocyclina lusitanica*, and algae, typical of our onshore upper Tithonian (Dupeuble *et al.*, 1988).

Colonial organisms

(Pls. 18 and 19)

This informal group includes coralline and siliceous sponges, corals, "stromatoporoids" and *Chaetetidae*. The local abundance and extent of these organisms points to their important role in the composition of the organic buildups. These organisms are common in the Cabeça Formation but also occur intercalated in other formations as bioclasts or isolated elements, or as small bioconstructions.

The coralline sponges are an important group of the biohermal and bioclastic piles facies of the Portuguese Upper Jurassic. In the Algarve Basin, these sponges are common in bioherms associated with other reef-builder organisms (Cabeça Formation). These sponges reach their greatest development in Biounit A (lower Kimmeridgian), and progressively decreasing through to Biounit D (upper Tithonian). We have observed that these sponges prevail in shallower-water facies, whereas the siliceous sponges are more numerous in deeper waters, as already verified by other authors.

Several forms are well represented in the Algarve Basin mainly by the following species: *Cladocoropsis mirabilis* Felix, *Corynella* cf. *quenstedti* (Zittel), *Neuropora lusitanica* Termier *et al.*, *Thalamopora lusitanica* Termier *et al.*, and *Burgundia trinorchii* Munier–Chalmas. The same species have also been found at S. Tiago do Cacém (80 km south of Lisbon) and in several locations in the Lusitanian Basin within identical microfacies (Ramalho, 1971, 1981; Termier *et al.*, 1985a, b). In our previous works (Ramalho, 1971, 1981) those species were designated as "Spongiaire fibreux" (*Corynella* cf. *quenstedti*), "Bryozoaire forme A" (*Neuropora lusitanica*), and *Barroisia*? sp. (*Thalamopora lusitanica)*.

The stromatoporoids and chaetetids cited in this study were classified by S. Rosendhal, to whom we express our thanks. According to this author the difficulties of systematically classifying these organisms suggest prudence in the acceptance of his proposed classification.

Ostracods and Charophytes

From the samples of marls and clays, we recognize the species presented in Tables 1 and 2.

Table 1 – Ostracods identified in the Upper Jurassic of the Algarve Basin and their stratigraphic occurrence in the Lusitanian Basin, according to (1) Helmdach (1971) and (2) Ramalho (1971). The species in open nomenclature are illustrated in Ramalho (1971).

Ostracods	ALGARVE BIOUNITS				Stratigraphic occurrence in the Lusitanian Basin
	Kimmer.		Tithon.		
	A	B	C	D	
Bisulcocypris algarbiensis Helm. & Ramalho	X				
Bisulcocypris gr. *fluxans*	X				
Monoceratina sp.	X				
Paracypris sp.	X				Tithonian (2)
Asciocythese sp. 2	X	X			Tithonian (2)
Cytherella gr. *suprajurassica* Oertli	X	X			Kimmeridgian–Tithonian (2)
Cytheropteron sp.	X	X			Tithonian (2)
Leiria striata Helmdach	X	X			Lower(?) Kimmeridgian (1)
Schuleridea sp. 1	X	X			Top Kimmeridgian and Tithonian
Timiriasevia mackerowi Bate	X			X	Lower(?) Kimmeridgian (1)
Fabanella ornata (Steghaus)				X	Tithonian (2)

Table 2 – Charophytes identified from the Upper Jurassic of the Algarve Basin and their stratigraphic occurrence in the Lusitanian Basin, according to (1) Helmdach (1971), (2) Ramalho (1971), and (3) Pereira (2002)

Charophytes	**ALGARVE BIOUNITS**				**Stratigraphic occurrence in the Lusitanian Basin**
	Kimmer.		**Tithon.**		
	A	**B**	**C**	**D**	
Dictyoclavator ramalhoi Gramb.	X				
Echinochara n.sp.	X				
Porochara fusca Mädler	X				Upper Callovian–middle Oxfordian (3)
Parochara raskyae Mädler	X				Lower(?) Kimmeridgian (1); middle Oxfordian
Dictyoclavator fieri (Donze)					Upper Tithonian–Lower Berriasian (2)
Globator rectispirale Feist				X	Upper Tithonian–Lower(?) Berriasian (3) "Purbeckian" (2)
Nodosoclavator bradleyi (Harris)				X	Upper Tithonian–Lower(?) Berriasian (3) "Purbeckian" (2)
Perimneste horrida Harris				X	

According to these results, it is possible to distinguish two different associations of ostracods and charophytes of stratigraphic interest: one for Biounits A and B (Kimmeridgian) and another for Biounit D (upper Tithonian). This is particularly important with respect to the charophytes because of their good stratigraphic correlation with the Lusitanian Basin.

From Crustaceans s. l. we have found sections of appendages and levels with coprolites corresponding to the species described below.

Favreina aff. ***prusensis*** (Paréjas)
(Pl. 20, Figs. 2–4)

The specimens present circular transverse sections, some of which are slightly flattened, with the following dimensions:

- Diameters (extreme values) = 0.852x0.710 to 1.420x1.126 mm;
- Longitudinal sections present a rectangular profile with:
  Length x thickness = 1.080 x 0.900;
  1.420 x 0.710; 1.420 x 0.990 mm.

It was not possible to define the outline of the "channel" sections with precision, but they are probably rounded with diameters of around 0.020–0.025 mm, disposed in about ten rows with each having around 15–20 sections. The rows are symmetrically disposed, with the central rows being quite straight and the others weakly arched as meridian lines. The distance between these rows in equatorial zone is about 0.090 mm.

In lateral view, the "channels" are generally longitudinal straight parallel lines separated by a distance of 0.070–0.120 mm. In some specimens, these lines may be wavy although surrounded by straight ones.

The very numerous "channels" per row, reaching 150 or more in transverse sections in our forms, is the highest number cited to coprolite species in the available literature.

The type-specimens of *Favreina prusensis* (Paréjas) presents an irregular circular transverse section and a high number of "channels" (66–136), but in our specimens they are not disposed in a "complicated branching zig-zag series" in contrast to the observations of Elliot (1962).

On the basis of the above characteristics, we consider that these specimens may correspond to a new species. They occur in the upper Kimmeridgian (Escarpão Formation) of the Benaçoitão Section.

7.2. The palaeogeographic distribution of foraminifers and dasyclads in the Tethys Mediterranean domain and the Algarve Basin

7.2.1. Palaeogeographic overview

A simplified Late Jurassic palaeogeography of the Mediterranean region is presented in Fig. 9. The northern Tethyan margin (Laurasia continent) was oriented E–W and extended from 20°N to 30°N palaeolatitude, and included both the Iberian and southern European carbonate platforms.

The marine platforms of the southern Tethyan margin (Gondwana continent) were oriented NW–SE, and extended from about 20°N to south of the palaeoequator and included the North African and Middle East territories.

Italy, Greece, and southern Turkey were isolated islands in shallow Gondwana seas and located far from the northern and southern Tethyan platforms. This palaeogeographic situation may explain certain differences registered in the distribution of foraminifer and dasyclad assemblages between these territories and neighbouring regions such as those covered by modern-day France, Austria, and the former Yugoslavian territory (see Section 7.2.2.).

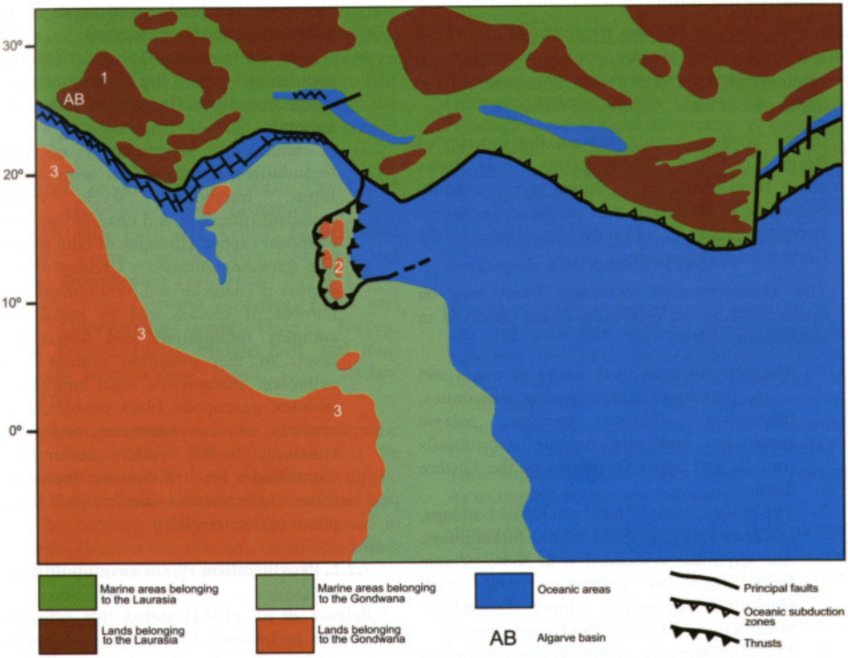

Fig. 9 – Upper Jurassic palaeogeographic map of the Mediterranean Tethys domain (simplified from Sartoni & Venturini, 1988). 1 – Iberia; 2 – Italy, Greece and South Turkey; 3 – North African and Middle Eastern territories.

The final phase of the Upper Jurassic sedimentary cycle

The lowermost preserved Upper Jurassic sediments of the Algarve Basin are pelagic and are dated from the middle Oxfordian, and correspond to the initial transgressive phase of a sedimentary cycle. This phase persisted with relatively deepwater ammonitic levels of the upper Oxfordian–lowermost Kimmeridgian. From the lowermost Kimmeridgian to the lowermost Cretaceous, that sedimentary cycle is completed by a slow regressive trend.

However, it is important to note that during this regressive trend, a short transgressive event took place during the deposition of the upper part of the Limestones with *Anchispirocyclina lusitanica* Formation, which was registered in both sectors of the Algarve Basin.

In the Eastern Sector, the Bias outcrop (see Fig. 1 and Section 7.1.3) shows several levels with calpionellids interbedded with limestones of the upper part of the *A. lusitanica* Formation.

In the Western Sector, the smaller outcrop of Bordoal (see Fig. 1 and Section 2.1.2) shows about 10 m of marine limestone layers probably belonging to the upper part of the *A. lusitanica* Formation, and directly overlying the Carboniferous basement.

The aforementioned regressive trend may be synthesized by the following stages observed in the Eastern Sector:

1- The deposition of thick series of marls and marly limestones with abundant ammonites, belemnites, siliceous sponges, pelagic organisms, and rare benthic microfossils (middle and upper Oxfordian of the Eastern Sector).

2- The development of local microbial buildups, siliceous sponges, small sessile foraminifers, and serpulids, associated with some pelagic forms such as ammonites and small planktonic organisms (upper Oxfordian–lower Kimmeridgian of the Eastern Sector).

3- The disappearance of the previous microbial buildups, giving way to bioherms and piles represented by thick micritic limestones with argillaceous interbeds, containing abundant corals, stromatoporoids, chaetetids, and coralline sponges, and commonly associated with microbial encrusting structures and varying degrees of dolomitization (lower Kimmeridgian of the Eastern Sector).

4- A rapid decrease in the number of reefal organisms, giving way to thick limestones and marly layers, laterally dolomitized, with abundant oncolithic levels, and containing complex foraminifers, dasyclads, codiaceans, and gastropods (lower Kimmeridgian of both sectors).

5- With a lithology identical to that of the underlying unit, the disappearance of corals, stromatoporoids, and the majority of coralline sponges is observed. Foraminifers and dasyclads are still abundant as are charophytes and ostracods (upper Kimmeridgian of both sectors).

6- A decrease in palaeobiodiversity (species and populations) of the foraminifers and calcareous algae (lower Tithonian of both sectors).

7- A remarkable development of complex foraminifers and dasyclads with some new forms. Interbedded levels containing abundant ostracods and charophytes continue to appear (upper Tithonian of both sectors).

8- The transition Jurassic – Cretaceous on both sectors is characterized by a reduction of the number of species and in populations of complex foraminifers and dasyclads. The levels of that transition commonly show ostracods, charophytes, algal laminites, algal nodules, gastropods, black pebbles, erosional surfaces, intraconglomerates, and shrinkage structures. In the Western Sector, we also mentioned a level of dinosaur footprints. All these characteristics confirm the regressive phase of that transition.

7.2.2. Provincialism *versus* cosmopolitism

Pelissié *et al.* (1982) stated that only for the Dogger and Lower Cretaceous is it possible to consider provincialism based on species of large foraminifers and dasyclads. The same opinion was expressed by Bassoulet *et al.* (1985) regarding the cosmopolitism of foraminifers. In addition, on the basis of the geographical distribution of the most common larger foraminifers (*Alveosepta jaccardi, Kurnubia palastiniensis, Labyrinthina mirabilis, Parurgonina caelinensis, Pseudocyclammina lituus*, and *Anchispirocyclina lusitanica)*, Fourcade & Michaud (1987) did not also propose bioprovinces for the Upper Jurassic of the Tethyan domain.

Subsequently, Kuznetsova *et al.* (1996) presented a "biogeographical sketch of the Mediterranean realm for the Middle to the Upper Jurassic as determined using foraminifera," in which three bioprovinces are defined based only on genera from the Middle Jurassic to Early Cretaceous.

More than 30 years have passed since the study of Pelissié *et al.* (1982), and like those authors we also have noticed an "impoverished peopling area" for some of the most important Tethyan species. As yet, we have been unable to find references regarding the occurrence of the following important species in the stated countries:

Alveosepta jaccardi: Sicily, Jordan, Egypt, and Libya; ***Anchispirocyclina lusitanica***: Greece, Egypt, Middle East, and Arabia; ***Labyrinthina mirabilis***: Egypt, Tunisia, Libya, Iran, Iraq, and Arabia; ***Parurgonina caelinensis*****:** Egypt, Libya, Iran, and Iraq; ***Clypeina jurassica***: Egypt and Libya; ***Campbeliella striata***: Greece, Turkey, Egypt, Tunisia, Libya, Middle East, and Iraq; ***Kurnubia palastiniensis***: Libya, Sicily, Jordan, and Egypt.

The palaeogeography of the Late Jurassic Mediterranean Tethys (Fig. 9) shows that the distance of the modern-day regions – Tunisia, Libya, Egypt, Arabia, Middle East, Iran, and Iraq from the northern Tethyan margin increased in that order because this margin was oriented such that it had an essentially constant palaeolatitude. Differently, the territories of those countries situated on the northern margin of the Gondwana continent, where was oriented NW–SE and whose extent covered a wide range of palaeolatitude. Probably, this palaeogeographic configuration was associated with a particular distribution of palaeotemperatures and SE ocean currents, which would account the differences in distribution of some species.

Regarding the occurrence of microfossils, it is also interesting to note the situation for the territories corresponding to modern-day Italy and Greece, which were isolated in the middle of a Tethys shallow sea (Fig. 9), with respect to four of these important species:

Italy: *Clypeina jurassica* and *Campbeliella striata* are commonly cited in the literature, but *Alveosepta jaccardi* and *Anchispirocyclina lusitanica* are rarely mentioned.

Greece: *A. jaccardi, C. striata*, and *C. jurassica* are rarely mentioned, and *A. lusitanica* seems to be absent.

These "anomalies" contrast strongly with the occurrence of these species in the neighbouring territories of modern-day France, Austria, Germany, and the former Yugoslavian territory. Although some of these absences may eventually be reversed by future investigations, it seems possible that the palaeogeographical situation may explain these "anomalies".

7.2.3. Remarks on the stratigraphic and geographic distribution of species

Among the Tethys Mediterranean countries, there are still important differences in knowledge regarding the Late Jurassic foraminifera and algae, making it difficult to compare the stratigraphic distribution and occurrence of the various species. Also adding to the uncertainty are the different stratigraphic ranges attributed to some important species from country to country. As examples, we use the following:

Alveosepta jaccardi is also cited in the Tithonian of Turkey (Altiner, 1991), of Morocco (Hussner, 1985), and of Italy (Barotollo & Carras, 1990; Sinni & Masse, 1994), whereas this species is considered typical of the upper Oxfordian to upper Kimmeridgian by the majority of authors.

Anchispirocyclina lusitanica is also cited from the Kimmeridgian of several countries, including

Portugal[6] (Maync, 1959), Morocco (Viotti, 1965), France (Dufaure, 1958), Romania (Dragastan, 1968), and Spain (Canerot, 1979). However a great majotity of the authors accepted this species to characterize the upper Tithonian.

It would be important to determine the validity of these stratigraphic distributions to allow more precise stratigraphic use to be made of those important microfossils.

Nevertheless, we have compared the species citations of those groups identified in carbonate series of about 20 different Mesogean countries. The most cited species by numerical order of citations (in parenthesis), but not including *Trocholina* spp., are as follows:

Foraminifers: *Kurnubia palastiniensis* (20), *Alveosepta jaccardi* (19), *Anchispirocyclina lusitanica* (18), *Mohlerina basiliensis* (18), *Pseudocyclammina lituus* (17), *Everticyclammina virguliana* (17), *Protopeneraplis striata* (14), *"Valvulina"* gr. *lugeoni* (14), *Parurgonina caelinensis* (14), *Labyrinthina mirabilis* (13), and *Rectocyclammina chouberti* (13).

Algae (dasyclads): *Salpingoporella annulata* (18), *Clypeina jurassica* (18), *Campbeliella striata* (15), *Salpingoporella pygmaea* (15), *Actinoporella podolica* (15), *Heteroporella lemmensis* (11), and *Clypeina solkani* (11).

All these species are also present in the Upper Jurassic of the Algarve Basin, emphasising its strong Tethyan character.

The five countries with higher palaeobiodiversities are (in order of its decreasing):

Foraminifers: France, Turkey, Morocco, Portugal, and Spain.

Algae (dasyclads): France, the former Yugoslavian territory, Germany, Romania, and Portugal (Algarve).

Finally, the countries with greater number of species that also appear in the Algarve Basin are:

Foraminifers: France, Spain, Turkey, and Morocco.

Algae (dasyclads): France, Germany, Spain, and the former Yugoslavian territory.

In conclusion, the palaeomicrodiversity (foraminifers and dasyclads) of the Algarve Basin Upper Jurassic is quite high in the Tethyan context, and presents special affinities with France, Spain, and Morocco (foraminifers).

8. STRATIGRAPHIC MICROPALAEONTOLOGY

8.1. The Tethyan realm

Since 1960, several biozonation schemes have been proposed for the Upper Jurassic neritic facies based on foraminifers and algae. Generally, these biozonations have only regional value as a consequence of the relatively limited geographic distribution of the species on which the zonations are based. However, the species in such biozonations are not always the same. For instance, *Alveosepta jaccardi* and *Anchispirocyclina lusitanica* do not appear in Italian, former Yugoslavian territory, or Romanian biozonations, where *Kurnubia palastiniensis* and *Campbeliella striata* are largely used. In the biozonations of Spain, France, and the Middle East, these two lituolids are good markers for the biozonations but not *Campbeliella striata.*

On the basis of our examination of the literature, we have summarized the most important cited species. According to their wider geographical distributions and shorter stratigraphic ranges, we have chosen and quoted the following:

a) **Lower–middle Oxfordian:** *Praekurnubia crusei.*

b) **Middle–upper Oxfordian**: *Kurnubia palastiniensis.*

c) **Upper Oxfordian – Upper Kimmeridgian:** *Alveosepta jaccardi, Kurnubia palastiniensis, Kilianina rahonensis, Parurgonina caelinensis*, and *Labyrinthina mirabilis.*

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[6] With respect to Portugal, Maync's arguments are outdated since our study (Ramalho, 1971). Boudagher–Fadel (2008, Pl. 4.12) illustrates a section of *A. lusitanica* from Portugal based on Ramalho (1971), which she mistakenly attributed to the Kimmeridgian, rather than to "Portlandian B", which we regard as the correct assignation.

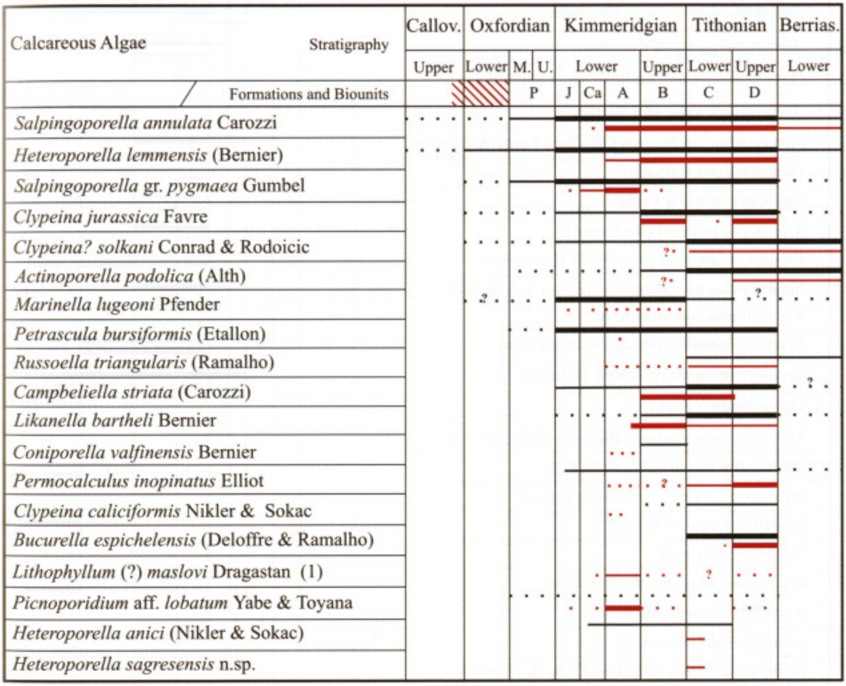
d) **Upper Kimmeridgian – Lower Tithonian**: *Everticyclammina virguliana, Clypeina jurassica,* and *Campbeliella striata.*

e) **Upper Tithonian**: *Anchispirocyclina lusitanica* and *Feurtillia frequens.*

These assemblages are based on the stratigraphic intervals in which these species are more commonly cited.

For our approach to the stratigraphic importance of the Tethyan foraminifera and algal species, we have compiled and selected (from more than 200 literature citations) the relevant stratigraphic ranges. The results are presented in Table 3 (in black), for which we make the following observations:

Table 3 - Comparasition between stratigraphic distribution and abundance of the Thethysian neritic microfossils (in black) and those of the Algarve Basin (in red) during the Late Jurassic. · · · rare; — common; ▬ abundant. P - Peral Fm; J - Jordana Fm; Ca - Cabeça Fm; A, B, C and D - biounits of Escarpão and *A. lusitanica* Fms. Note: This stratigraphic distribution (in red) respects the data of all geological sections of the Algarve Basin. The Berriasian also includes data from Rey (1982, 1983).



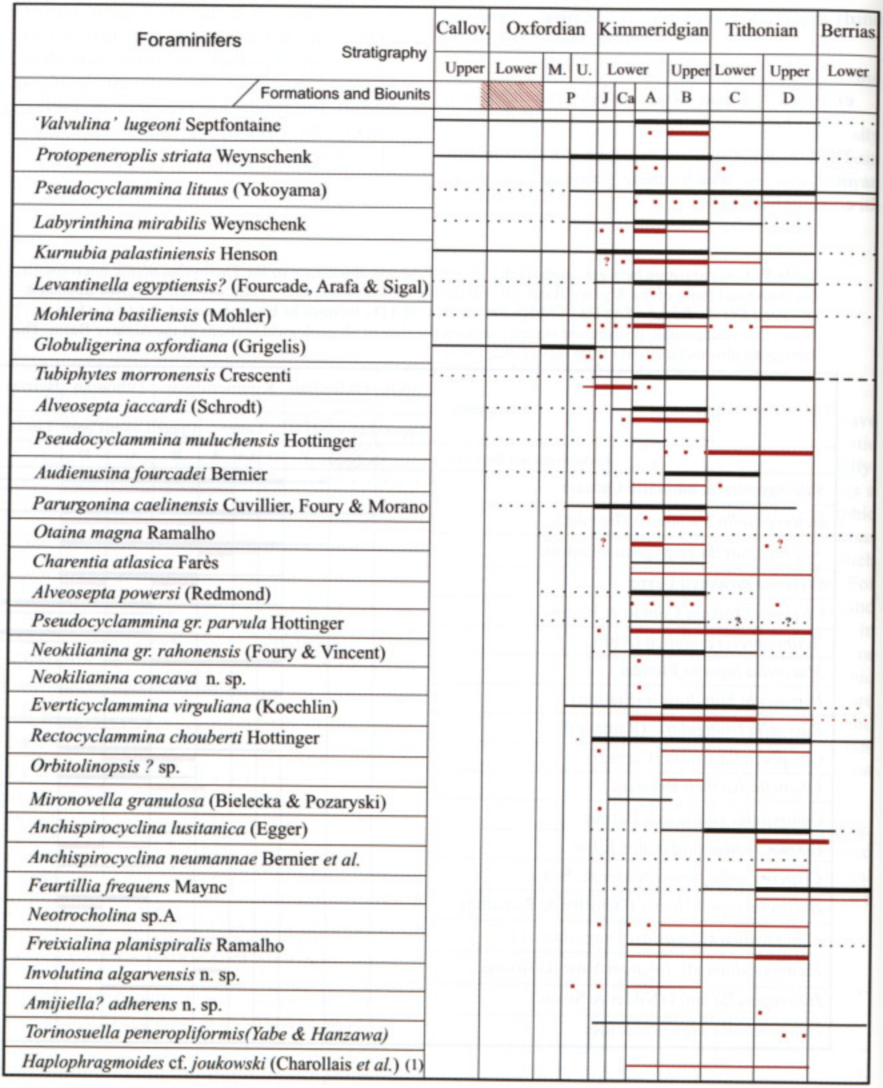
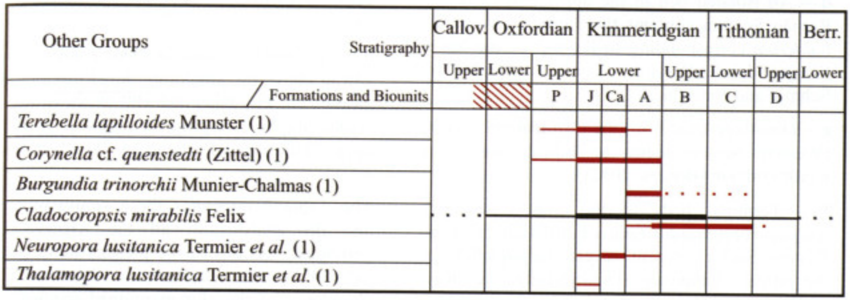

Foraminifers
Stratigraphy
Formations and Biounits
Callov.
Oxfordian
Kimmeridgian
Tithonian
Berrias.
Upper
Lower
M.
U.
Lower
Upper
Lower
Upper
Lower
P
J
Ca
A
B
C
D
'Valvulina' lugeoni Septfontaine
Protopeneroplis striata Weynschenk
Pseudocyclammina lituus (Yokoyama)
Labyrinthina mirabilis Weynschenk
Kurnubia palastiniensis Henson
Levantinella egyptiensis? (Fourcade, Arafa & Sigal)
Mohlerina basiliensis (Mohler)
Globuligerina oxfordiana (Grigelis)
Tubiphytes morronensis Crescenti
Alveosepta jaccardi (Schrodt)
Pseudocyclammina muluchensis Hottinger
Audienusina fourcadei Bernier
Parurgonina caelinensis Cuvillier, Foury & Morano
Otaina magna Ramalho
Charentia atlasica Farès
Alveosepta powersi (Redmond)
Pseudocyclammina gr. parvula Hottinger
Neokilianina gr. rahonensis (Foury & Vincent)
Neokilianina concava n. sp.
Everticyclammina virguliana (Koechlin)
Rectocyclammina chouberti Hottinger
Orbitolinopsis ? sp.
Mironovella granulosa (Bielecka & Pozaryski)
Anchispirocyclina lusitanica (Egger)
Anchispirocyclina neumannae Bernier et al.
Feurtillia frequens Maync
Neotrocholina sp.A
Freixialina planispiralis Ramalho
Involutina algarvensis n. sp.
Amijiella? adherens n. sp.
Torinosuella peneropliformis(Yabe & Hanzawa)
Haplophragmoides cf. joukowski (Charollais et al.) (1)
?
?
?
?
?
?

Table 3 - (continued)



(1) - It was not possible to get significant stratigraphic data relative to the Tethyan domain

(1) Several species occurring in the Callovian persist into the Upper Jurassic, in some cases with great importance, such as "*Valvulina" lugeoni, Kurnubia palastiniensis*, and *Labyrinthina mirabilis.* The planktonic form *Globuligerina oxfordiana* also appears in the Upper Jurassic.

(2) The Oxfordian is marked by a modest appearance of several new foraminifer species, which are important in the overlying two stages, and include *Alveosepta jaccardi, Parurgonina caelinensis, Kilianina rahonensis*, and *Rectocyclammina chouberti.* The Oxfordian was relatively poor in dasyclads. However, we should bear in mind that the lower Oxfordian geological record in the Mediterranean region has been strongly affected by erosional hiatuses and emersion events.

(3) The Kimmeridgian presents a burst of new species and large populations related to foraminifers and dasyclads.

(4) The Tithonian is characterized by a small decrease in foraminifera species but is richer in dasyclad forms.

(5) The Jurassic–Cretaceous transition is marked by the disappearance of most of the foraminifera and dasyclad species and also by the impoverishment of the remaining populations.

8.2. The Algarve Basin

8.2.1. Significant biostratigraphic data

Algarve pelagic organisms

For the purpose of the present study, it is important to evaluate the stratigraphic relevance of the pelagic organisms found in the Upper Jurassic of Algarve onshore, as follows:

a – The basal conglomerate of the Sagres region, marking the Middle–Upper Jurassic transition, contains numerous nodules with ammonites that indicate a middle Oxfordian age (Rocha, 1976).

b – The Peral and Jordana formations of the Eastern Sector contain ammonites that allow a biozonation to be established from the middle Oxfordian to the lowermost Kimmeridgian (Marques, 1983; Marques et al., 1998).

c – *Globuligerina oxfordiana* was found in the upper beds of the Peral Formation and in the lower Kimmeridgian of Rocha microbial build up. This planktonic foraminifer is also abundant in the upper Oxfordian of the northern Tethyan margin.

d – An isolated bed in the upper part of the S. Romão Section contains the ammonite *Idoceras balderum* corresponding to the top of the lower Kimmeridgian (Divisum Zone), as reported by Schmid and Jonischkeit (1995).

e – Dinoflagellates from the Carrapateira section (Western Sector) seems to indicate the lower Kimmeridgian (Borges, 2012).

f – Terminal beds of the Limestones with *Anchispirocyclina lusitanica* Formation, from the Eastern Sector, present several calpionellids of the upper Tithonian (Durand-Delga & Rey, 1982).

Significant stratigraphic data from the Lusitanian Basin

Ammonites

In the southern Lusitanian Basin (Arrábida region), some rare ammonites identified by H. Tintant have been found interbedded in Upper Jurassic sections, allowing the dating of hemipelagic and neritic series and supporting the micropalaeontological biozonation (Ramalho, 1971). These ammonites are as follows:

- *Lithacoceras siliceum* (Quenst.), characteristic of the base of the Tithonian.
- *Virgatosphinctes frequens* Oppel, of the upper Tithonian.

Microfossils

The most important stratigraphic conclusions from the Arrábida region that may be useful for the Algarve sections are as follows:

a – *Alveosepta jaccardi* and *Labyrinthina mirabilis* are not found above the base of the Tithonian, which is marked by the ammonite species *Lithacoceras siliceum* (Quenst.).

b – *Kurnubia palastiniensis* is not found above the first occurrence of *Anchispirocyclina lusitanica*, disappearing in the lower Tithonian (Portlandian A, cf. Ramalho, 1971).

c – The appearance of *Campbeliella striata* and *Clypeina jurassica* is below the base of the Tithonian. *C. striata* disappears at the base of the upper Tithonian (Portlandian B cf. Ramalho 1971).

d – *Anchispirocyclina lusitanica* appears about 250 m above the ammonitic level that marks the base of the Tithonian and 100 m above the level containing *Virgatosphinctes frequens* in the full upper Tithonian (Portlandian B, cf. Ramalho, 1971).

The Table 3 integrates these stratigraphic data and the analysis of all the Algarve Basin geological sections of the present study (in red), as well as the stratigraphic distribution and abundance of the aforementioned species of the Tethyan domain, according to the literature (in black).

8.2.2. Definition of Biounits

The distribution of microfossils presented in Table 3 allowed us to consider several assemblages with biostratigraphic value, which we refer to as **biounits** (A, B, C, and D), with respect to the Escarpão and *Anchispirocyclina lusitanica* formations, and helps to complete the definitions of the biounits. These biounits are characterized as follows:

(1) **Biounit A**: *Alveosepta jaccardi* and *Kurnubia palastiniensis* are abundant. *Campbeliella striata* and *Clypeina jurassica* are absent.

(2) **Biounit B**: *A. jaccardi* and *K. palastiniensis* are abundant and are associated with *C. striata* and *C. jurassica.*

These two biounits present the higher biodiversity in foraminifers, compared to Biounits C and D, most of them exclusive. They are also very rich in different species of dasyclads.

(3) **Biounit C**: Of the Biounit B species, only *C. striata* remains. Biounit C is the poorest in terms of the number of different species.

(4) **Biounit D**: This biounit is characterized by the presence of *Anchispirocyclina lusitanica*, which is associated with different species and large populations of foraminifers and algae, of which *A. neumannae* and *Feurtillia frequens*

are exclusive and *Bucurella espichelensis* reaches its greatest abundance.

Also worthy of mention are the following points:

a. Levels of the Jordana Formation reveal several foraminifers and dasyclads that also appear in Biounit A (see Sections 1.2.2. and 1.2.4.). The Cerro da Cabeça Formation also contains a few sections of *Alveosepta jaccardi, Kurnubia palastiniensis (?), Trocholina* gr. *alpina-elongata, Mohlerina basiliensis, Terquemella* sp., *Salpingoporella* gr. *pygmaea, S. annulata*, and dasyclad fragments, all of which are common in Biounit A.

b. The Asseca Section shows an alternation of the typical biohermal microfacies of the Cerro da Cabeça Formation with levels of Biounit A microfacies of the Escarpão Formation (see Section 1.2.2.).

These observations seem to suggest that both the Jordana and Cerro da Cabeça formations could be related to Biounit A (see also Sections 1.2.4 above and 9.1.2 further below).

8.2.3. Biozonation of the Algarve Basin

On the basis of the distribution of microfossils (Table 3), we propose the biozonation scheme as presented in Fig. 10. This scheme completes the previous models proposed for Portugal (Ramalho, 1981) and for the Algarve Basin (Ramalho, 1972-73; 1985) with respect to the environments rich in complex arenaceous foraminifers and dasyclads. We note the close correspondence of the biozonation of the Algarve Basin with that of Arrábida (southernmost part of the Lusitanian Basin) (Ramalho, 1971).

8.2.4. Biostratigraphic conclusions

a) The Callovian presents pelagic facies and is well dated by ammonites (Rocha, 1976), but its upper part is missing because of the Middle–Late Jurassic erosional hiatus.

b) The lower Oxfordian and the basal middle Oxfordian (Plicatilis Zone) are represented by ammonites in the basal conglomerate of the Upper Jurassic series in the western Algarve Basin (Rocha, 1976).

c) The Peral Formation is very rich in ammonites that have been studied by Marques (1983); these ammonites are dated from the Plicatilis Zone (middle Oxfordian base) to the upper Oxfordian. The Hydraulic limestones of Loulé Formation is considered to be a carbonate equivalent of the lower part of the Peral Formation, and is attributed to the middle Oxfordian based on ammonites found by Choffat (1883–87).

d) The Jordana Formation has been dated using rare ammonites and its base was placed in the lowermost Kimmeridgian (Platynota Zone) by Marques *et al.* (1998).

e) The Cerro da Cabeça Formation should also belong to the lower Kimmeridgian, according to the results of the S. Romão Section, where this formation is overlain by more than 150 m of the Escarpão Formation, dated by ammonites as the top of the lower Kimmeridgian (Divisum Zone).

f) The Escarpão Formation was subdivided into three biounits as defined above. It is easy to recognize a good correlation between Biounits A and B and lower and upper Kimmeridgian, respectively, which is supported by the age of the Carrapateira section (see Section 2.1.2.) and by the ammonites of the S. Romão Section (see Section 1.2.3.). By its position, we consider Biounit C as lower Tithonian.

g) The Limestones with *Anchispirocyclina lusitanica* Formation corresponds to Biounit D, and in our opinion most of this formation belongs to the upper Tithonian based on the ages given by the occurrence of this large foraminifer. In the Algarve Basin, this age assignation is also supported by calpionellids (Durand-Delga & Rey, 1982). However, the uppermost layers of this formation probably belong to the lowermost Berriasian (Galbrun *et al.*, 1990).

h) The Jurassic–Cretaceous transition is marked by a clear impoverishment in foraminifers and dasyclad species (see Section 9.2.4).

i) The stratigraphic ranges of microfossil foraminifers, algae, and various other organisms of the Upper Jurassic deposits of the Algarve Basin allow us to present a regional biozonation scheme (Fig. 10).

j) The comparison of the stratigraphic distribution of the Algarve species and their relative abundance with the identical forms of the Tethyan domain (Table 3) shows a good correlation, which supports our stratigraphic conclusions.

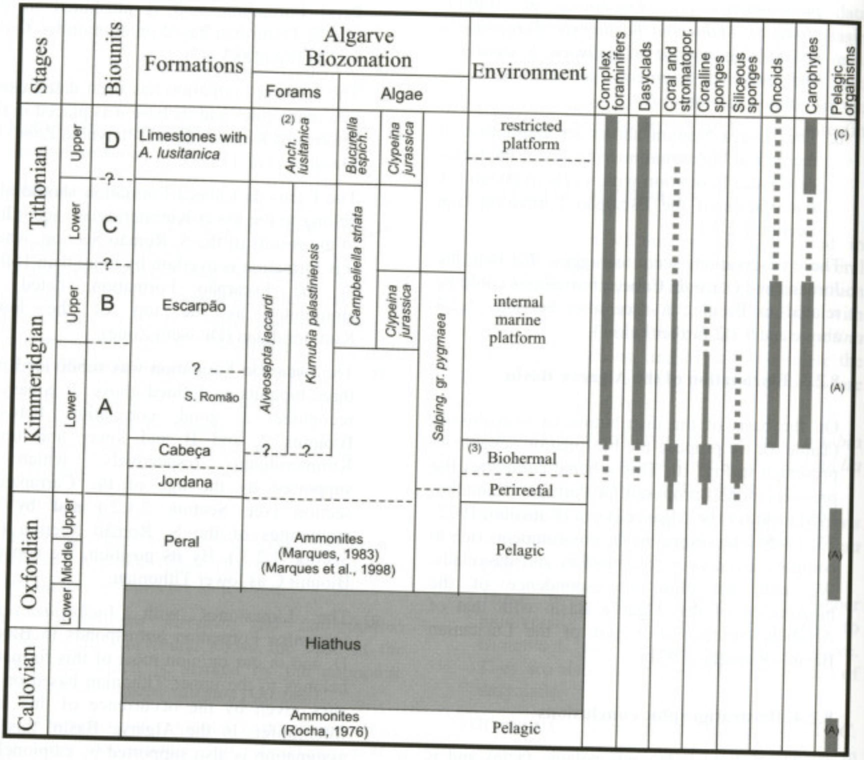


Fig.10 – Biozonation scheme, based on neritic microfossils (foraminifers and calcareous algae) and supported by ammonites and calpionellids, proposed for the Late Jurassic of the Algarve Basin. (1) – Associated with *Labyrinthina mirabilis, Parurgonina caelinensis* and *Otaina magna*; (2) – Associated with *Feurtillia frequens* and *Anchispirocyclina neumannae;* (3) Corals, stromatoporoids, microbial structures, coralline sponges; A – Ammonites; C – Calpionellids.

9. PALAEOENVIRONMENTAL REMARKS

9.1. Tectonics and sedimentation

The epicontinental platform of the Algarve Basin during the Late Jurassic extended to at least the actual −200 m bathymetric line (Fig. 1). The sedimentation in the basin was directly influenced by the extensional tectonics related to the opening of the central Atlantic Ocean and, according to Terrinha *et al.* (2013), the reactivation of the preexisting faults divided the basin into different blocks (Fig. 2). Therefore, the palaeoenvironments and the distribution of facies were controlled not only by synsedimentary tectonics but also by a persistent extensional subsidence that was much stronger in the Eastern Sector of the Algarve Basin than in the Western Sector, as discussed further below. Terrinha *et al.* (2013) also proposed that this continuous subsidence was affected by two tectonic inversions during the Late Jurassic, each with duration of about 1 to 5 million years, as a consequence of compressive movements (Fig. 11). Those authors associated the first inversion with the Callovian–Oxfordian discontinuity and the second with the Late Jurassic–Cretaceous transition, affecting the Berriasian and Valanginian sedimentary record (Rey, 1983).

The most important tectonic movements affecting the Algarve Upper Jurassic geologic record were vertical. In the onshore, these movements were different in the Western and Eastern sectors. The westernmost area of the Algarve Basin (Sagres) also underwent a tilting event from which a low-angle unconformity resulted. In those movements a positive vertical component was predominant, causing an important hiatus between the upper Callovian and the middle Oxfordian (see section 2.1.1) in contrast to the Eastern Sector where this hiatus seems to be less important. In the Eastern Sector the basement would have maintained its depth, allowing the deposition of a thick pelagic series during the middle Oxfordian through to the earliest Kimmeridgian.

However, the Algarve offshore shows a different tectonic behaviour, with its various tectonic blocks being separated by important faults (Fig. 2), movement on which controlled the water depth of the sea-bed sedimentation (Fig.12).

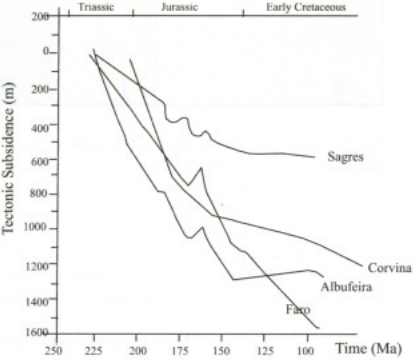


Fig. 11 – Tectonic subsidence curves for the Algarve Basin from the Triassic to Early Cretaceous, (Terrinha *et al.*, 2013).

An examination of the uppermost Jurassic series of the easternmost blocks allows us to conclude that the Corvina 1 and Algarve 1 drill holes show relatively deep sea facies. In contrast, the western blocks (Sagres, Imperador 1, and Ruivo 1) show shallow-water to subaerial facies (Fig. 12).

The most extreme situation can be observed in the block where Ruivo 1 is situated; this block underwent an important positive vertical displacement, with corresponding emersion and erosion dating from the middle Callovian to the Late Cretaceous.

9.1.1. Variation in the thickness of biounits

In Table 4, we compare the thicknesses of biounits measured in different geological sections of the Algarve Basin.

Generally speaking, it is possible to conclude that the thickness of each biounit is greater (by 2 to 6 times) in the Eastern Sector compared with the Western Sector, and this is consistent with the patterns shown by the tectonic subsidence values calculated for the two sectors (Terrinha *et al.*, 2013), as displayed in Fig. 11.

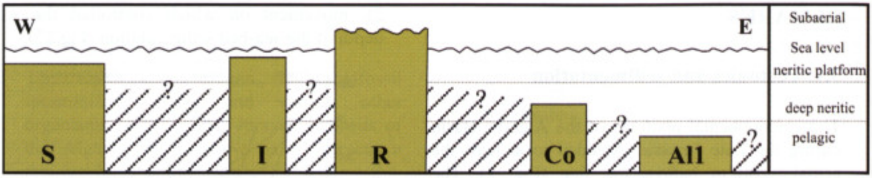


Fig. 12 – Hypothetical positions of the tectonic blocks of Sagres (S), Imperador (I), Ruivo (R), Corvina (Co), and Algarve 1 (Al) in relation to the Late Jurassic sea level, based on data from the Algarve offshore (sea-bed and drill-hole samples) and on the tectonic scheme of Terrinha *et al.* (2013) (see Fig. 2). Tectonic block with no available data: oblique lines.

Table 4 – Thickness of biounits (in metres) from geological sections of the Algarve Basin Upper Jurassic. T – Carrapateira; O – Tonel; S – Benaçoitão; U – Cêrro do Monte; Q – Ribeira da Torre; Y – Fóia do Carro; AA – Zavial; AB – Almádena; AM – Escarpão; AN – S. Romão; AZ – Asseca; AO – Ribeira de Séqua.

Biounits	**Western Sector (geological sections)**									**Eastern Sector (geological sections)**				
	T	O	S	U	Q	Y	AA	AB	average	AM	AN	AZ	AO	average
D	-	-	-	-	>30	30	30	65?	40	240-	-	-	-	240
C	-	-	-	50?	80	-	-	-	65	90	-	170	>100	>120
B	40?	>25	>35	40?	50?	-	-	-	>38	210	-	170	70	150
A	>120	80	15	-	-	-	-	-	>71	180	>330	270	45	>206

9.1.2. The relationship between limestones and marls

On the basis of field data, we have also calculated the variation in the relative thickness of limestone and marl layers in successive 20-m portions along the geological cross-section of Escarpão, the most complete cross-section in the Algarve Basin (Fig. 13).

The curve shown in Fig. 13 reveals a cyclical behaviour of deposition of the biounits. The lower parts are richer in limestones and the upper parts in marls. Biounits A and B correspond to different cycles, but Biounits C and D correspond to one cycle. However, based on the first cycle profile, the Jordana and Cerro da Cabeça formations would seem to belong to this cycle's lower part, which continues into Biounit A. This also supports the discussion on the relationship between Biounit A and the Jordana and Cabeça formations (see Sections 1.2.4 and 8.2.2). It also seems probable that the increase in the amount of clay upwards from the lower Escarpão Formation inhibited biohermal development in the Cerro da Cabeça Formation. It should also be noted that each of these three cycles has approximately the same thickness (200 m).

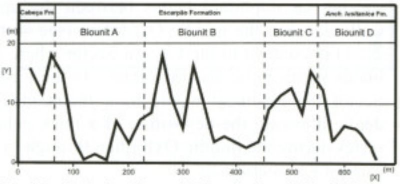


Fig.13 – Variation, for each 20 m, in the relative thickness of limestones and marls, in Biounits A, B, C and D in the Escarpão geological Section. (Total thickness: 660 m).

9.1.3. Extrabasinal detritic inputs

With the exception of the clayey and marly interbeds, the input of terrestrial sediments is reduced to a few thin occurrences of conglomerates, sandstones, silts, and dispersed quartz clasts in our thick carbonate series. This happens at the transition from the Peral to Jordana formations (see Section 1.2). However, there is the exception of the Séqua Section near Tavira (Eastern Sector), where sandstone interbeds are abundant in Biounit B. It is interesting to note that in the Algarve offshore, the area south of Tavira registered the more important and persistent inputs of fine terrigenous sediments during the Late Jurassic, as can be observed in the Corvina 1 and Algarve 1 wells.

This generally weak detritic input seems to corroborate the predominance of arid climates (see Section 5) and an absence of significant continental uplifts in the Algarve onshore area during the Late Jurassic.

9.2. Microfacies data and palaeoenvironments

9.2.1. Sea-water palaeotemperature

It is generally recognized that the shallow waters of the northern Tethyan margin were warm in the area of the palaeolatitude of the Algarve Basin. The large and complex foraminifer associations, which were abundant during the Kimmeridgian and Tithonian, the diversity of dasyclads and their widespread extent, and the persistence and dimensions of both corals and stromatoporoids, in some places forming bioherms, confirm that assessment.

9.2.2. Depth and extent of the shallow-water marine platform

According to Marques (1983), the Peral Formation was deposited in a water depth of 50 to 200 m. However, the upper layers of this formation commonly show detritic elements (quartz grains, sandstones, and conglomerates), indicating the influence of terrestrial sources.

The geological record of most parts of the Escarpão and *A. lusitanica* formations (Kimmeridgian, Tithonian, and the transition to Cretaceous) corresponds to an internal area of an open-marine carbonate platform, which could have experienced both local and global variations in water depth.

Those depth variations are represented by black-pebble and charophyte levels, erosional surfaces, algal laminites, intraconglomerates, and bird's-eye structures, interbedded within the more marine facies, as shown by the Escarpão and *A. lusitanica* formations.

The global variations in water depth in the Algarve Basin were probably related to the evolution of eustatic sea level at the end of the Jurassic. According to Hallam (2001) the sea level was higher during the late Oxfordian–early Kimmeridgian, which was followed by a shallow-water regime during the late Kimmeridgian–Tithonian, and finally a partial emersion occurred during the Upper Jurassic–Early Cretaceous transition.

In the Eastern Sector, the Peral, Jordana, and Cabeça formations, which have no equivalent in the Western Sector, correspond to about 400 m of limestones and marls that were deposited during the middle Oxfordian–early Kimmeridgian, which indicates that the basement rock in this sector was much lower than that in the Western Sector.

The area covered by the Escarpão and *A. lusitanica* formations includes the onshore outcrops and in the Algarve Basin extends at least to the edge of the present Sagres continental shelf, according to the results of the Ocean Drilling Program (e.g. Dupeuble *et al.*, 1988). This is also recognized along the offshore of Portugal (Alentejo, Santiago do Cacém, Arrábida, Sintra–Cascais, until the Galicia Bank, e.g. Baldy et al., 1977). The persistence of the microfacies of these two formations in the Algarve Basin and their considerable thickness implies the maintenance of palaeoenvironmental conditions and the absence of significant tectonic movements during the Kimmeridgian–Tithonian.

Unfortunately, in the Algarve Basin the offshore drillholes are at some distance from land but all of them cut through Upper Jurassic deep-water sediments. It is possible that the transition from shallow- to deeper-water facies occurs between those drill holes and the actual coastline, and therefore we do not exclude the possibility that a future investigation will record barrier or patch reefs nearer the edge of the Algarve palaeoshelf.

9.2.3. Hydrodynamism

In the Algarve Basin the dominance of micritic limestones, the abundant and locally thick marly interbeds, the abundance of oncolithic beds, and the scarce presence of hydrodynamic structures and oolithic levels, together point to a predominant low- to moderate-energy depositional environment during the Upper Jurassic.

9.2.4. Microfossil biodiversity

The changes in palaeobiodiversity shown by the benthic foraminifers in the Algarve Basin follow the evolution trend recorded for the Tethyan Late Jurassic: a burst of new forms during the Kimmeridgian followed by a slight decrease at the end of this stage and a strong decay (30%) by the end of the Tithonian (Boudagher-Fadel, 2008). This extinction has been related to terrestrial megaphenomena: several asteroid impacts and a large basaltic eruption in the Pacific that geochronologically coincide with the Jurassic–Cretaceous transition (in Boudagher-Fadel, 2008).

According to Aguirre & Riding (2005), the global evolution of dasyclads also shows a rapid increase in the number of genera and species from the Oxfordian to the Tithonian, as also recorded in the Algarve Basin. However, the Tethyan Berriasian was characterized by a slight decrease in dasyclad biodiversity, which is not observed for the Algarve Basin.

As dicussed in Section 9.1, the Jurassic-Cretaceous transition in the Algarve Basin was affected by a general eustatic emersion, which was reinforced by the movements related to the regional tectonic inversion, certainly with negative palaeodiversity consequences.

10. FINAL CONCLUSIONS

(1) This micropalaeontological study of the neritic Upper Jurassic of the Algarve Basin reveals rich microfossil contents, including foraminifers with three new species (*Neokilianina concava* n. sp., *Involutina algarvensis* n. sp. and *Amijiella? adherens* n. sp.) calcareous algae, namely dasiclads with a new species (*Heteroporella sagresensis* n. sp.) calcareous sponges, ostracods, charophytes, and large variety of reefal macrofossils.

(2) The palaeobiodiversity of these microfauna and microflora is high in the Tethyan context, showing particular affinities with the microfauna and microflora of Spain, France, and Morocco.

(3) During the late Oxfordian–Tithonian, the Algarve Basin was a shallow, stable carbonate platform, similar to other marine platforms of the Tethyan margins. At least in the western Algarve Basin, this platform occupied all the offshore continental shelf, where the microfacies are the same as those of the present onshore outcrops.

(4) A new biozonation scheme is proposed for the Upper Jurassic of the Algarve Basin, based on complex foraminifers and calcareous algae and supported by the occurrence of ammonites. It was also possible to establish what we term "biounits" to subdivide the studied formations.

(5) There is a good stratigraphic correlation between the microfossils of the Algarve Basin and those of the Mediterranean Tethys region, which supports the dating of the studied formations and biounits.

(6) The evolution of the Algarve Basin microfacies shows that the Eastern and Western sectors of the basin experienced different tectonic regimes during the late Callovian–middle Oxfordian interval.

However, an almost identical evolution for both sectors is inferred during the lower Kimmeridgian to Tithonian, under the influence of a slow global sea-level regression and regional-scale tectonic subsidence.

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PLATES

PLATE 1

Foraminifers (1)

1 – Coarsely agglutinated Lituolid. Lower Kimmeridgian (Escarpão Formation). Asseca geological Section (AZ-21). x 20

2 – Coarsely agglutinated Lituolid. Lower Kimmeridgian (Escarpão Formation). Asseca geological Section (AZ-58). x 20

3 – Coarsely agglutinated Lituolid. Lower Kimmeridgian (Escarpão Formation). S. Romão geological section (AN-63). x 25

4 – Coarsely agglutinated Lituolid. Lower Kimmeridgian (Escarpão Formation). Asseca geological Section (AZ-21). x 12

5 – *Pseudocyclammina parvula* Hottinger. Upper Kimmeridgian (Escarpão Formation). Asseca geological Section (AP-14). x 30

6 – *Pseudocyclammina parvula* Hottinger. Lower Kimmeridgian (Escarpão Formation). Asseca geological Section. (AZ-117). x 20

7 – *Pseudocyclammina muluchensis* Hottinger. Lower Kimmeridgian (Escarpão Formation). Tonel geological Section (0-43). x 25

8 – *Alveosepta jaccardi* (Schrodt). Lower Kimmeridgian (Escarpão Formation). Tonel geological Section (0-31). x 15

9 – *Alveosepta jaccardi* (Schrodt). Lower Kimmeridgian (Escarpão Formation). Tonel geological Section (0-31). x 8

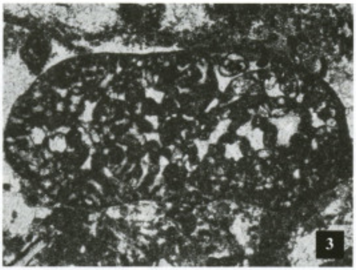
10 – *Alveosepta jaccardi* (Schrodt). Lower Kimmeridgian (Escarpão Formation). Escarpão geological Section (AM-82). x 20

11- – *Alveosepta powersi* (Redmond). Lower Kimmeridgian (Escarpão Formation). Escarpão geological Section (AM-213). x 20

PLATE 1


1


2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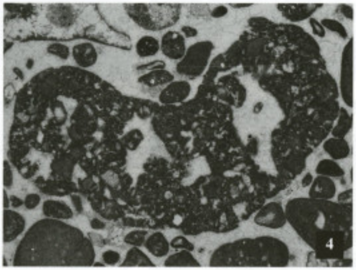
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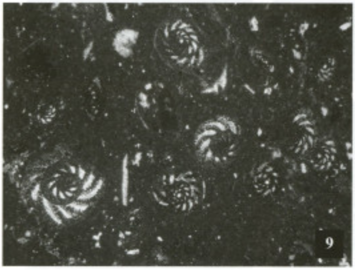
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PLATE 2

Foraminifers (2)

Neokilianina concava n. sp.

All thin sections are from the Lower Kimmeridgian (Escarpão Formation) of the Tonel geological Section. (samples O-9)

1-2 – Subaxial sections x 20

3 – Subaxial section. Holotype (HOLOT. 0-9 x 9). x 25

4 – Subaxial section. x 20

5 – Subaxial section. Paratype (PARAT. 0-9 f). x 15

6-10 – Axial sections (Fig.6: x 20; Fig.7: x 25; Fig. 8: x 25; Fig.9: x 30; Fig.10: x 32)

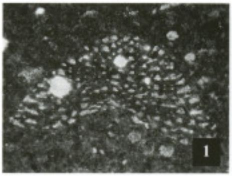
11 – Axial section showing the embryonic chambers. Paratype (PARAT. O-9 x10). x 33

12-13 – Subaxial sections. x 25

14-17 – Axial sections showing the embryonic chambers (Fig.14: x 40; Fig.15:x 30; Fig.16:x 35; Fig.17: x 35)

18 – Transverse section probably of *N. concava*.sp. x 33

PLATE 2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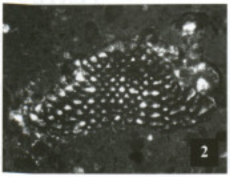
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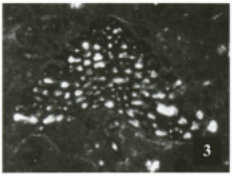
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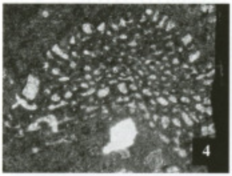
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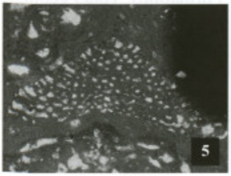
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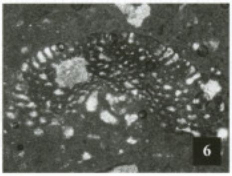
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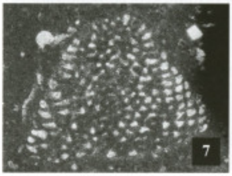
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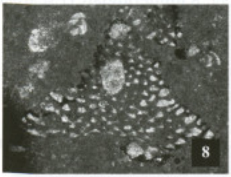
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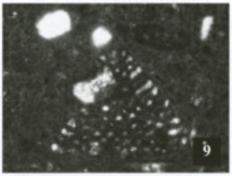
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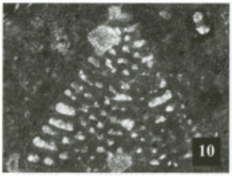
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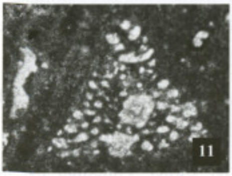
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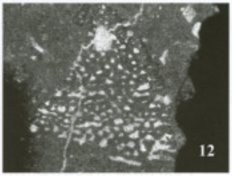
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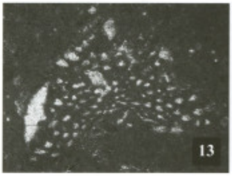
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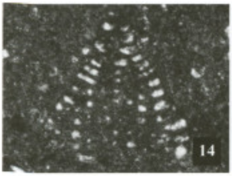
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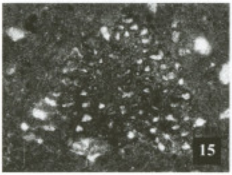
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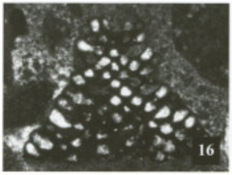
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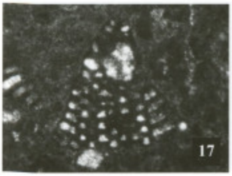
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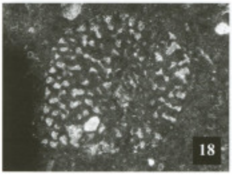
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PLATE 3

Foraminifers (3)

1-2 – *Neokilianina* gr. *rahonensis* (Foury & Vincent). Subaxial sections. Lower Kimmeridgian (Escarpão Formation). Tonel geological Section (O-9). x 20

3-4 – *Neokilianina* gr. *rahonensis* (Foury & Vincent). Axial sections showing the embryonic chambers. Lower Kimmeridgian (Escarpão Formation). Tonel geological Section (O-9) (Fig. 3: x 30; Fig. 4: x 40)

5-6 – *Neokilianina* gr. *rahonensis?* (Foury & Vincent). Transverse sections. Lower Kimmeridgian (Escarpão Formation). Tonel geological Section (O-9) (Fig. 5: x 25; Fig. 6: x 33)

7 – *Neokilianina* (?) *lata* (Oberhauser), included in an oncoid. Lower Kimmeridgian (Escarpão Formation). Asseca geological Section (AZ-110). x 25

8 – *Haplophragmoides* sp. Upper Kimmeridgian (Escarpão Formation). Benaçoitão geological Section (S-128). x 70

9 – *Haplophragmoides* cf. *joukowski* Charollais *et al.* Upper Tithonian. (*A. lusitanica* Formation). Almádena geological Section (AB - 68 A). x 100

10 – *Haplophragmoides* sp. Lower Tithonian (Escarpão Formation) Loulé-Faro geological Section (AD-131). x 33

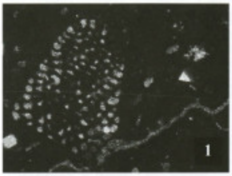
11 – *Haplophragmoides* cf. *joukowski* Charollais *et al.* Upper Tithonian (*A. lusitanica* Formation). Loulé-Faro geological Section (AD-262). x 40

12 – *Haplophragmoides* cf. *joukowski* Charollais *et al.* Upper Tithonian. (*A. lusitanica* Formation). Almádena geological Section (AB -68 A). x 75

13 – *Feurtillia frequens* Maync. Upper Tithonian (*A. lusitanica* Formation). Loulé-Faro geological Section (AD-262). x 35

14 – *Feurtillia frequens* Maync. Upper Tithonian (*A. lusitanica* Formation). Almádena geological Section (AB-68 A). x 58

PLATE 3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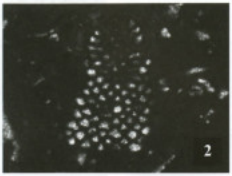
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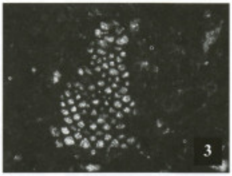
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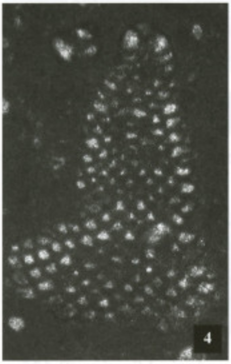
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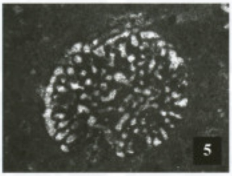
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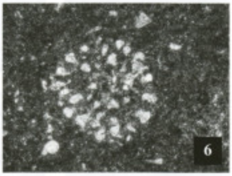
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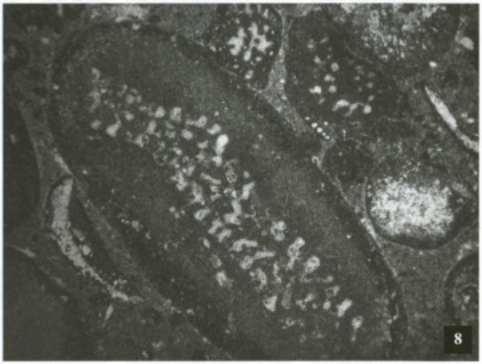
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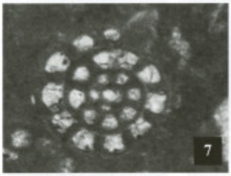
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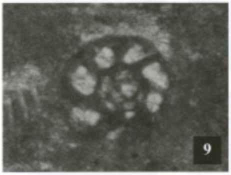
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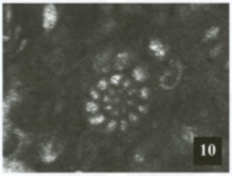
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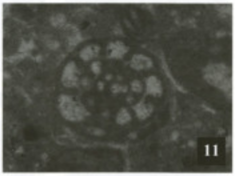
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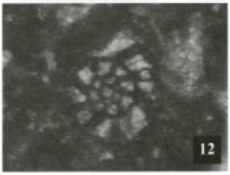
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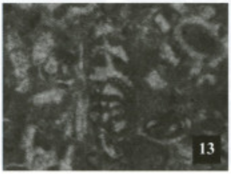
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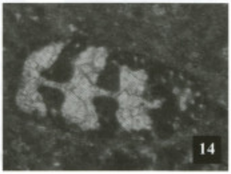
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PLATE 4

Foraminifers (4)

Amijiella (?) adherens n. sp.

Obs.: All thin-sections are from the base of the upper Tithonian (*A. lusitanica* Formation). Escarpão geological Section (AM-466)

1 – Holotype (HOLOT. AM-466 d). x 35

2 – Holotype (HOLOT. AM-466 d). x 30

3 – Holotype (HOLOT. AM-466 c). x 25

4-9 – Thin sections of free and adherent forms (4. AM-466 c x 35; 5. AM-466 d x 40; 6. AM-466 b x 30; 7. AM-466 b x 37; 8. AM-466 d x 25; 9. AM-466 d x48)

10-11 – Possible macrosphaeric forms of *A.? adherens* (10. AM-466 x 85; 11.AM-466 a x 85)

Orbitolinopsis ? sp.

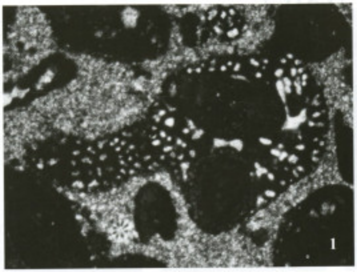
12 – Upper Kimmeridgian (Escarpão Formation). Benaçoitão geological Section (S-67 a). x 40

13 – Upper Kimmeridgian (Escarpão Formation). Benaçoitão geological Section (S-125 a). x 55

14 – Upper Kimmeridgian (Escarpão Formation). Benaçoitão geological Section (S-125 a). x 50

15 – Upper Kimmeridgian (Escarpão Formation). Ribeira da Torre geological Section (Q bis 10 a). x 40

PLATE 4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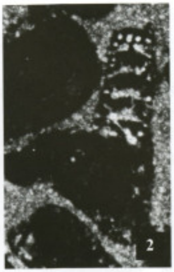
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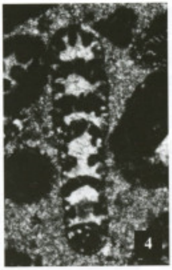
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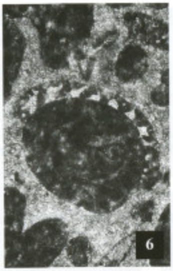
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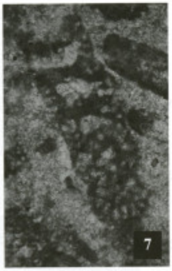
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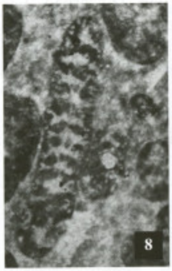
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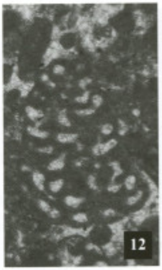
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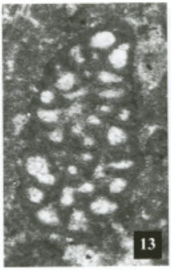
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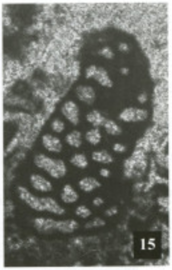
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PLATE 5

Foraminifers (5)

1 – *Otaina magna* Ramalho. Lower Kimmeridgian (Escarpão Formation). Asseca geological Section (AZ-134). x 15

2 – *Otaina magna* Ramalho. Upper Tithonian (*A. lusitanica* Formation). Bias geological Section (AE-69). x 10

3 – *Otaina magna* Ramalho. Upper Tithonian (*A. lusitanica* Formation). Bias geological Section (AE-108). x 10

4 – *Otaina magna* Ramalho. Upper Tithonian (*A. lusitanica* Formation). Bias geological Section (AE-94). x 15

5 – *Otaina magna* Ramalho. Upper Kimmeridgian (Escarpão Formation). Escarpão geological Section (AM-234). x 20

6 – *Otaina magna* Ramalho. Transverse section. Upper Kimmeridgian (Escarpão Formation). Asseca geological Section (AP-4). x 15

7 – *Otaina magna* Ramalho. Transverse section. Upper Kimmeridgian (Escarpão Formation). Asseca geological Section (AP-18). x 10

8 – *Everticyclammina virguliana* (Koechlin). Lower Kimmeridgian (Escarpão Formation). Tonel geological Section (O-13). x 25

9 – *Everticyclammina virguliana* (Koechlin). Lower Kimmeridgian (Escarpão Formation). S. Romão geological Section (AN-226). x 15

10 – *Torinosuella peneropliformis* (Yabe & Hanzawa). Upper Tithonian (*A. lusitanica* Formation). Loulé-Faro geological Section (AD-232 b). x 25

11 – *Anchispirocyclina lusitanica* (Egger). Abnormal specimen. Upper Tithonian (*A. lusitanica* Formation). Bias geological Section (AE-89). x 20

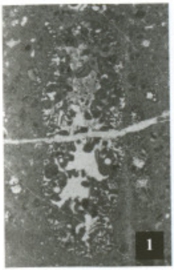
12 – *Anchispirocyclina lusitanica* (Egger), associated to *Pseudocyclammina lituus* (Yokoyama). Upper Tithonian (*A. lusitanica* Formation). Escarpão geological Section (AM-485). x 25

13 – *Anchispirocyclina lusitanica* (Egger). Upper Tithonian (*A. lusitanica* Formation), Almádena geological Section (AB-68 Aa). x 45

14 – *Anchispirocyclina lusitanica* (Egger). Subaxial section showing the free spaces on the interior marginal side. Upper Tithonian *(A. lusitanica* Formation). Loulé- Faro geological Section (AD-262). x 20

15 – *Anchispirocyclina lusitanica* (Egger). Subaxial section of a microsphaeric specimen, associated to *Otaina magna* Ramalho and *Trocholina gr. alpina* (Leupold). Upper Tithonian (*A.lusitanica* Formation). Bias geological Section (AE-94). x 5

PLATE 5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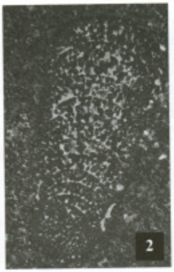
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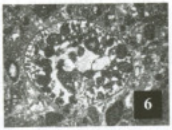
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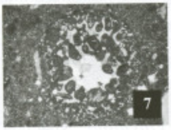
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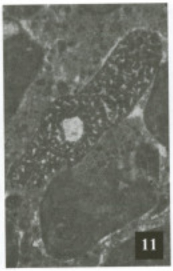
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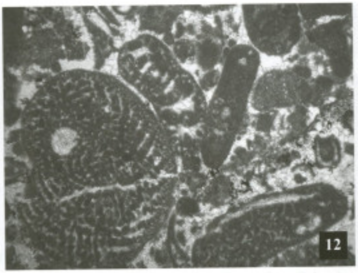
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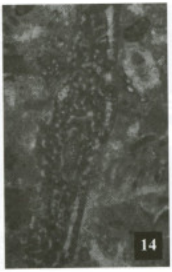
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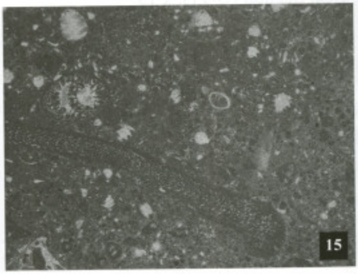
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PLATE 6

Foraminifers (6)

1 – *Anchispirocyclina lusitanica* (Egger) showing the free spaces on the interior marginal side. Upper Tithonian. Espichel Cape geological Section (Lusitanian Basin). x 15

2 – *Anchispirocyclina neumannae* Bernier *et al.* Upper Tithonian (*A. lusitanica* Formation) Almádena geological Section (AB-62). x 20

3 – *Anchispirocyclina neumannae* Bernier *et al.* affected by dolomitisation. Upper Tithonian (*A. lusitanica* Formation). Almádena geological Section (AB-7). x 5

4 – *Anchispirocyclina neumannae* Bernier *et al.* Upper Tithonian (*A. lusitanica* Formation). Almádena geological Section (AB-5). x 15

5 – *Anchispirocyclina neumannae* Bernier *et al.* Upper Tithonian. Almádena geological Section (AB-62). x 20

6 – *Coscinophragma cribrosum* (Reuss). Lowermost Kimmeridgian (Jordana Formation). Machados geological Section (AS-51). x 23

7 – *Coscinophragma cribrosum* (Reuss). Lower Kimmeridgian (Escarpão Formation). Conceição de Tavira geological Section (AV-17). x 20

8 – "*Valvulina*" gr. *lugeoni* Septfontaine (= *Valvulina* "speciale" cf. Septfontaine, 1981). Lower Kimmeridgian (Escarpão Formation). Tonel geological Section (O-5 z). x 30

9 – "*Valvulina*" gr. *lugeoni* Septfontaine. Upper Kimmeridgian (Escarpão Formation). Benaçoitão geological Section (S-67). x 70

10 – *Siphovalvulina?* sp. Upper Kimmeridgian (Escarpão Formation). Escarpão geological Section (AM-319). x 30

11 – *Paravalvulina* aff. *complicata* Septfontaine. Lower Kimmeridigian (Escarpão Formation). Tonel geological Section (O-9x10). x 30

12 – *Paravalvulina* aff. *complicata* Septfontaine. Lower Kimmeridigian (Escarpão Formation). Tonel geological Section (O-11). x 13

13 – *Paravalvulina* aff. *complicata* Septfontaine. Lower Kimmeridigian (Escarpão Formation). Tonel geological Section (O-5). x 20

14 – *Paravalvulina* aff. *complicata* Septfontaine. Lower Kimmeridigian (Escarpão Formation). Tonel geological Section (O-5b). x 25

15 – *Paravalvulina* aff. *complicata* Septfontaine. Lower Kimmeridigian (Escarpão Formation). Tonel geological Section (O-5). x 28

PLATE 6


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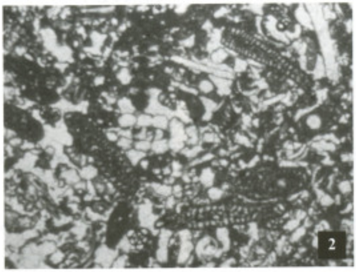
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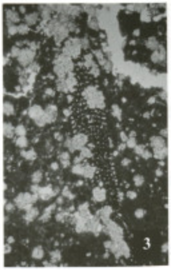
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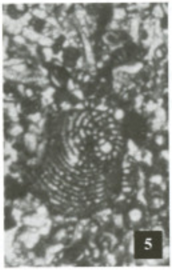
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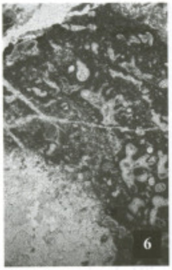
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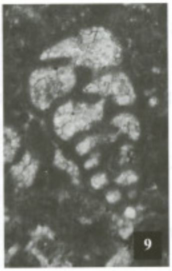
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PLATE 7

Foraminifers (7)

1 – 2 *Parurgonina caelinensis* Cuvillier *et al.* Upper Kimmeridgian (Escarpão Formation). Escarpão geological Section (AM-293). x 25

3 – *Labyrinthina mirabilis* Weynschenk. Lower Kimmeridgian (Escarpão Formation).Asseca geological Section (AZ-83). x 25

4 – *Labyrinthina mirabilis* Weynschenk. Lower Kimmeridgian (Escarpão Formation).Asseca geological Section (AZ-58). x 25

5 – *Kurnubia palastiniensis* Henson. Upper Kimmeridgian (Escarpão Formation). Escarpão geological Section (AM-238). x 15

6 – *Kurnubia palastiniensis* Henson, *Salpingorella annulata* Carozzi, *Campbeliella striata* (Carozzi) and *Heteroporella lemmensis* (Bernier). Upper Kimmeridgian (Escarpão Formation). Benaçoitão geological Section (S-128). x 15

7 – *Levantinella egyptiensis* ? Fourcade *et al.* Lower Kimmeridgian (Escarpão Formation). S. Romão geological Section (AN-180). x 20

8 – *Levantinella egyptiensis* ? Fourcade *et al.* Upper Kimmeridgian (Escarpão Formation). Escarpão geological Section (AM-238). x 25

9 – *Rectocyclammina chouberti* Hottinger. Upper Tithonian (*A. lusitanica* Formation). Bias geological Section (AE-18). x 20

10 - *Rectocyclammina chouberti* Hottinger. Upper Tithonian (*A. lusitanica* Formation). Bias geological Section (AE-18). x 20

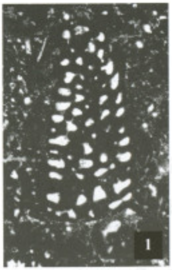
11 – *Audienusina fourcadei* Bernier. Lower Kimmeridgian (Escarpão Formation). Conceição de Tavira geological Section (AV- 40). x 33

12 – *Charentia atlasica* Farès. Upper Kimmeridgian (Escarpão Formation). Loulé-Faro geological Section (AD-87b). x 50

13 – *Freixialina planispiralis* Ramalho. Lower Kimmeridgian (Escarpão Formation). Escarpão geological Section (AM-44B). x 90

14 - *Freixialina planispiralis* Ramalho. Lower Tithonian (Escarpão Formation). Escarpão geological Section (AM-442). x 45

PLATE 7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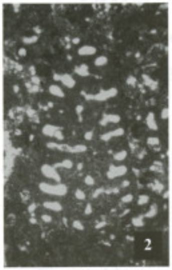
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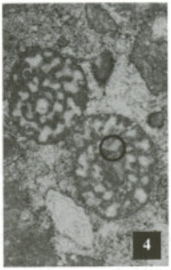
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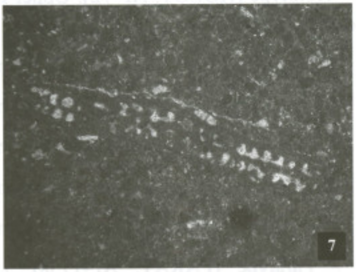
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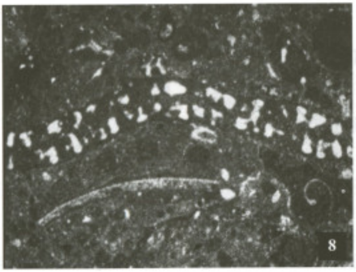
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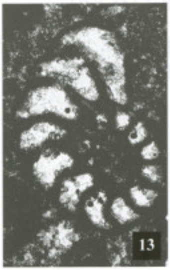
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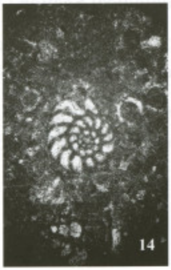
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PLATE 8

Foraminifers (8)

Involutina algarvensis n. sp

Type 1 – Axial sections (Figs 1-9)

1 – Upper Kimmeridgian (Escarpão Formation). Asseca geological Section (AP-41). x 55

2 – Paratype (PARAT. AP-173). Upper Kimmeridgian (Escarpão Formation). Asseca geological Section (AP-173). x 50

3 – Holotype (HOLOT. AP-72). Upper Kimmeridgian (Escarpão Formation). Asseca geological Section (AP-72). x 70

4 – Upper Kimmeridgian (Escarpão Formation). Asseca geological Section (AP-14). x 65

5 – Upper Kimmeridgian (Escarpão Formation). Asseca geological Section (AP-161). x 70

6 – Upper Kimmeridgian (Escarpão Formation). Asseca geological Section (AP-39). x 55

7 – Upper Kimmeridgian (Escarpão Formation). Asseca geological Section (AP-160). x 70

8 – Upper Kimmeridgian (Escarpão Formation). Asseca geological Section (AP-173). x 73

9 – Paratype (PARAT. AP-173a). Upper Kimmeridgian (Escarpão Formation). Asseca geological Section (AP-173a). x 65

10 – Type 2. Upper Kimmeridgian (Escarpão Formation). Asseca geological Section (AP-72). x 80

11 – Type 2. Upper Kimmeridgian (Escarpão Formation). Asseca geological Section (AP-72). x 65

12 - 13 – Type 2. Upper Kimmeridgian (Escarpão Formation). Asseca geological Section (AP-154) (Fig. 12 : x 75; Fig. 13: x 63)

14 – Oblique subequatorial section. Upper Kimmeridgian (Escarpão Formation). Asseca geological Section (AP-173). x 93

15 – Oblique subequatorial section. Upper Kimmeridgian (Escarpão Formation). Asseca geological Section (AP-181). x 67

16 – Oblique subaxial section. Upper Kimmeridgian (Escarpão Formation). Asseca geological Section (AP-14). x 65

PLATE 8


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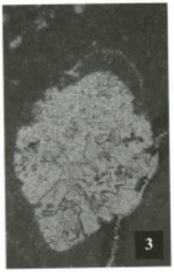
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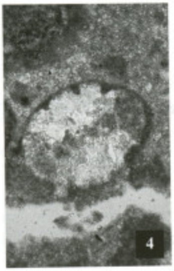
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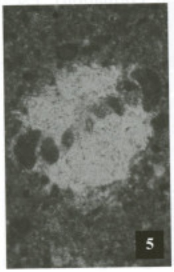
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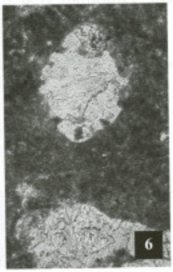
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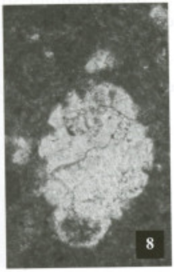
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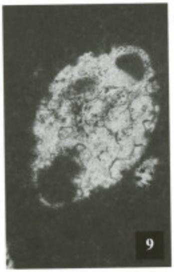
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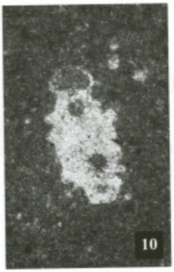
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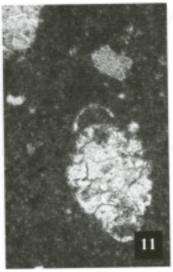
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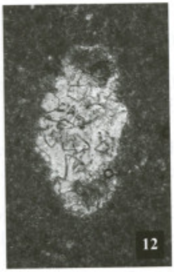
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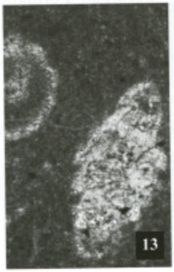
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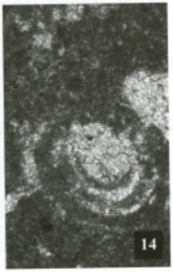
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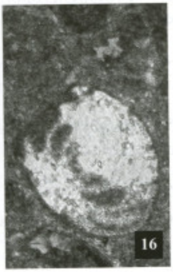
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PLATE 9

Foraminifers (9)

1 – *Neotrocholina* sp. B. Subaxial section. Lower Tithonian (Escarpão Formation). Escarpão geological Section (AM-438a). x 70

2 – *Neotrocholina* sp. A. Upper Kimmeridgian (Escarpão Formation). Asseca geological Section (AP-19). x 70

3 – *Neotrocholina* sp. A. Upper Kimmeridgian (Escarpão Formation). Ribeira de Séqua geological Section (AO-62). x 70

4 – *Neotrocholina* sp. A. Basal section. Lower Tithonian (Escarpão Formation). Escarpão geological Section (AM-436). x 55

5 – *Neotrocholina* sp. A. Basal section. Lower Tithonian (Escarpão Formation). Escarpão geological Section (AM-442a). x 60

6 – *Neotrocholina* sp. A. Lower Tithonian (Escarpão Formation). Escarpão geological Section (AM-437). x 70

7 – *Neotrocholina sp. A.* Lower Tithonian (Escarpão Formation). Escarpão geological Section (AM-438). x 65

8 – *Neotrocholina* sp. A. Lower Tithonian (Escarpão Formation). Tonel geological Section (O-13). x 85

9 – *Neotrocholina* sp. A. Upper Tithonian (*A. lusitanica* Formation). Escarpão geological Section (AM-505). x 130

10 – *Neotrocholina* sp. C. Lower Tithonian (Escarpão Formation). Escarpão geological Section (AM-437). x 125

11 – *Mironovella granulosa* (Bielecka & Pozaryski). Axial section. Lowermost Kimmeridgian (Jordana Formation). Ribeira do Colmeal geological Section (AQ-220). x 65

12 – Protopeneropolis striata Weynschenk. Lower Kimmeridgian (Escarpão Formation). Benaçoitão geological Section (S-17a). x 130

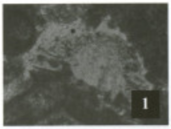
13 – Protopeneropolis striata Weynschenk. Lower Kimmeridgian (Escarpão Formation). Benaçoitão geological Section (S-17a). x 105

14 – Keramosphaera cf. allobrogensis Steinhauser *et al.* Lower Kimmeridgian (Escarpão Formation). Asseca geological Section (AZ-39). x 15

15 – *Mohlerina basiliensis* (Mohler). Lower Kimmeridgian (Escarpão Formation). Conceição de Tavira geological section (AV – 44). x 50

16 – Koskinobulina socialis Cherchi & Schroeder. Lower Kimmeridgian (Escarpão Formation). Conceição de Tavira geological Section (AV-31g). x 15

PLATE 9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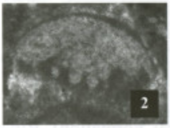
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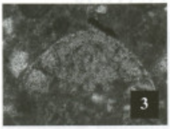
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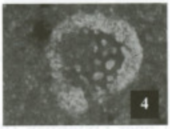
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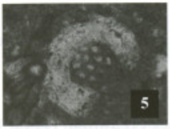
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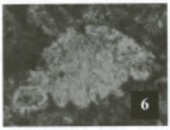
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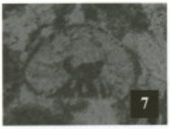
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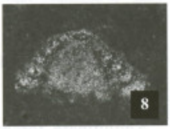
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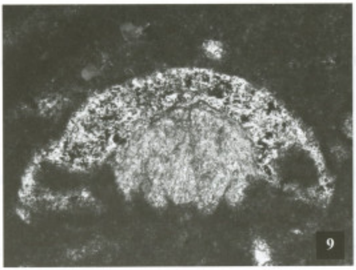
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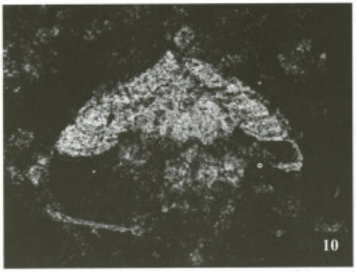
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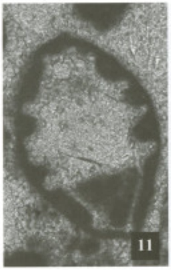
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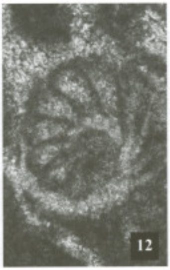
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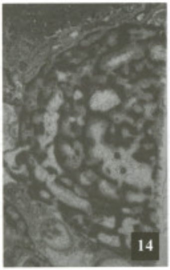
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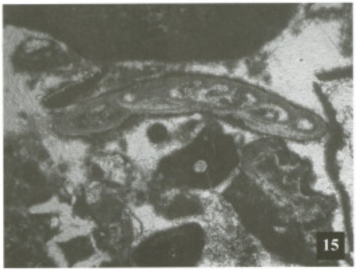
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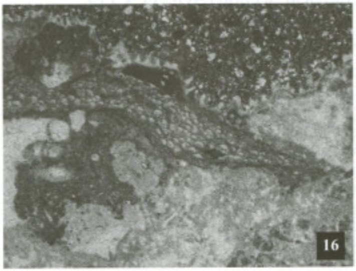
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PLATE 10

Pelagic microfossils (1)

Benthic organisms

1 – Placopsilina sp. Upper Oxfordian (Peral Formation). Ribeira do Colmeal geological Section (AQ-84). x 20

2 – Placopsilina sp. Upper Oxfordian (Peral Formation). Ribeira do Colmeal geological Section (AQ-95). x 25

3 – Agglutinate foraminifer and *Saccocoma.* Upper Oxfordian (Peral Formation). Ribeira do Colmeal geological Section (AQ-153). x 30

4 – Textulariidae ?. Upper Oxfordian (Peral Formation). Ribeira do Colmeal geological Section (AQ-59). x 150

Planktonic organisms

5 – Globochaete sp. Upper Oxfordian (Peral Formation). Ribeira do Colmeal geological Section (AQ-114). x 65

6 – Globochaete sp. Lowermost Kimmeridgian (Jordana Formation). Machados geological Section (AS-2A). x 65

7 – Siliceous sponge spicules microfacies. Lowermost Kimmeridgian (Jordana Formation). Rocha microbial mound (AU-55). x 15

8 – Globuligerina oxfordiana (Grigelis). Upper Oxfordian (Peral Formation). Ribeira do Colmeal geological Section (AQ-23). x 210

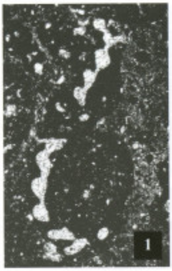
9 – Globuligerina oxfordiana (Grigelis). Upper Oxfordian (Peral Formation). Ribeira do Colmeal geological Section (AQ-21). x 160

10 – Globuligerina oxfordiana (Grigelis). Upper Oxfordian (Peral Formation). Ribeira do Colmeal geological Section (AQ-21). x 175

11 – "Calcisphaera" s.l. and "filaments". Upper Oxfordian (Peral Formation). Ribeira do Colmeal geological Section (AQ-135). x 35

12-13 – Radiolarians? Upper Oxfordian (Peral Formation). Ribeira do Colmeal geological Section (AQ-72). x 145

PLATE 10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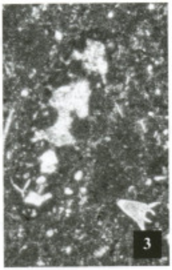
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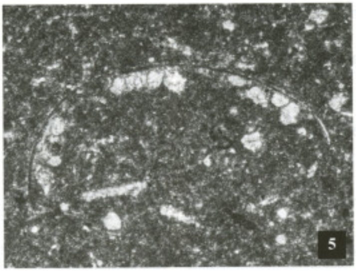
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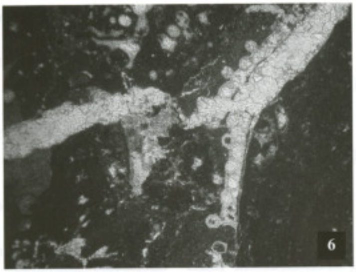
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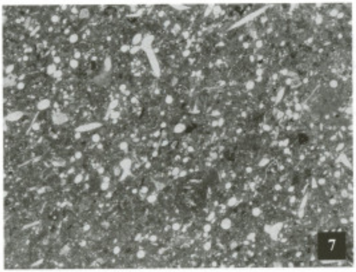
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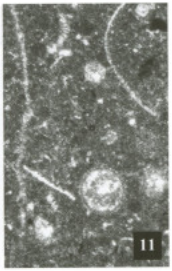
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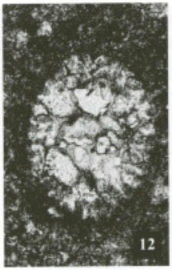
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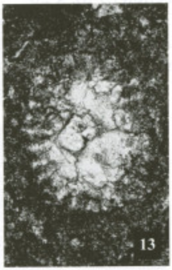
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PLATE 11

Pelagic microfossils (2)

Benthic

1 – Serpulids. Lower Kimmeridgian (Escarpão Formation). Asseca geological Section (AZ-78A). x 45

Planktonic

2 – *Saccocoma.* Upper Oxfordian (Peral Formation). Ribeira do Colmeal geological Section (AQ-153). x 110

3 - *Saccocoma.* Lowermost Kimmeridgian (Jordana Formation). Rocha microbial mound (AU-51). x 45

4 - *Saccocoma.* Upper Oxfordian (Peral Formation). Ribeira do Colmeal geological Section (AQ-104). x 40

5 - *Saccocoma.* Upper Oxfordian (Peral Formation). Ribeira do Colmeal geological Section (AQ-102). x 60

6 - *Saccocoma.* Lowermost Kimmeridgian (Jordana Formation). Rocha microbial mound (AU-51). x 50

7 - *Saccocoma.* Upper Oxfordian (Peral Formation). Ribeira do Colmeal geological Section (AQ-97). x 40

8 – Pelagic bivalve. Its shell fragments gave place to "filaments" identical of Fig.10. Upper Oxfordian (Peral Formation). Ribeira do Colmeal geological Section (AQ-112). x 7

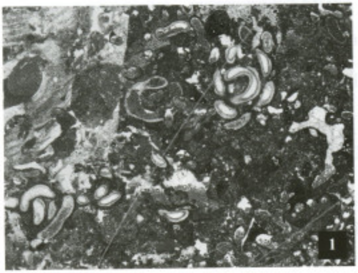
9 – *Bullopora tuberculata* Septfontaine. Lowermost Kimmeridgian (Jordana Formation). Asseca geological Section (AZ-28A). x 37

10 – "Filaments" (bivalves). Lowermost Kimmeridgian (Jordana Formation). Rocha microbial mound (AU-48). x 40

11 – "Filaments"(bivalves and ostracods). Middle-Upper Jurassic transition. Benaçoitão geological Section (S-8). x 20

12 – "Filaments" (bivalves). Upper Oxfordian (Peral Formation). Ribeira do Colmeal geological Section (AQ-21). x 25

PLATE 11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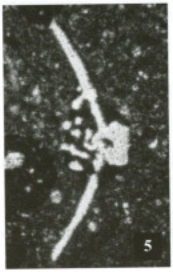
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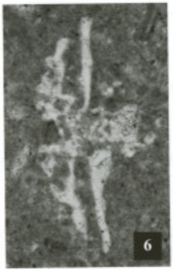
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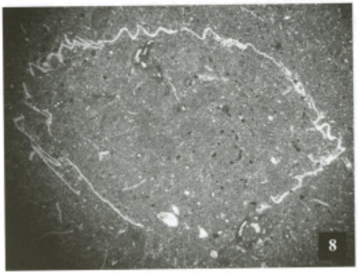
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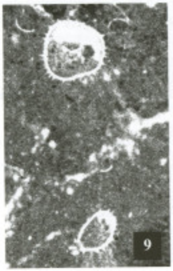
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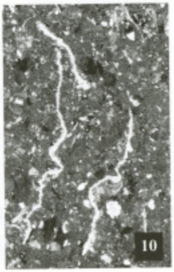
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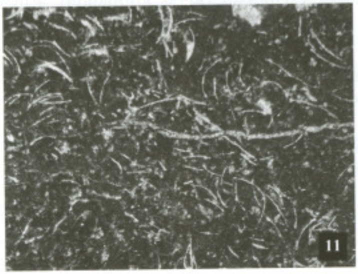
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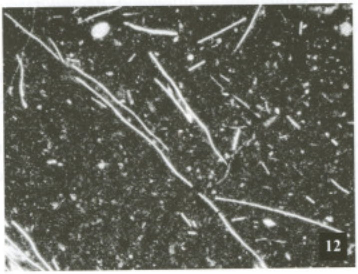
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PLATE 12

Other benthic organisms of pelagic facies

1 – Troglotella incrustans Wernli & Fookes. Lower Kimmeridgian (Escarpão Formation) Conceição de Tavira geological Section (AV-42A). x 20

2 – Troglotella incrustans Wernli & Fookes. Lower Kimmeridgian (Escarpão Formation), Conceição de Tavira geological Section (AV-42A). x 20

3 – Tubiphytes morronensis Crescenti. Upper Oxfordian (Peral Formation). Ribeira do Colmeal geological Section (AQ-104). x 25

4 – Tubiphytes morronensis Crescenti. Lowermost Kimmeridgian (Jordana Formation). Rocha microbial mound (AU-51). x 30

5 – Tubiphytes morronensis Crescenti. Upper Oxfordian (Peral Formation). Ribeira do Colmeal geological Section (AQ-185). x 20

6 – Terebella lapilloides Munster. Lowermost Kimmeridgian (Jordana Formation). Ribeira do Colmeal geological Section (AQ-187). x 30

7 – Terebella lapilloides Munster. Lowermost Kimmeridgian (Jordana Formation). Ribeira do Colmeal geological Section (AQ-187). x 15

8 – Coscinophragma cribrosum (Reuss). Upper Tithonian (*A. lusitanica* Formation). Bias geological Section (AE-89). x 10

9 – Serpulids. Lower Kimmeridgian (Escarpão Formation). Asseca geological Section (AZ-46). x 5

10 – Organic structure and *Terebella lapilloides* Munster with geopetal cavities. Lower Kimmeridgian (Escarpão Formation). Asseca geological Section (AZ-39). x 5

11 – Vegetable structure. Upper Oxfordian (Peral Formation). Ribeira do Colmeal geological Section (AQ-71). X 20

12 – Problematica: *Bacinella irregularis?* Upper Oxfordian (Peral Formation). Ribeira do Colmeal geological Section (AQ-76). x 20

13 – Problematica: organism agglomerating siliceous sponge spicules. Lowermost Kimmeridgian (Jordana Formation). Machados geological Section (AS-51). x 20

14 – Problematica: organism agglomerating siliceous sponge spicules. Lowermost Kimmeridgian (Jordana Formation). Machados geological Section (AS-14A). x 23

PLATE 12

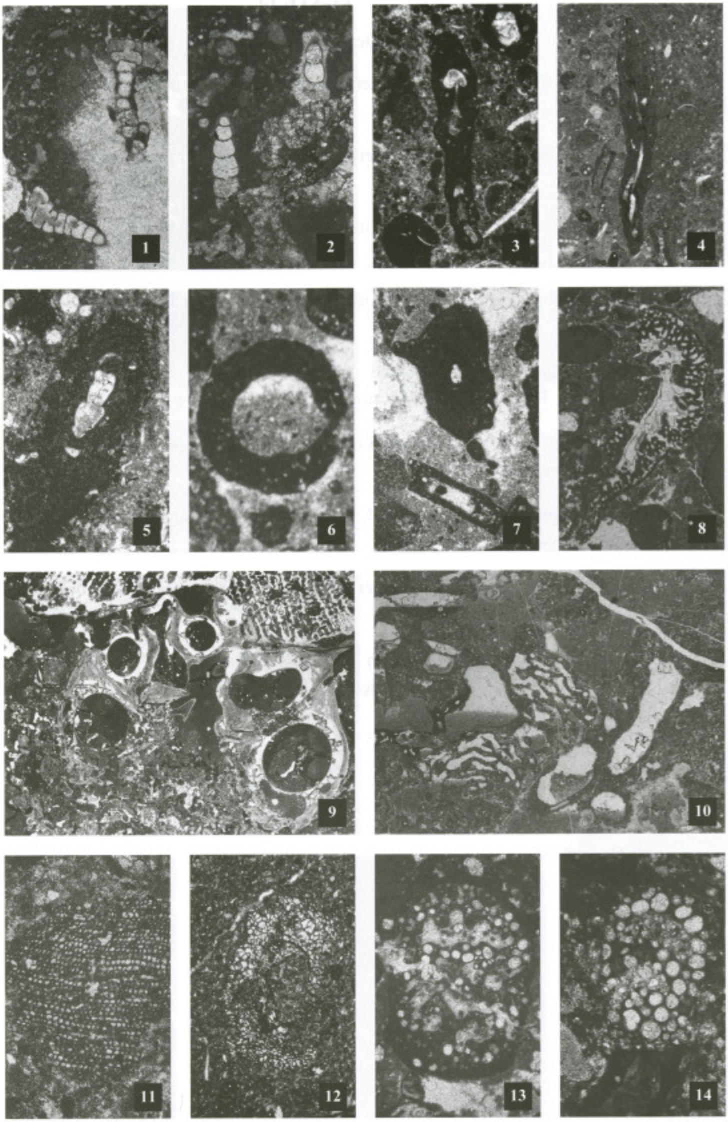


PLATE 13

Calcareous Algae (1)

1 – Likanella bartheli Bernier. Upper Kimmeridgian (Escarpão Formation). Escarpão geological Section (AM-228). x 30

2 – Likanella bartheli Bernier. Upper Kimmeridgian (Escarpão Formation). Escarpão geological Section (AM-228). x 25

3 – Actinoporella podolica (Alth). Upper Tithonian (*A. lusitanica* Formation). Bias geological Section (AE-21). x 25

4 – Actinoporella podolica (Alth). Upper Tithonian (*A. lusitanica* Formation). Bias geological Section (AE-21). x 25

5 – Salpingoporella annulata Carozzi and *"Valvulina" lugeoni* Septfontaine. Lower Kimmeridgian (Escarpão Formation). Tonel geological Section (O-22). x 10

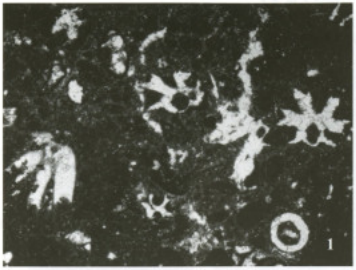
6 – Salpingoporella gr. *pygmaea* Gümbel. Lowermost Kimmeridgian (Jordana Formation). Ribeira do Colmeal geological Section (AQ-215). x 65

7 – Salpinpogorella gr. *pygmaea* Gümbel. Lower Kimmeridgian (Escarpão Formation). S. Romão geological Section (AN-126). x 20

8 – Clypeina jurassica Favre. Upper Kimmeridgian (Escarpão Formation). Ribeira da Torre geological Section (Q-60). x 20

9 – Salpingoporella pygmaea Gümbel with greater dimensions than the common specimens. Lower Kimmeridgian (Escarpão Formation). Conceição de Tavira geological Section (AV-51). x 30

PLATE 13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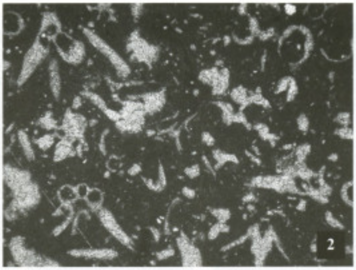
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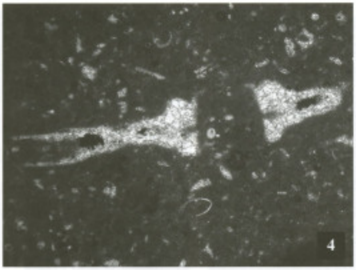
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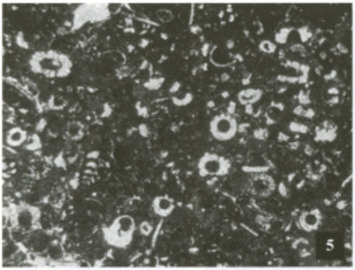
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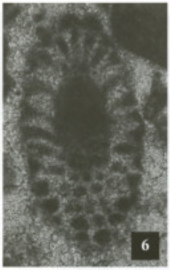
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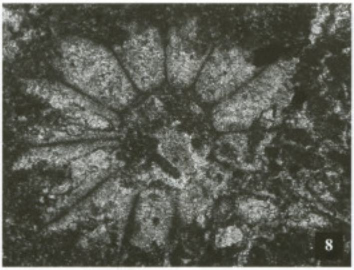
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PLATE 14

Calcareous Algae (2)

1 – Clypeina? solkani Conrad & Radoicic. Upper Tithonian (*A. lusitanica* Formation). Almadena geological Section (AI-29). x 90

2 – Clypeina? solkani Conrad & Radoicic. Upper Tithonian (*A. lusitanica* Formation). Loulé-Faro geological Section (AD-259a). x 2

3 – "Salpingoporella" gigantea (Carozzi). Lower Kimmeridgian (Escarpão Formation). Asseca geological Section (AZ-90). x 15

4 – "Salpingoporella" gigantea (Carozzi). Lower Kimmeridgian (Escarpão Formation). Asseca geological Section (AZ-104). x 15

5 – Coniporella valfinensis Bernier. Lower Kimmeridgian (Escarpão Formation). Conceição de Tavira geological Section (AV-17). x 5

6 – Griphoporella minima? Nikler & Sokac. Upper Kimmeridgian (Escarpão Formation). Escarpão geological Section (AM-467). x 15

7 – Griphoporella piae? Dragastan. Lower Kimmeridgian (Escarpão Formation). Conceição de Tavira geological Section (AV-51). x 12

8 – Griphoporella piae? Dragastan. Upper Kimmeridgian (Escarpão Formation). Asseca geological Section (AZ-86). x 18

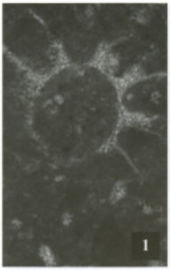
9 – Macroporella aff. *praturloni* Dragastan. Lower Kimmeridgian (Escarpão Formation). Escarpão geological Section (AM-37). x 20

10 – *Macroporella* aff. *praturloni* Dragastan. Lower Kimmeridgian (Escarpão Formation). Conceição de Tavira geological Section (AV-51). x 30

11 – *Petrascula bursiformis* (Etallon). Lower Kimmeridgian (Escarpão Formation). Escarpão geological Section (AM-638). x 15

12 – *Petrascula bursiformis* (Etallon) Lower Kimmeridgian (Cerro da Cabeça Formation). Asseca geological Section (AZ-11). x 10

PLATE 14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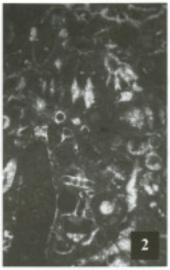
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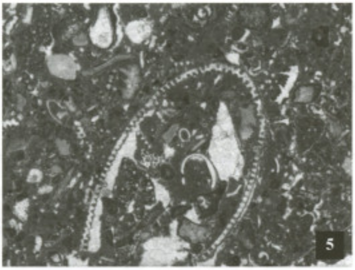
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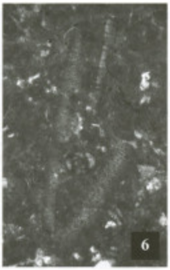
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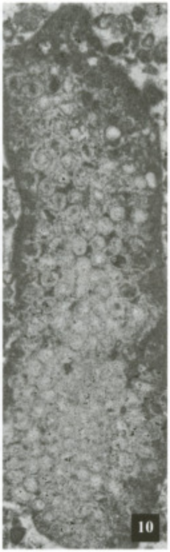
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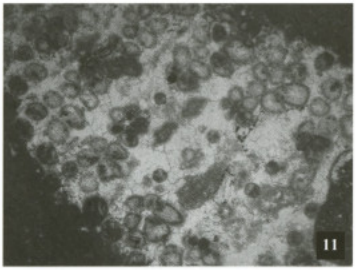
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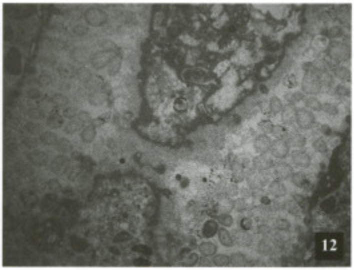
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PLATE 15

Calcareous algae (3)

1 – Heteroporella anici Nickler & Sokac. Upper Kimmeridgian (Escarpão Formation). Asseca geological Section (AP-14). x 20

2 – Heteroporella anici Nickler & Sokac. Upper Kimmeridgian (Escarpão Formation). Asseca geological Section (AP-15). x 50

3 – Heteroporella anici Nickler & Sokac. Upper Kimmeridgian (Escarpão Formation). Asseca geological Section (AP-15). x 33

4 – Heteroporella lemmensis (Bernier). Upper Tithonian. (*A. lusitanica* Formation). Escarpão geological Section (AM-525). x 30

5 – Heteroporella lemmensis (Bernier). Transverse section. Upper Kimmeridgian (Escarpão Formation). Benaçoitão geological Section (S-128 b). x 30

6 – Heteroporella lemmensis (Bernier). Upper Tithonian (*A. lusitanica* Formation). Escarpão geological Section (AM-525). x 25

7 – Heteroporella sagresensis n. sp. Oblique axial section. Upper Kimmeridgian (Escarpão Formation). Benaçoitão geological Section (S-128). Paratype (PARAT. S-128a). x 25

8 – Heteroporella sagresensis n. sp. Oblique section. Upper Kimmeridgian (Escarpão Formation). Benaçoitão geological Section (S-103). Holotype (HOLOT. S-103b). x 25

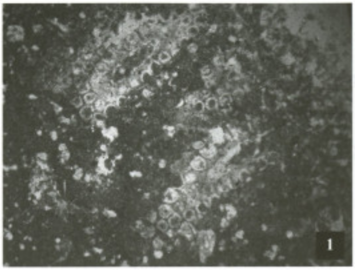
9 – Heteroporella sagresensis n. sp. Transverse section. Upper Kimmeridgian (Escarpão Formation). Benaçoitão geological Section (S-128). Holotype (HOLOT. S-128c). x 25

10 – Heteroporella sagresensis n. sp. Transverse section. Upper Kimmeridgian (Escarpão Formation). Benaçoitão geological Section (S-128). Paratype (PARAT. S-128b). x 22

11 – Bucurella espichelensis (Deloffre & Ramalho). "Siamese" specimens. Upper Tithonian (*A. lusitanica* Formation). Escarpão geological Section (AM-485). x 20

12 – Campbeliella striata (Carozzi). Upper Kimmeridgian (Escarpão Formation). Cerro do Monte geological Section (U-46). x 35

PLATE 15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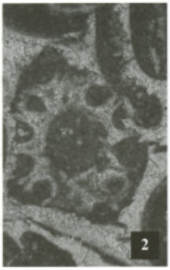
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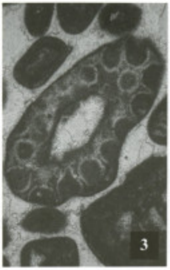
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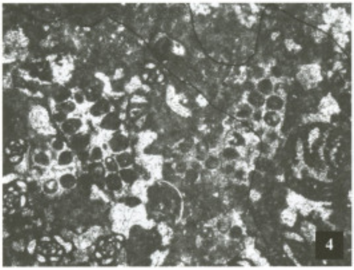
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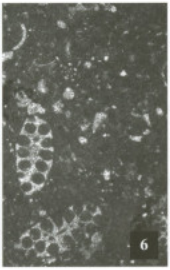
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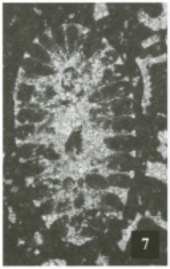
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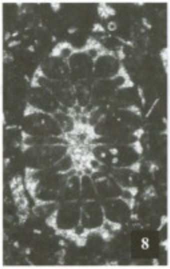
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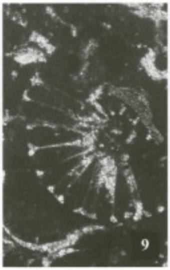
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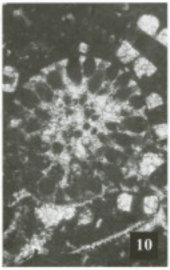
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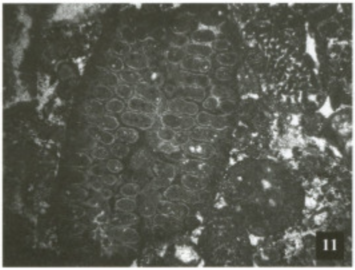
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PLATE 16

Calcareous algae (4)

1 – Terquemella sp. type A. Lower Kimmeridgian (Escarpão Formation). Conceição de Tavira geological Section (AV-40). x 60

2 – Terquemella sp. type B. Lower Kimmeridgian (Escarpão Formation). Asseca geological Section (AZ-112). x 100

3 - Terquemella microfacies Upper Tithonian (*A. lusitanica* Formation). Loulé-Faro geological Section (AD-209). x 5

4 – Russoella triangularis (Ramalho). Upper Tithonian (*A. lusitanica* Formation). Loulé-Faro geological Section (AD-209). x 110

5 – Permocalculus inopinatus Elliot. Upper Tithonian (*A. lusitanica* Formation). Bias geological Section (AE-116). x 25

6 – Permocalculus inopinatus Elliot. Lower Tithonian (Escarpão Formation). Escarpão geological Section (AM-445). x 25

7 – Arabicodium sp. Lower Kimmeridgian (Cabeça Formation). Conceição de Tavira geological Section (AV-4). x 20

8 – Arabicodium sp. Lower Kimmeridgian (Escarpão Formation). Conceição de Tavira geological Section (AV-20). x 20

9 – Lithophyllum (?) maslovi Dragastan. Lower Kimmeridgian (Escarpão Formation). Escarpão geological Section (AM-53). x 15

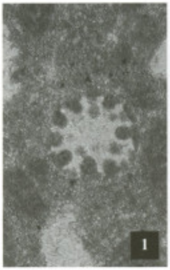
10 – Lithophyllum (?) maslovi Dragastan. Upper Tithonian (*A. lusitanica* Formation). Escarpão geological Section (AM-496). x 40

11 – Lithophyllum (?) maslovi Dragastan. Upper Tithonian (*A. lusitanica* Formation). Loulé-Faro geological Section (AD- 204a). x 15

12 – Thaumatoporella parvovesiculifera (Raineri). Upper Tithonian (*A, lusitanica* Formation). Loulé-Faro geological Section (AD-186). x 30

13 – Marinella lugeoni Pfender. Lower Kimmeridgian (Escarpão Formation). S. Romão geological Section (AN-136). x 15

PLATE 16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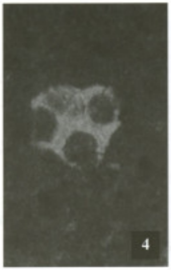
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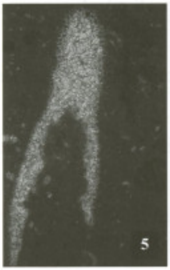
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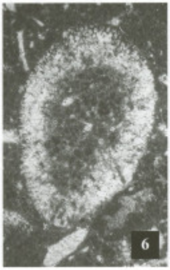
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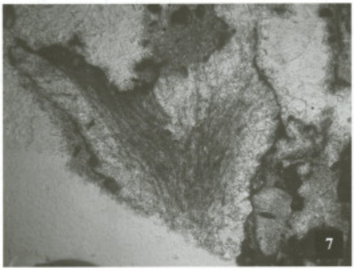
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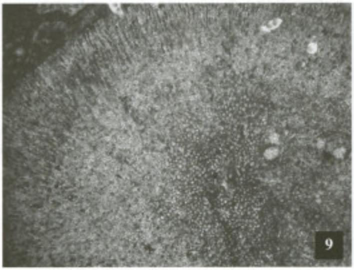
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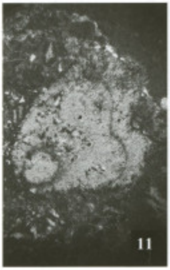
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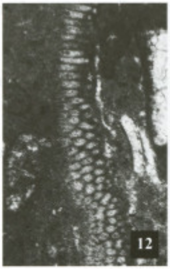
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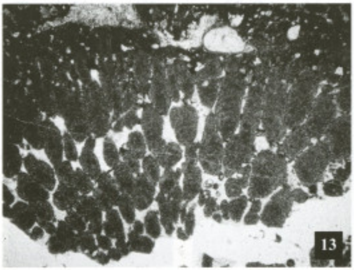
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PLATE 17

Calcareous algae (5)

1 – *Cayeuxia* gr. *moldavica* Frollo. Upper Kimmeridgian (Escarpão Formation). Ribeira da Torre geological Section (Q-33). x 30

2 – *Cayeuxia* gr. *moldavica* Frollo. Upper Tithonian (*A. lusitanica* Formation). Almádena geological Section (AB-39). x 10

3 – *Cayeuxia* gr. *moldavica* Frollo. Lower Kimmeridgian (Escarpão Formation). Benaçoitão geological Section (S-54). x 10

4 – *Cayeuxia* gr. *piae* Frollo. Lower Kimmeridgian (Escarpão Formation). Asseca geological Section (AZ-93). x 15

5 – *Cayeuxia* gr. *piae* Frollo. Upper Tithonian (*A. lusitanica* Formation). Loulé-Faro geological Section (AD-206). x 5

6 – *Cayeuxia* gr. *piae* Frollo associated with stromatoporoid fragments. Lower Kimmeridgian (Escarpão Formation). Conceição de Tavira geological Section (AV-42). x 5

7 – *Picnoporidium* aff. *lobatum* Yabe & Toyana. Lower Kimmeridgian (Escarpão Formation). Conceição de Tavira geological Section (AV-20). x 15

8 – *Picnoporidium* aff. *lobatum* Yabe & Toyana. Lower Kimmeridgian (Escarpão Formation). Conceição de Tavira geological Section (AV-34). x 35

9 – Alga AD-75. Upper Kimmeridgian (Escarpão Formation). Loulé - Faro geological Section (AD-77a). x 10

10 – Alga AD-75. Upper Kimmeridgian (Escarpão Formation). Loulé-Faro geological Section (AD-75b). x 5

11 – Alga AD-75, detail of the specimen Fig. 14. Upper Kimmeridgian (Escarpão Formation. Loulé-Faro geological Section (AD-75d). x 30

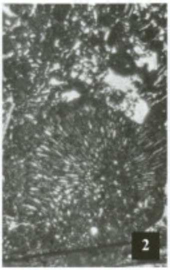
12 – Alga AD-75. Upper Kimmeridgian (Escarpão Formation). Loulé-Faro geological Section (AD-75b). x 10

13 – Alga AD-75. Upper Kimmeridgian (Escarpão Formation). Loulé-Faro geological Section (AD-75 b). x 20

14 – Alga AD-75. Upper Kimmeridgian (Escarpão Formation). Loulé-Faro geological Section (AD-75d). x 15

PLATE 17


1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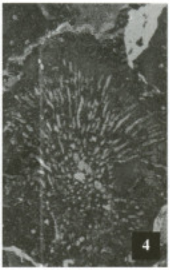
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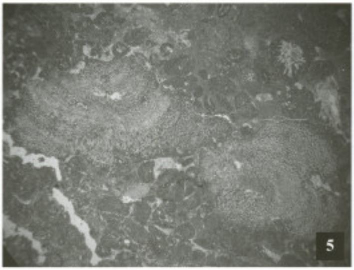
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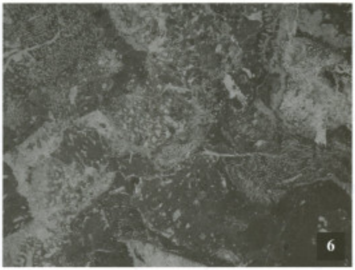
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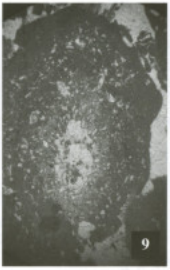
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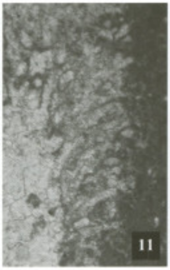
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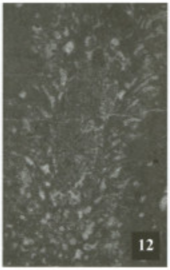
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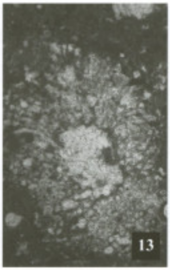
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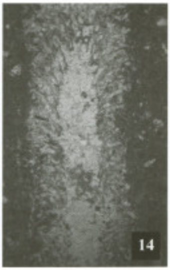
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PLATE 18

Colonial organisms (1)

1 – Thalamopora lusitanica Termier *et al.* Lowermost Kimmeridgian (Jordana Formation). Ribeira do Colmeal geological Section (AQ-230). x 25

2 – Neuropora lusitanica Termier *et al.* Lower Kimmeridgian (Escarpão Formation). S. Romão geological Section (AN-59). x 20

3 – Neuropora lusitanica Termier *et al.* Lower Kimmeridgian (Cabeça Formation). Ribeira de Séqua geological Section (AO-10). x 10

4 – Neuropora lusitanica Termier *et al.* Lower Kimmeridgian (Cabeça Formation). Machados geological Section (AS-70). x 20

5 – Corynella cf. *quenstedti* (Zittel). Lower Kimmeridgian (Escarpão Formation). S. Romão geological Section (AN-73). x 10

6 – Corynella cf. *quenstedti* (Zittel). Lower Kimmeridgian (Escarpão Formation). Asseca geological Section (AZ-69). x 10

7 – Burgundia trinorchii Munier-Chalmas. Lower Kimmeridgian (Escarpão Formation). S. Romão geological Section (AN-224). x 5

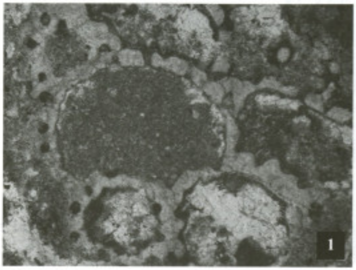
8 – Burgundia trinorchii Munier-Chalmas. Lower Kimmeridgian (Escarpão Formation). Asseca geological Section (AZ-93). x 10

9 – Burgundia trinorchii Munier-Chalmas and *Dehornella choffati* (Dehorne). Lower Kimmeridgian (Escarpão Formation). Asseca geological Section (AZ-138). x 5

10 – Dehornella choffati (Dehorne). Detail of the Structure. Lower Kimmeridgian (Escarpão Formation). Asseca geological Section (AZ-49). x 15

11 – Cladocoropsis mirabilis Felix. Lower Kimmeridgian (Escarpão Formation). Cerro do Monte geological Section (U-56). x 2

PLATE 18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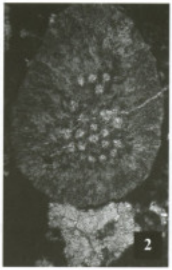
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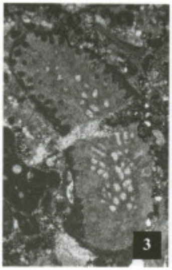
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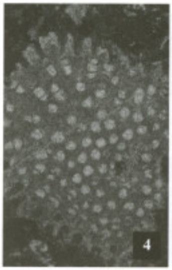
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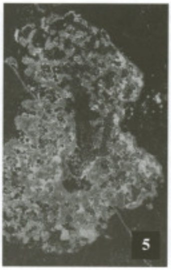
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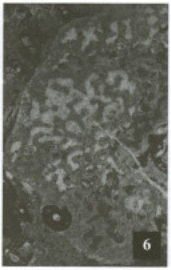
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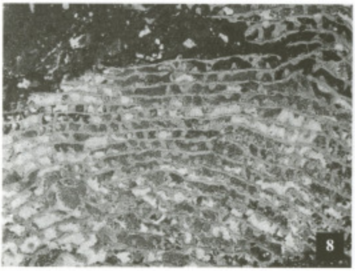
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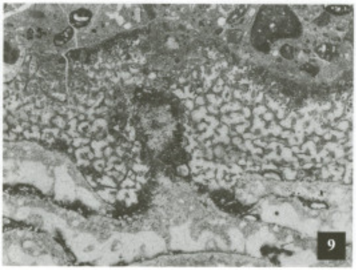
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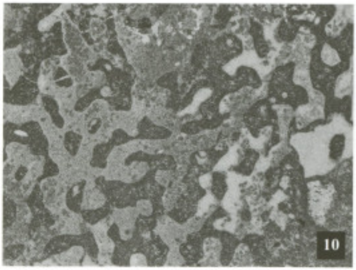
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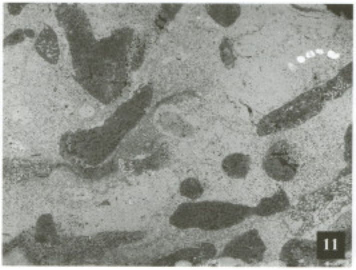
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PLATE 19

Colonial organisms (2)

1 – Ptychochaetetes sp. Lower Kimmeridgian (Escarpão Formation). Asseca geological Formation (AZ-139). x 10

2 – Ptychochaetetes sp. Lower Kimmeridgian (Escarpão Formation). Conceição de Tavira geological Section (AV-33). x 5

3 – Parastromatopora sp. Lower Kimmeridgian (Escarpão Formation). Asseca geological Section (AZ-122). x 8

4 – Blastochaetetes sp. Lower Kimmeridgian (Escarpão Formation). Asseca geological Section (AZ-41). x 20

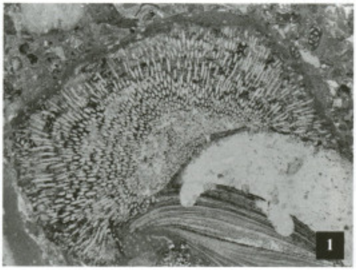
5 – Parachaetetes sp. Lower Kimmeridgian (Escarpão Formation). Asseca geological Section (AZ-122). x 12

6 – Dehornella sp. burrowed by a lithophag bivalve. Lower Kimmeridgian (Escarpão Formation. Asseca geological Section (AZ-49). x 6

7 – Shuqraia sp. burrowed by a lithophag bivalve. Lower Kimmeridgian (Escarpão Formation). Asseca geological Section (AZ-98). x 5

8 – Promillopora sp. and *Troglotella?*. Lower Kimmeridgian (Escarpão Formation). Asseca geological Section (AZ-107a). x 5

PLATE 19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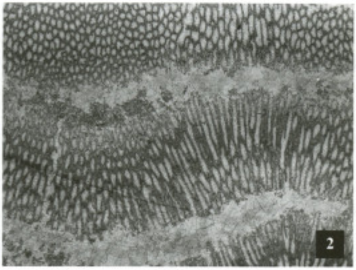
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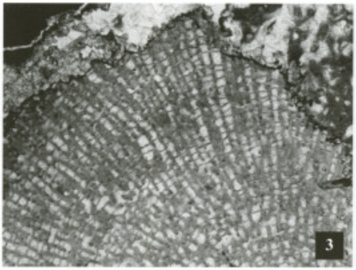
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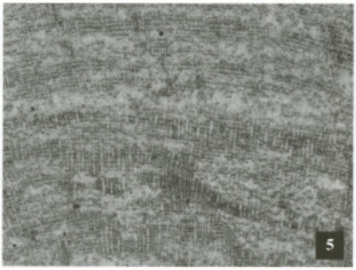
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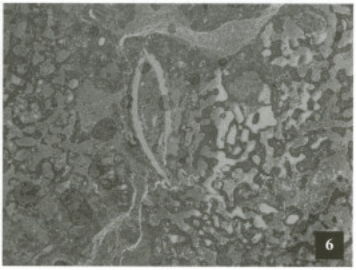
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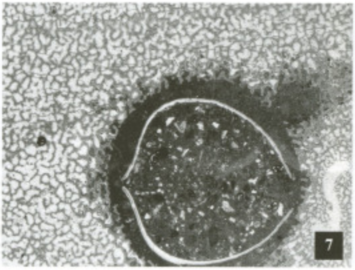
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PLATE 20

1 – Crustacean appendages. Upper Kimmeridgian (Escarpão Formation). Benaçoitão geological Section (S-89). x 20

2 – *Favreina* aff. *prusensis* (Paréjas). Upper Kimmeridgian (Escarpão Formation). Benaçoitão geological Section (S-89). x 15

3 - *Favreina* aff. *prusensis* (Paréjas). Upper Kimmeridgian (Escarpão Formation). Benaçoitão geological Section (S-89). x 20

4 - *Favreina* aff. *prusensis* (Paréjas). Upper Kimmeridgian (Escarpão Formation). Benaçoitão geological Section (S-89). x 20

5 – *Bacinella?* and *Girvanella* nodules. Lower Kimmeridgian (Escarpão Formation). Tonel geological Section (O-5). x 3

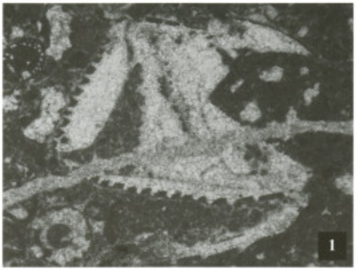
6 – *Bacinella irregularis* Radoicic envelloping *Campbeliella striata* (Carozzi). Base of the upper Tithonian (*A. lusitanica* Formation). Loulé-Faro geological Section (AD-188a). x 10

7 – Microbial structure with geopetal cavities. Lower Kimmeridgian (Escarpão Formation). Carrapateira geological Section (T-78). x 5

8 – A pilling up of bivalve shells probably due to weak sea-bottom currents. Lowermost Kimmeridgian (Jordana Formation). Loulé-Faro geological Section (AD-204). x 7

9 – Silicified zone (upper part of the figure) affecting micritic sediment containing siliceous sponge spicules. Lowermost Kimmeridgian (Jordana Formation). Ribeira do Colmeal geological Section (AQ-206). x 5

PLATE 20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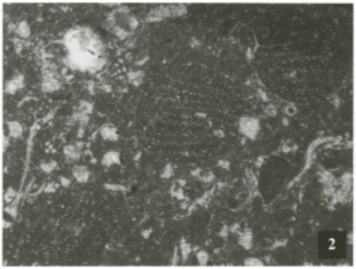
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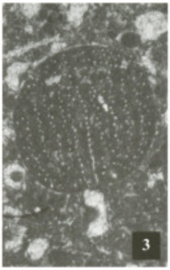
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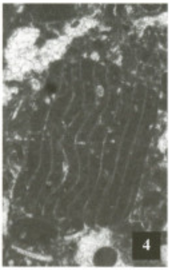
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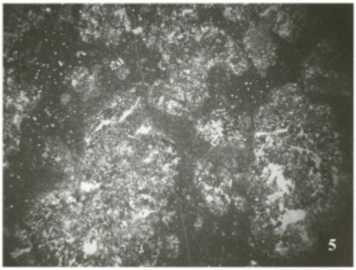
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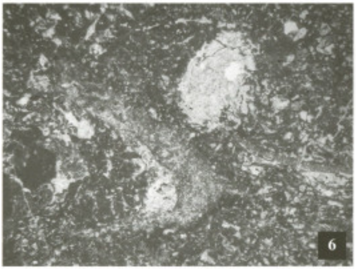
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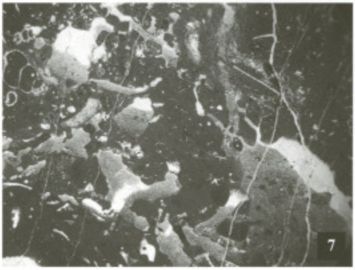
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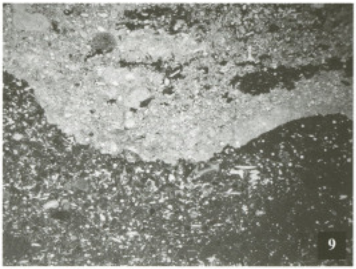
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