

*Microfacies studies of carbonate rocks from Jurassic outcrops
in the north of Faro, Southern Portugal*

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RESUMO

Palavras-chave: Microfácies — Jurássico médio e superior — Algarve.

Apresenta-se o estudo das microfácies de rochas carbonatadas do Jurássico médio e superior a Norte de Faro.

As rochas carbonatadas estudadas foram subdivididas em nove tipos de microfácies (MF). As primeiras quatro são representadas por sedimentos de plataforma carbonatada, características de pequena profundidade. São compatíveis com as zonas de fácies 6 a 8 de Wilson. Não estão representados fragmentos de fácies recifais ou calcários clásticos litorais. Estes tipos de MF repetem-se várias vezes no tempo sem, todavia, apresentarem ciclicidade. O desenvolvimento vertical das diferentes fácies indica interdigitação apertada.

As MF são típicas de ambientes intertidais ou subtidais de pequena profundidade; tanto o quartzo autigênico como a fraca diversidade faunística e florística verificada em várias camadas apontam para a ocorrência de áreas restritas temporárias.

A ocorrência de *Dictyoconus cayeuxi* LUCAS e de amonites do Calloviano nos níveis superiores ao conjunto estudado, sugerem, para este, idade batoniana.

Os tipos de microfácies 5 a 9 (Oxfordiano/Kimmeridgiano) revelam condições de sedimentação muito diferentes; calcários recifais alternam com sedimentos pelágicos de maior profundidade. Os calcários micríticos do Oxfordiano são caracterizados por conterem intercalações halodápicas enquanto que as do Oxfordiano/Kimmeridgiano com «fabrics» tuberolíticas estão, às vezes, fortemente silicificadas.

Só se atingiram estádios iniciais de crescimento de «patch reef» durante o desenvolvimento dos calcários de pequena profundidade do Oxfordiano/Kimmeridgiano.

RÉSUMÉ

Mots-clés: Microfaciès — Jurassique moyen et supérieur — Algarve.

Les microfaciès des roches carbonatées du Jurassique moyen et supérieur de la région au Nord de Faro sont présentés; ils ont été reportés en neuf types (MF) successifs.

Les 4 premiers correspondent à des sédiments de plate-forme carbonatée de faible profondeur et sont compatibles avec les zones 6 à 8 de Wilson. Les débris récifaux et les calcaires clastiques littoraux sont absents. Les différents types de MF se répètent plusieurs fois dans le temps

sans toutefois présenter une disposition cyclique. Ces MF sont typiques d'environnements intertidaux ou subtidaux de faible profondeur. La présence de quartz autigène aussi bien que la faible diversité des faunes et des flores observées dans les différentes couches indique l'existence de bassins temporaires fermés.

La présence de *Dictyoconus cayeuxi* LUCAS et d'ammonites du Callovien dans les niveaux susjacentes suggère un âge bathonien pour ces 4 premiers types.

Les types suivants (5 à 9 = Oxfordien à Kimmeridgien) montrent des conditions de sédimentation très différentes: calcaires récifaux alternant avec des sédiments pélagiques de profondeur plus forte. Les calcaires micrétiques de l'Oxfordien sont caractérisés par la présence d'intercalations alodapiques tandis que ceux de l'Oxfordien-Kimmeridgien avec «fabrics» tuberolitique sont parfois fortement silicifiés.

Seules les premières phases de croissance des «patch-reef» ont été atteintes pendant la formation des calcaires de faible profondeur de l'Oxfordien-Kimmeridgien.

ABSTRACT

Key-words: Microfacies — Middle and Upper Jurassic — Algarve.

The Middle and Upper Jurassic limestones investigated were subdivided into nine microfacies (MF) types. The firsts four represent Bathonian sediments with shallow water characteristics typical for carbonate platforms. They are comparable with Wilson's facies zones 6 to 8. Reef and reef debris, near-shore clastic-dominated limestones are not present. These MF-types are reiterated several times without cyclicity. The vertical development of the differentiated facies units indicates a close interfingering.

The microfacies data are typical of inter to shallow subtidal environments; both authigenous quartz and low faunal and floral diversity of several layers point to temporary restricted conditions.

The occurrence of *Dictyoconus cayeuxi* LUCAS and Callovian ammonites from the above lying strata argue for a Bathonian age.

The MF-types 5-9 (Oxfordian-Kimmeridgian) show completely different sedimentation conditions. Fully marine nearshore reefal limestones alternate with pelagic sediments formed at deeper shelf areas. The pelagic micritic limestones of Oxfordian age are characterized by alodapic intercalations whereas the Oxfordian/Kimmeridgian limestones with tuberolithic fabrics often show intensive silifications.

Only initial patch reef growth-stages were reached during the development of the Oxfordian and Kimmeridgian shallow water limestones.

1. INTRODUCTION

There are only two broader Jurassic outcrops of significance in Portugal:

- a) The Lusitanian basin in the North between Aveiro and Setubal;
- b) A small ribbon stretching along the southern coast from Sagres to Vila Real de St. António in the Algarve area (fig. 1).

(A smaller outcrop exists between both near Santiago de Cacém).

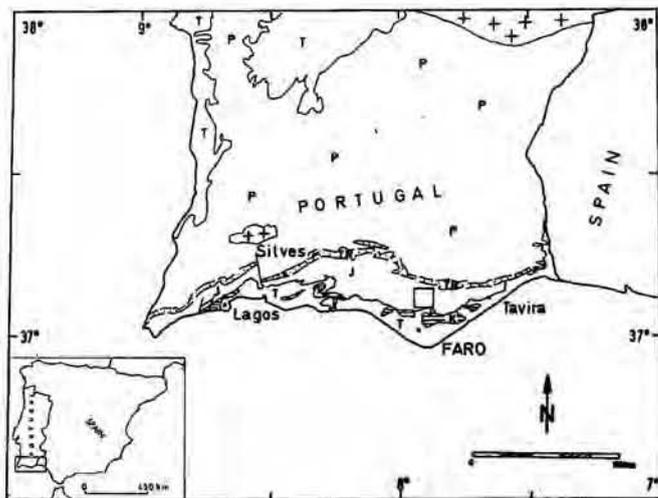
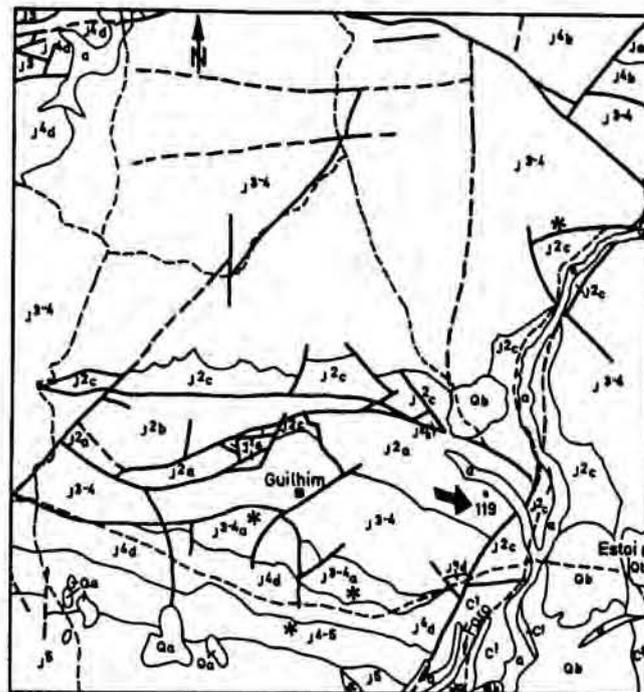


Fig. 1 — Distribution of the most important stratigraphic units of Southern Portugal. Small square north of Faro indicates the mapped area (see fig. 2). T = Tertiary, K = Cretaceous, J = Jurassic, TR = Triassic, P = Paleozoic

The first comprehensive studies concerning the Mesozoic of Portugal were published by P. CHOFFAT (1880, 1883-1887, recent literature has been summarized by ROCHA, 1976). The works of J. CH. PRATSCH (1958), R. B. ROCHA (1976) and of B. MARQUES (1983) concern specially the Algarve area.

The Lower Jurassic sediments consist of dolomites of Sinemurian age, ending with Portlandian limestones or dolostones. They are exposed in the western part of the

Algarve. The oldest strata in the eastern part are of Bathonian age. The carbonate rock column in the area investigated (about 10 km north of Faro) starts with Bathonian oolitic limestones representing the core of the west-east striking Guilhim upfold; they are flanked by Callovian to Kimmeridgian marls and limestones (fig. 2). The limestones here are exclusively shallow water deposits (representing the eastern flank of the Portuguese trough) in contrast to contemporaneous sediments of the western Algarve.



Q, Qb	Holocene	----	street
Qa	Pleistocene	----	strat. boundary
C1	Lower Cretaceous	----	fault
J5	Portlandian		
J4-5	Portlandian/Kimm.		
J4b, J4d	Kimmeridgian		
J3-4	Kimm./Oxfordian		
J2c	Callovian		
J2b	Lower to Middle Bathonian		
J2a	Bajocian		

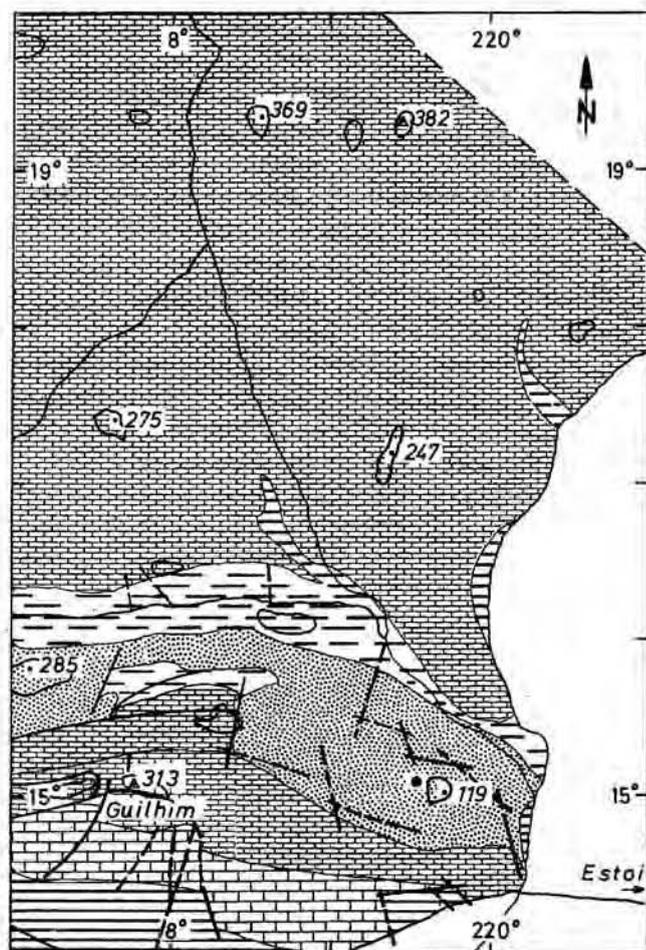


Fig. 2 — Geological map of the investigated area between Faro (south) and S. Brás de Alportel — modified after Carta Geológica de Portugal, 53-A Faro, 1985. Bathonian section was taken near the arrow (119 m). Oxfordian/Kimmeridgian samples were taken from locations indicated with stars (*)

The Bathonian rocks investigated were sampled bed by bed; the microfacies interpretation, based on both investigations of thin-sections and acetate peels, resulted in a tentative facies model. The facial development of the younger Jurassic carbonates were also studied, but were not integrated in an extended model.

2. DESCRIPTION OF THE NON-BIOGENIC BATHONIAN COMPONENTS

The description of non-biogenic components is based on the nomenclature given by E. FLÜGEL (1982). Ooids and oncoids were studied in detail:

Ooids: Four main types of ooids were distinguished here (Pl. 1, fig. 3, 4).

- a) Radial ooids with tangential substructure R_T -ooids: The R_T -ooids represent a combination of primary

radial structures with diagenetic alterations; the radial elements were interpreted to be original structures, based on comparison of their microstructure with other descriptions e.g. L. SIMONE (1974), P. HELLER & al. (1980), P. SANDBERG (1975).

- b) Tangential ooids with radial substructure T_R -ooids (Pl. 1, fig. 2): diameter, roundness and sphaericity of these ooids prove a formation under relatively agitated water energies, as occurs in oolitic shoals (FLÜGEL, 1982). The primary tangential structure is overprinted by subtle radial elements. This ooid type often shows intensive micritization.
- c) Micritic ooids M -ooids (Pl. 1, fig. 5): These are completely (or almost completely) micritized ooids of the T_R -types, confirmed by morphologic comparisons. They are a characteristic component type of the oopelsparites within the mixing zone.
- d) Radial ooids R -ooids (Pl. 1, fig. 7): This ooids are characterized by broad simple seams of prismatic crystals with radial orientation. They are typical components of protected areas behind ooid bars and can be compared with superficial ooids, as first described by L. ILLING (1954).

According to the classification of B. WILKINSON (1985) these ooids are primary radial ooids with an original calcitic fabric.

Ooid-types	R_T -type	T_R -type	M-type	R-type
Description Parameter				
Diameter (mm)	0,3–0,5	0,4–1,0	0,4–1,0	0,3–>1,0
Shape	Oval-round	Predominantly round	Predominantly round	Variable
Sphaericity	Low	High	High	Low-High
Internal structure	Radial subtangential	Tangential subradial	Tangential subradial	Radial
Number of laminae	2, rarely more	Somemany (10)	—	1–2
Width of sparitic laminae	40–70 micron	5–15 micron	—	20–100 micron
Nucleus	Peloid	Peloid	—	Divers

Fig. 3a — Summarized characteristics of the four main ooid-types

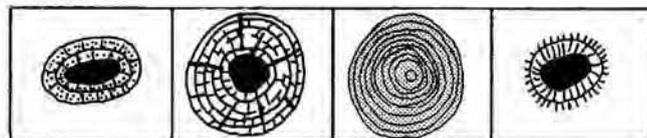


Fig. 3b — Microscopic appearance of the four main ooid-types

Oncoids: The oncoids were subdivided into two groups, micritic oncoids (type I with Lm) and *Bacinella*-oncoids (types II-VI with Lo, Lob, Lg and Ld, all summarized in fig.) The abbreviations stand for micritic laminae (Lm), laminae with «birdseye»-structures (Lo), blistery laminae (Lb), granular laminae (Lg), laminae with domelike organic overgrowths (Ld), figured in Pl. 1, fig. 6, Pl. 4, fig. 1, 2, 3.

Oncoids are defined as biosedimentary structures, that originated with the help of cyanobacteria (FLÜGEL, 1982). Types II-VI re additionally formed by *Bacinnella irregularis* and are therefore named *Bacinnella*-oncoids. The morphologic characteristics of each type is drawn in fig. 4. They were formed in subtidal environments with weak to moderate water currents.

K. DAHAYANAKE (1977) described *Bacinnella*-oncoids from Kimmeridgian limestones and differentiated three main types, each characteristic for different water depth. Though the morphologic characteristics are similar to the here described oncoids, an environmental dependance, comparable with K. Dahayanake could not be confirmed.

M. RAMALHO (1971) described Oxfordian/Kimmeridgian oncoids from Portugal and subdivided them in stromatolitic structures, oncoids and cyanophycean lumps. The latter show more uniform structures with predominantly birdseyes, possibly comparable to here described Lo-oncoids.

3. MICROFACIES TYPES OF THE BATHONIAN LIMESTONES

Four subfacies-types were differentiated within the widely distributed MF-type 1, all representing deposits of Wilson's facieszone 6 (platform sands). They were distinguished as to their variable contents of components (mainly different types of ooids).

The limestones of MF 1/4 were interpreted as central oolitic shoals, an assumption supported by the occurrence of exclusively R_T -ooids, by their very good sorting and by the low proportion of biogenic components. MF 1/1 and MF 1/2 represent the lateral facies equivalents with mixing of both, shoals and the grapestone facies. MF 1/3 frequently shows resediments of all three other subfacies.

MF 1: Oolitic facies

MF 1/1: Oopelsparites with T_R -ooids — grain/packstones (Pl. 1, fig. 2).

The most frequent components are T_R -ooids, followed by micritic ooids, ooids of the bahamite-type, broken and distorted ooids together with grapestones. The biogenic components are recrystallized bivalves, fragments of echinids and rare occurrences of *Dictyoconus cayeuxi* LUCAS.

Though altered by neomorphic processes, an epitactic overgrowth of sparitic crystals is indicated by coarse blocky cements. Broken, partly distorted ooids and detached ooid lamellae indicate an early diagenetic compaction. A younger cement generation was formed below the detached lamellae and was subsequently leached out again, creating a conspicuous secondary porosity.

MF 1/2: Oopelsparites of the mixing zone — grainstones (Pl. 1, fig. 5).

Strongly micritized T_R -, R_T -ooids and peloids occur; micritic and oolitic intraclasts are of subordinate importance. Foraminifera of «type 1» *Textularia* sp., *Involutina* sp., *Placopsilina* sp. occur together with *Tubiphytes obscurus* MISIK, and fragments of porostromate algae. Larger bio-clasts were derived from bivalve shells and fragments of echinids.

Within the neomorphic-sparitic groundmass, radial fibrous dog-teeth cements and gravitatively reinforced faser

cements could be observed. Thin limonitic crusts occur together with brownish epigenetic dolomitrhomboeders. Both are parts of the matrix cements.

MF 1/3: Conglomeratic oointrasparites — grainstones.

The composition of the components and neomorphic-sparitic groundmass are the same as MF 1/2. Here additionally well rounded clasts (several centimeters in diameter) occur, which contain the reworked component-assemblages of MF 1/1 and 1/2.

MF 1/4: Oopelsparites — grain/packstones (Pl. 1, fig. 3, 4).

The main constituents are ooids of the R_T -type together with peloids, intraclasts and detrital quartz. They are together with textulariids and miliolids, *Reophax* sp. and with rarely echinid fragments. The primary intergranular spaces (sometimes with geopetal internal sediments), were filled with dolosparitic cements.

MF 2: Intrapelmicrites with fenestral fabrics — bindstones (Pl. 1, fig. 1)

This faciestype with laminated fenestral fabrics in composed of micritic components, mostly algal peloids. Besides R-ooids, fragments of mollusc shells and few foraminifera were found. The laminated fabric is due to dark micritic layers of sediment-binding algal structures. Both peloidal sediment and algal laminites are interrupted by vertical dessiccation fissures and variable forms of birdseye structures. According to many authors (e.g. SHINN, 1983), this type of sediment was formed in shallow subtidal/supratidal environments, corresponding to facies zone 8 — restricted circulation shelf and tidal flats (WILSON, 1975).

MF 3: Grapestonefacies

MF 3 was deposited in calm waters of the shallow subtidal, and interfingers with zones of more agitated water of MF 3/2. Here the high diversity of organisms, the lack of R-ooids and the predominance of sparitic interparticular fabrics indicate a normal marine deposition.

MF 3/1: Intrapelmicrites with quiet water ooids — bindstones.

Peloids and light grey extraclasts are the main constituents of this subfacies. They occur in a micritic matrix which is partly altered to a microsparitic texture. Few grapestones and algal lumps occur. Nearly all components are surrounded by radial-oolithic cortices of the same type as known from the R-ooids.

Fragments of echinids, gastropods and *Cayeuxia* sp. are very rare.

MF 3/2: Intrapelsparites with *Bacinnella*-oncoids — bind/grainstones (Pl. 1, fig. 7).

Grapestones and lumps prevail within a micritic matrix, occurring together with R-ooids and extraclasts, T_R -ooids, superficial ooids, and *Bacinnella*-oncoids. Concerning the fossil content, a high diversity and a great number of individuals characterizes facies 3/2: Foraminifera «type 1», «type 2», *Haplophragmoides* sp., *Dictyoconus cayeuxi* LUCAS, *Textularia* sp., *Verneuilina* sp., *Involutina* sp., sessile forms and undeterminable litooids occur together with porostromate algae, different types of *Cayeuxia* sp., and *Bacinnella irregularis* RADOICIC, *Thaumatoporella parvovesiculifera* RAINERI, *Tubiphytes obscurus* MISIK. Bioclasts of molluscs,

bryozoans, echinids and ostracodes furthermore contribute to the sediment.

The former micritic groundmass is partly washed out. Vadose silts and coarse drusy neomorphous sparites indicate that freshwater vadose diagenesis was active.

MF 4: *Pelmicritic facies*

MF 4/1: Oncopelmicrites with bioclasts — wackestones.

Peloids, diagenetically altered R_T-oids R-oids, M-oids, micritic intraclasts and lithoclasts (composed of oncoids and ooids) occur. Among the oncoids types I-VI were formed (fig. 4). The following biota were found: *Reophax* sp., textulariids, verneuiliids, trochamminids, involutinids, *Placopsilina* sp., foraminifera «type 2», *Haplophragmoides* sp. Besides them cyanophyceans, microproblematica such as *Tubiphytes* sp., Problematicum A and *Favreina* sp. occur. Ruditic bioclasts consist of molluscs, brachiopods and echinids.

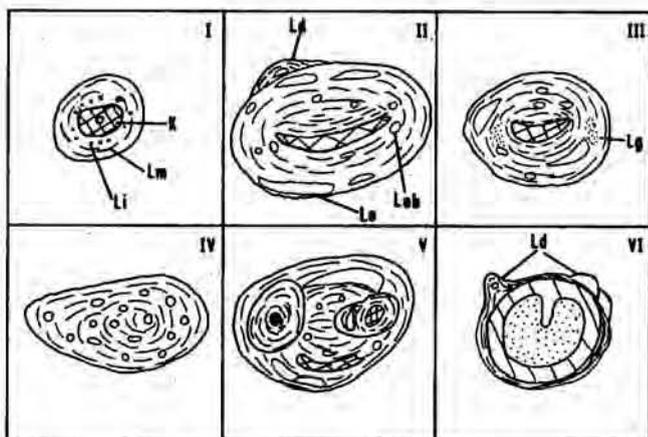


Fig. 4 — Sketches of the oncoid-types I-VI; abbreviations stand for: K = nucleus, Lm = laminae, Lo = birdseye-structure, Lob = blistery lamina, Lg = granular lamina, Ld = domelike biogenic overgrowth, Li = limonitic particles

The micritic to microsparitic groundmass is penetrated by a network of stylolithic seams, from which fine limonitic concretions start.

MF 4/2: Biopelmicrites — wackestones.

The most frequent components are peloids followed by foraminifera: «type 1», «type 2», *Reophax* sp., *Haplophragmoides* sp., textularians, verneuiliids, *Dictyoconus cayeuxi* LUCAS and lituolids, *Nodosaria* sp. and *Lenticulina* sp.

The pelmicritic groundmass can hardly be distinguished from that of MF 4/1: here more authigenic quartz was found, and the participation of oncoids is much lower.

MF 4/3: Oncopelmicrites — wackestones.

Besides micritic oncoids, peloids and aggregate grains which are the main constituents, only rare organisms — textulariids, gastropods and echinids were found.

The groundmass is micrite with subordinate sparite; vadose silts were observed.

MF 4/4: Algal pelmicrites — bindstones.

These rocks are made up of peloids, intraclasts, aggregate grains, *Cayeuxia* sp., *Thaumatoporella* sp. and gastropods.

Echinids, bryozoans and foraminifera (textularians, lituolids) are of subordinate significance.

Many primary structures were overprinted by a strong dolomitization, which made classification very difficult.

MF 4/5: Oncopelsparites — grain/packstones (P, 1, fig. 6).

This type is characterized by *Bacinella*-oncoids (types I-VI), peloids, intraclasts and coated grains on the one hand and by foraminifera (clast of *Dictyoconus*, textulariids, lituolids) on the other. Gastropods are the most important nuclei of the oncoids.

A neomorphically altered microsparite forms up the groundmass. It is interspersed with molds which were refilled with vadose silt. Authigenic quartz is very frequent.

The depositional environment of the sediments of MF 4 is due to unagitated water, comparable to pool-like intraplatform shallow basins, which were described by J. KUSS (1983) from Upper Triassic carbonates in the Northern Limestone Alps.

4. DISTRIBUTION OF THE ORGANISMS

The distribution of biomorpha is of subordinate significance with regard to the microfacial subdivision of the Bathonian section, as they do not exceed more than 3-7% of the total volume. However some characteristic associations enable a better interpretation of paleoecologic differences. The distribution of organisms is listed in Tabs. 1 and 2; the following derivations are possible:

— Organisms as a whole show low to moderate diversities. The most important components are foraminifera, echinids, molluscs, algae and microproblematica.

— Agglutinated lituolids and textulariids predominate among the foraminifera. There are only rare miliolids, which indicate shallow shelf environments. Few nodosariids only occur within MF 4/1.

— Echinids occur in nearly all MF-types with changing values. They also occur together with authigenic quartz which were possibly formed within lagoonal/evaporitic environments. The mixing of stenohaline and hypersaline particles is explained by the close facies-interfingering with rapid lateral and vertical changes.

— Concerning the extreme hypersaline conditions the gastropods are more resistant than lamellibranches. The conspicuous predominance of gastropods (i.e. MF 3/2, 4/3, 4/5) could be interpreted as an indication of a deterioration of living conditions.

— Both porostromate and spongiostromate algae can be differentiated. Among the porostromata *Cayeuxia* sp. exclusively occur as allochthonous fragments. Spongiostromata often occur together with microproblematica. They have their widest distribution within the grapestone facies and the loferites.

— Dasycladaceans do not occur except few single fragments of *Clypeina* sp. and *Terquemella* sp.; they were described as typical shallow water indicators from different rethyan Triassic, Liassic and Upper Jurassic localities (FLÜGEL, 1982). The almost complete absence of this group in the area investigated reflects the general scarcity of dasycladacean algae within Dogger sediments (BASSOULET *et al.*, 1978).

Three microproblematica were additionally described from Bathonian limestones, that could not be compared with others:

Tab. 1 — Distribution of the most important components, biota and sedimentological data which were taken into consideration for the classification of MF-types 1-4

MF-types components	1.1	1.2	1.3	1.4	2	3.1	3.2	4.1	4.2	4.3	4.4	4.5
ooids: T _R	40 %	●	●	—	—	—	—	—	—	—	—	—
R _T	—	13 %	18 %	40 %	—	—	—	10 %	—	—	—	—
M	—	●	●	—	—	—	—	—	—	—	—	—
R	—	—	—	—	—	80 %	10-35 %	●	—	—	—	—
oncoids	—	—	—	—	—	—	●	●	—	●	—	●
aggregate grains	●	●	●	—	—	●	●	●	—	●	—	—
peloids	●	●	●	●	●	●	●	●	●	●	●	●
coated grains	●	●	●	●	—	—	●	●	—	●	●	—
intraclasts	●	●	●	●	—	●	—	●	—	●	●	●
extraclasts	—	—	—	—	—	—	●	—	—	—	—	—
Ammodiscidae ("Type 1")	—	●	●	●	—	—	●	—	—	—	—	●
Reophacidae	—	●	●	●	—	—	●	●	●	●	●	—
Lituolidae: Placopsilina "Type 2"	—	●	●	●	—	—	●	●	●	—	●	—
Textulariidae	—	●	●	●	●	—	●	●	●	●	●	●
Ataxophragmiidae	—	●	●	●	●	—	●	●	●	●	●	●
Orbitolinidae: "Dictyoconus"	●	—	—	—	—	—	●	—	●	—	—	●
Involutinidae	—	●	—	●	—	—	●	●	—	●	●	●
Nodosariidae	—	—	—	—	—	—	—	—	●	—	—	—
not identified foraminifera	●	●	●	—	●	●	●	●	●	●	—	●
foraminifera/9 cm ²	1	13	13	15	3/19	1	20	26	30	13	11	50
Porostromata	●	●	●	—	—	●	●	●	—	—	●	—
Spongiostromata	—	—	—	—	●	●	●	—	—	—	—	●
Clypeina	●	●	—	—	—	—	—	—	●	—	—	—
Terquemella	—	●	—	—	—	—	—	—	—	—	—	—
Thaumatoporella	●	—	—	—	—	—	●	—	—	—	●	—
Bacinella	—	—	—	—	—	—	●	●	—	—	—	●
Tubiphytes	●	●	—	—	—	—	●	●	—	—	—	●
unknown algae	—	—	—	—	—	—	—	●	●	—	—	—
other organisms: bivalves	●	●	●	●	●	●	●	●	●	—	—	—
gastropods	●	●	●	●	—	●	●	●	—	●	●	●
ostracods	—	—	—	—	—	—	—	●	—	—	—	—
bryocoans	—	—	—	—	—	—	●	—	—	—	●	—
brachiopods	—	—	—	—	—	—	—	●	—	—	—	—
echinoderms	●	●	●	●	—	●	●	●	—	●	●	—
Favreina	—	—	—	—	—	—	—	●	—	—	—	—
groundmass	dol.neo- sparit	dol.neo- sparit	dol.neo- sparit	dol.neo- sparit	neospar- partly earlydia- gen. dol.	dd.neo- sparit	dol.neo- sparit	micrit	micrit	micrit	micrit, overprint- ed by dol.	dol.neo- sparit
size of components	f.- m. arenitic	f.- c. arenitic	f.aren- ruditic	f.- m. arenitic	f.aren- nitic	f.- m. arenitic	f.- m. arenitic	f.aren- nitic	f.aren- ruditic	f.aren- ruditic	f.aren- ruditic	f.aren- ruditic
roundness	moderate - good	moderate - good	moderate - good	good	--	good	good	good	--	good	good- moderate	good
texture	grain/ pack- stone	grain- stone	grain- stone	grain/ pack- stone	bind- stone	grain/ pack- stone	grain/ pack- stone	wacke- stone	mud/ wacke- stone	wacke- stone	wacke- stone	wacke- stone

Tab. 2 — Summarized presentation of all determined biota ranging from Bathonian to Kimmeridgian within MF-types 1-9

	BATHONIAN	OXFORDIAN	KIMMERIDGIAN
Foraminifera:			
Ammodiscidae: "Typ 1" sp. indet.	X		
<i>Tolypammina</i> sp.	X	X	X
Reophacidae: <i>Reophax</i> sp.	X	X	X
Lituolidae: "Typ 2" cf. <i>Haplophragmoides</i> sp.	X		
<i>Nautiloculina oolithica</i> MOHLER		X	X
<i>Pseudocylammina</i> sp.	X	X	X
<i>Anchispirocyclina lusitanica</i> EGGER			X
<i>Haplophragmium</i> sp.		X	X
<i>Placopsilina</i> sp.	X	X	X
Textulariidae: <i>Textularia</i> sp.	X	X	X
Ataxophragmiidae: <i>Verneuilina</i> sp.	X		X
Trochamminidae: div. sp.	X		
Orbitolinidae: " <i>Dictyoconus</i> " <i>cayeuxi</i> LUCAS	X		
Nubeculariidae: <i>Nubecularia</i> sp.		X	X
<i>Ophthalmidium</i> sp.		X	X
<i>Nodophthalmidium</i> sp.		X	X
Miliolidae: <i>Quinqueloculina</i> sp.		X	X
div. sp.	X	X	X
Involutinidae: <i>Involutina</i> sp.	X		
<i>Trocholina alpina-elongata</i> LEUPOLD			X
<i>Trocholina</i> sp.		X	X
Nodosariidae: <i>Nodosaria</i> sp.	X		
<i>Lenticulina</i> sp.	X	X	X
Foraminifera: div. sp.	X	X	X
Porifera: Hexactinellida		X	X
Hydrozoa: <i>Ellipsactinia</i> sp.			X
Anthozoa: <i>Thecosmilia</i> sp.		X	X
div. sp.		X	X
Mollusca: Lamellibranchiata	X	X	X
Ammonoidea: Lamell-Aptychus	X		
Artropoda: Ostracoda	X	X	X
Bryozoa	X	X	X
Brachiopoda	X	X	X
Echinodermata: Crinoidea	X	X	X
<i>Saccocoma</i> sp.		X	X
Holothuroidea	X	X	X
Echinoidea	X	X	X
Serpulida		X	X
Algae:			
Dasycladacea: <i>Clypeina</i> sp.	X		
<i>Terquemella</i> sp.	X		
Cyanophyceae: <i>Cayeuxia</i> sp.	X		
Spongiostromata	X	X	X
Solenoporaceae: div. sp.		X	
Mikroproblematika: <i>Tubiphytes obscurus</i> MISIK	X	X	X
<i>Bacinella irregularis</i> RADOICIC	X		
<i>Thaumatoporella parvovesiculifera</i> RAINERI	X	X	X
Problematikum 2 SENOWBARI-DARYAN		X	X
<i>Baccanella</i> sp.		X	
<i>Favreina</i> sp.	X		

- a) Problematicum A — bowl-like encrustations (Pl. 4, fig. 10, 14). It often encrusts ooids and oncoids, and is formed by a half-moon shaped sparitic dot 50-200 μm in diameter which is embraced by an about 50 μm thick micritic envelope. It might be confused with foraminifers of the *Nubecularia* type. In contrast, Problematicum A yields only a single chamber with a characteristic microgranular wall structure; moreover, it is much larger than *Nubecularia* (occurrence within MF 1,4).
- b) Problematicum B («Kettenalge», Pl. 4, fig. 13): This structure is formed by brick-like elements (40 μm long) which are linked at their small sides, thus forming chains with one above the other. They only appear in sponge-spicule limestones. Their outer shape is reminiscent of bivalve shells, but the described reticulate internal structure is either caused by diagenetic processes or by algal activity.
- c) Problematicum C (Pl. 4, fig. 2): This form consists of micritic/sparitic intercalations with outer diameters of 3-5 mm. No criteria could be found to suggest participation of *Bacinella* sp. and *Tubiphytes* sp.; cyanophytes probably produced these structures. (MF 4/2).

5. SPACIAL RELATIONS AND FACIES MODEL OF THE BATHONIAN MICROFACIES TYPES

All four MF-types are characteristic formations of a shallow carbonate platform. Its distribution is limited to

areas which correspond to Wilson's facies zones 6 to 8. Neither sediments of a platform slope nor of the uppermost inter and supertidal areas were observed. There are no indications of a significant input of terrigenous material. The sediments nearest to the coast are formed by intrapelsparites with fenestral fabrics (Pl. 1, fig. 1) which are flanked seawards by pelmicrites.

At the outer seaward platform side, sedimentation starts with an extended oolitic barrier which can be subdivided with the help of different oolitic types. The following facies types can be traced from the seaward side towards the coast: Oolitic conglomerates with freshwater diagenesis characterizing episodic fluctuations of the sea level. They are interfingering with a mixed-oolitic facies (besides ooids, cortoids, intraclasts and micritized bioclasts occur). Further onto the coast bioclastic pelmicrites were deposited in protected areas of FZ 7. Here oncoïd-bearing pelmicrites with grapestones, quitwater-ooids and porostromate algae were formed within shallow basins and pools.

Different MF-types of facies zone 6-8 interfinger within short vertical distances, documenting rapid facies changes; rhythmic cyclicities of the described microfacies types could not be observed.

The tentative environmental model of fig. 6 is based on both microscopic and field data: the vertical sequence of the Bathonian section (fig. 5) with rapid interfingering of a shallow carbonate platform. The spacial distribution of the described MF-types is sketched (fig. 6).

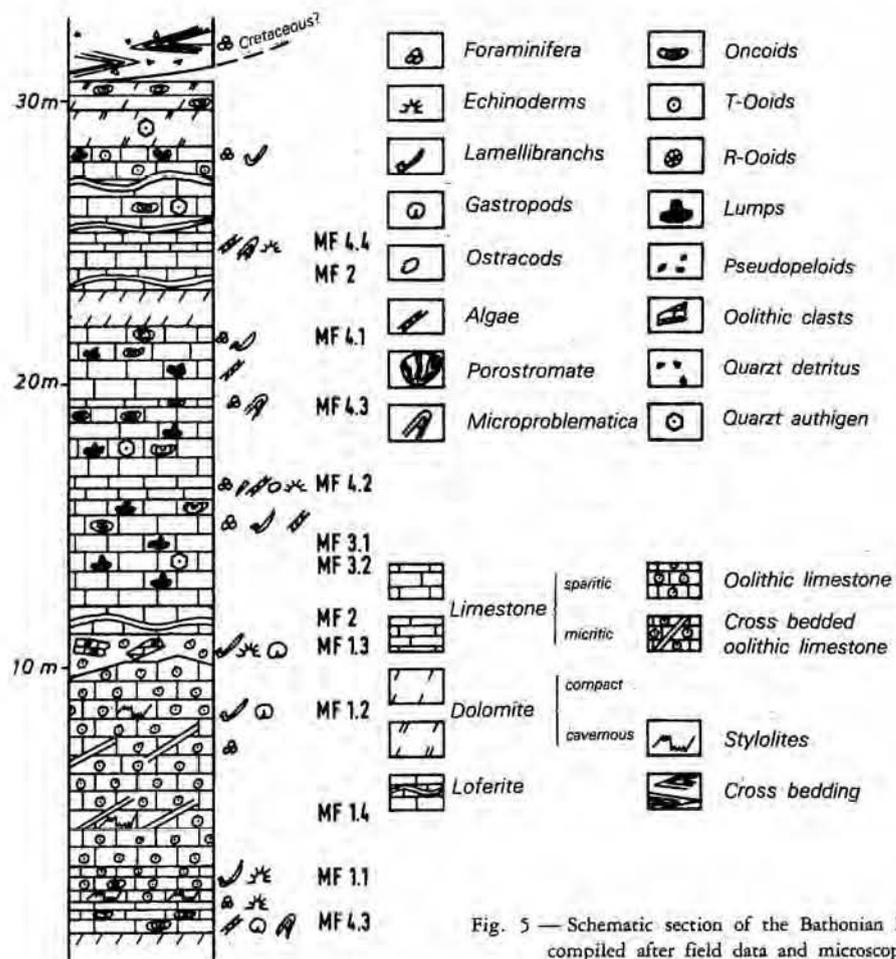


Fig. 5 — Schematic section of the Bathonian limestones north of Faro, compiled after field data and microscopic investigations.

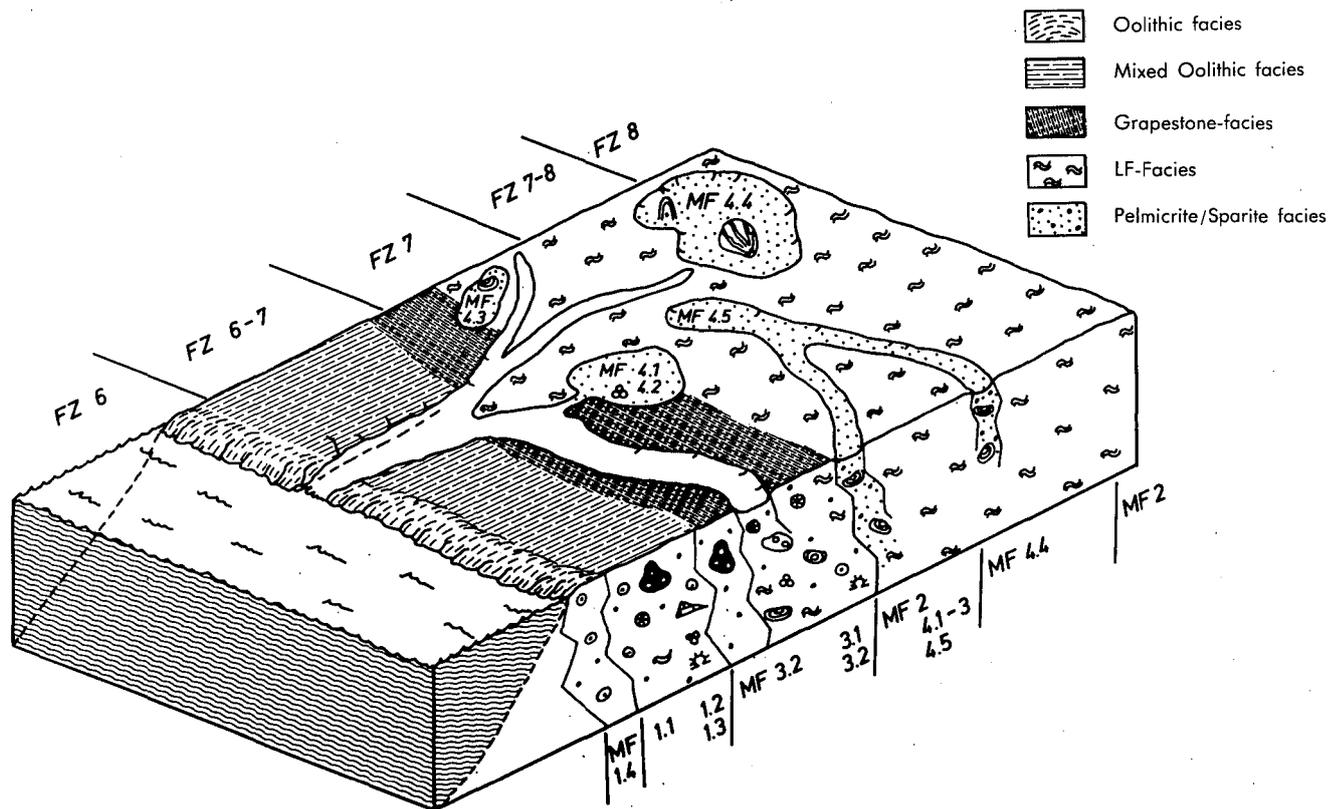


Fig. 6 — Tentative environmental model of the carbonate platform during Bathonian time, showing the close interfingering of the described facies types 1-4 (signatures as fig. 5)

6. MICROFACIES TYPES OF THE OXFORDIAN AND KIMMERIDGIAN

MF 5: *Micrite-dominated pelagic mud-/wackestones* (Pl. 2, fig. 2, 3).

MF 5/1: Intrapelmicrites and dismicrites.

The limestones of the Oxfordian/Kimmeridgian boundary are characterized by pelagic sediments. Several hardgrounds which were encrusted by serpulids are typical at the lower part, whereas rhythmic intercalations of graded grain/packstones (interpreted as allodapic limestones *sensu* MEISCHNER, 1964) characterize the Oxfordian micritic carbonates (Pl. 2, fig. 3).

As regards the fossil content, both are nearly identical: *Reophax* sp., *Placopsilina* sp., *Nubecularia* sp., *Tolypammina* sp., nodosariids and miliolids occur together with filaments, ostracodes, holothurids, crinoids, *Saccocoma* sp., *Tubiphytes* sp., spongiostromata and the finegrained debris of all mentioned organisms.

The turbiditic layers are bedded or graded biointrasparites (grain-/packstones), which show a typical mixture of both shallow marine and deep water elements. The following organisms could be determined: *Haplobragmium* sp., *Nautiloculina oolithica* MOHLER, *Reophax* sp., *Nubecularia* sp., *Tolypammina* sp., *Quinqueloculina* sp., *Lenticulina* sp., together with textulariids, filaments, ostracodes, lamellibranchs, brachiopods, serpulids, echinids (mostly crinoids); fragments of unidentifiable corals and bryozoans occur with *Thaumatoporella* sp. and *Tubiphytes* sp.

Other components are peloids, micritic intraclasts, algal intraclasts, micritic oncoids and oncoids made up of red

algae. All these show bad sorting and roundness, often with grading of those components which are arranged by current processes.

The boundary between autochthonous and allochthonous parts is always very sharp. An erosive cutting of turbidites in form of conspicuous bottom marks is visible at several positions in the section.

MF 5/2: Intramicrites.

They consist of intraformational breccias, which show reworked micritic intraclasts, bedded within a micritic matrix of the same pelagic habitus.

MF 6: *Shallow subtidal and intertidal carbonates*

MF 6/1: Biomicritic boundstones with LF-structures.

Strongly recrystallized biota are encrusted by thick spongiostromate algae, which may also bind sandy particles, forming biosedimentary structures. Several layers of these dark micritic crusts (sometimes with fine lamination), show a conspicuous pattern of fenestral fabrics with oval-elongated birdseyes, which were partly leached out, creating a secondary porosity.

MF 6/2: Red algal oncosparites and micrites, wacke/grainstones (Pl. 2, fig. 5).

Two types of encrustation occur: the oncoids of type II are made up of red algae, which encrust both *Trocholina* sp. and *Nautiloculina* sp.; they are very common within grainstones. The oncoids of the micritic sediments yield fragments of echinids as nuclei, which also occur without encrustations.

The second type consists of co-operating algal and foraminiferal encrustations, forming irregular crusts of several mm thickness. Many biogenic components yield a conspicuous late-diagenetic dolomitization.

MF 7: Reefoid limestones — bound-/rudstones

MF 7/1: Coral bafflestones of the Upper Oxfordian (Pl. 2, fig. 4).

Corals of the *Thecosmilia*-type are the most important constituents, which cannot be determined on species-level because of their strong recrystallization. S. ROSENDAHL (1985) gave a summarizing description of Oxfordian/Kimmeridgian corals from Algarve. The corals are often encrusted by *Tubiphytes* sp., algae and foraminifera (*Nubecularia* sp. and *Tolypammina* sp.). Moreover, the corals and their debris act as substrate for serpulids, bryozoans and *Baccinella* sp. The space between the coral branches has a pelmicritic composition with textulariids, *Nautiloculina* sp., *Quinqueloculina* sp., ostracodes, brachiopods and crinoids.

MF 7/2: Frame-/rudstones of the Kimmeridgian.

They are made up of predominantly reef-detritus; primary framebuilders are hydrozoans (*Ellipsactinia* sp. together with other unidentifiable species) and corals. Both act as substrate for encrustations of bryozoans, *Tubiphytes*/algae-associations, serpulids and sessile foraminifera (*Tolypammina* sp.); the former framebuilders show conspicuous borings and intense recrystallization. The matrix consists of pelmicrite/-sparite with micritic intraclasts and reefoid bioclasts.

The following biota were recognized: textulariids, verneuiliids, *Haplophragmoides* sp., monaxone sponge spiculae, brachiopods, echinid-fragments, very fine networks of red algal knobs, red algae with parallel tubes (70 µm in diameter) and spongiostromate algae. *Tubiphytes* sp. and *Baccinella irregularis* also occur.

MF 8: Biomicrites of Upper Oxfordian/Lower Kimmeridgian — bioclastic wackestones.

MF 8/1: Tuberolithic limestones with sponge spicules (Pl. 2, fig. 9).

Comparable facies types were described from Upper Jurassic limestones from Southern Germany by G. FRITZ (1959), E. FLÜGEL & T. STEIGER (1981) and M. SCHORR & R. KOCH (1986). The main constituents are monaxone spicules of siliceous sponges, fragments of hexactellinids (partly calcified), filaments, crinoids (*Saccocoma* sp.), tuberoids and *Tubiphytes* sp.; textulariids, ophralmiids and encrusting foraminifera are of subordinate significance. The layered texture with thin beds enriched or depleted with bioclasts is sometimes reworked by endobiotic activities.

MF 8/2: Biointramicrite with sponge spicules and echinids-wacke/-packstones (Pl. 2, fig. 7).

Here biodetritus occur together with subangular, micritic intraclasts and peloids. Textulariids, *Reophax* sp., monaxone sponge spicules, bryozoans, crinoids, *Tubiphytes*/algae-associations were observed together with *Problematicum* sp. 2 SENOWBARI-DARYAN and *Problematicum* B.

MF 9: Foraminiferal micrites-mud-/wackestones (Pl. 2, fig. 8).

The following biota are very common within these micrites of the Upper Kimmeridgian: *Anchispirocyclina lusitanica* EGGER, *Nautiloculina oolithica* MOHLER, *Trocholina alpina-elongata* LEUPOLD, *Quinqueloculina* sp.; cryptalgal textures

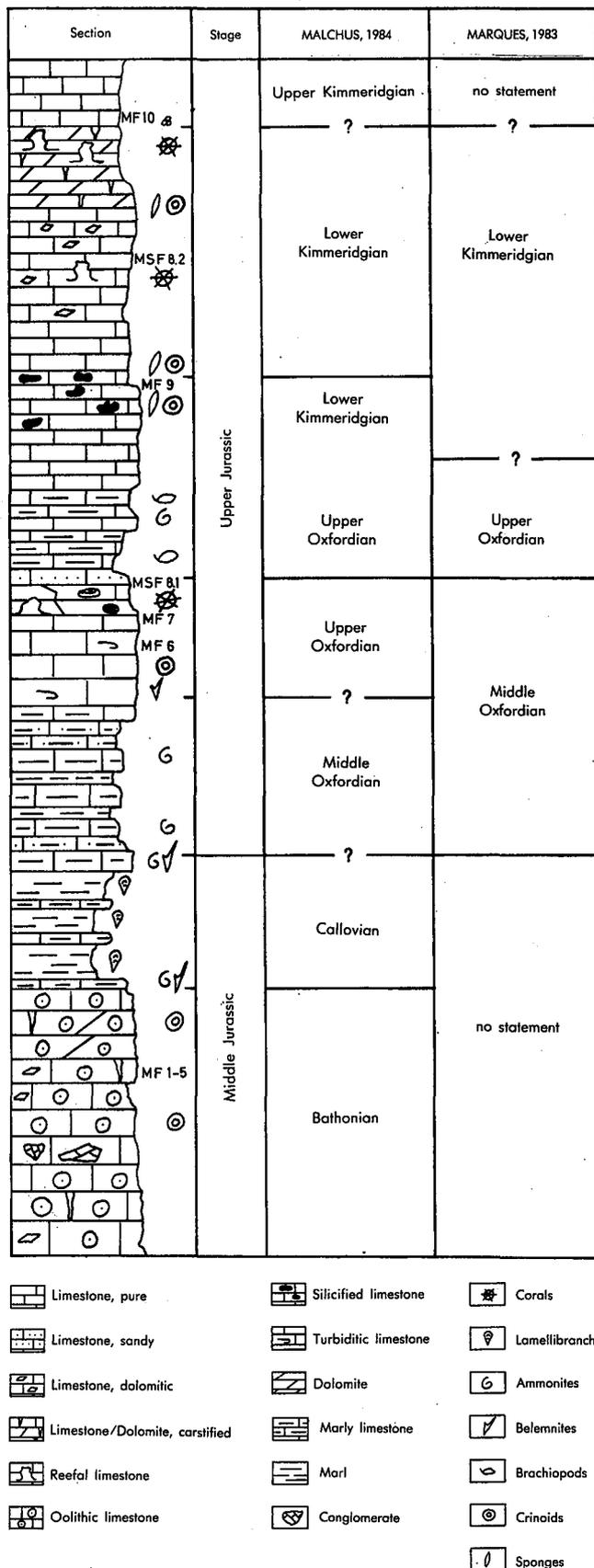


Fig. 7 — Schematic section of the Bathonian-Kimmeridgian sequence. The stratigraphic subdivision is based on own observations on a neighbouring section of B. MARQUES (1983), taken in the area of Moncarapacho. The complete thickness is estimated 300-400 m (signatures see fig. 5)

and shells of molluscs are also present. There are no indicators of pelagic sedimentation.

These sediments were not taken into consideration, though their outcrops connect directly south of the Kimmeridgian reefoid limestones (fig. 2).

All following microfacies types of the Oxfordian/Kimmeridgian sequence (with the exception of MF 5) are characterized by a silicification which took only distinct biota (mainly ostracodes and echinids). This silicification is seen in connection with the deposition of siliceous sponge spicules. A conspicuous silicification is visible within facies 8/1, expressed by cm-thick layered lumps of SiO₂.

7. SUMMARY AND CONCLUSIONS

The different microfacies types of the Bathonian/Kimmeridgian sediments also reflect the lithologic and facial contrasts visible in the field. They were formed by transgressive/regressive fluctuations; at the beginning of the Bathonian an extended carbonate platform (MF 1-4) existed.

The transgressive Callovian sediments constitute a 60 m thick sequence of bituminous greenish/greyish marls and

shales which were not considered in microfacies investigations. Small ammonites, belemnites and many small lamelli-branches (*Bositra* sp.) characterize these sediments.

The transition to the Middle/Upper Oxfordian is marked by a regressive phase with condensation horizons in the western Algarve (ROCHA, 1976), which are overlain by pelagic limestones with filaments and *Saccocoma* sp. They contain turbiditic sediments of MF 5. Micrites and red algal-oncosparites follow above, representing shallow areas (MF 4). They interfinger with small patches and biohermal structures of MF 7/1. The marls above with crinoids, brachiopods and ammonites again indicate a deepening of the sedimentation area.

Sponge-spiculitic limestones were formed at the Oxfordian/Kimmeridgian transition (MF 8). The following regression enabled the settlement of hydrozoan and coral colonies (MF 7/2), which were overlain by micritic deeper water limestones of the Upper Kimmeridgian.

The stratigraphic classification of fig. 7 was possible by comparison with sections, described from Moncarapacho by B. MARQUES (1983).

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**DOCUMENTAÇÃO
FOTOGRAFICA**

PLATE I

Microfacies types of the Bathonian

- Fig. 1 — Intrapelmicrite with birdseye structures of MF 2.
- Fig. 2 — Oopelsparite with T_R -ooids of the central ooid bar (MF 1/1). Freshwater diagenesis is indicated by oomolds and partly dissolved lamellae.
- Fig. 3 — Well sorted oopelsparite with R_T -ooids, peloids, intraclasts and authigenic quartzes of MF 1/4.
- Fig. 4 — Detail of R_T -ooids, the peloidal nucleus is surrounded by a cortex of primary radial needles with a subordinate tangential fabric (MF 1/4).
- Fig. 5 — Oopelsparite of the mixing zone with M-ooids, R_T -ooids, peloids and intraclasts of MF 1/2.
- Fig. 6 — Oncopelsparite with different types of oncoids (MF 4/5).
- Fig. 7 — Partly washed-out grapestone facies with R-ooids of MF 3/2.

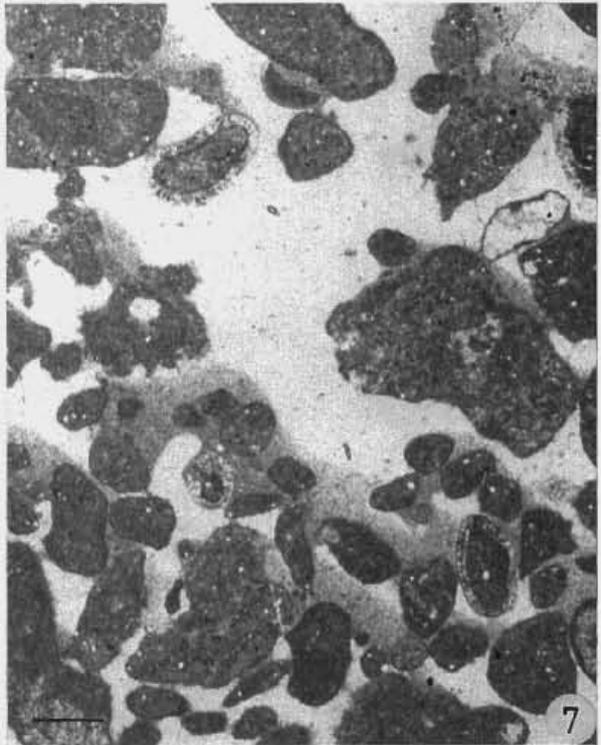
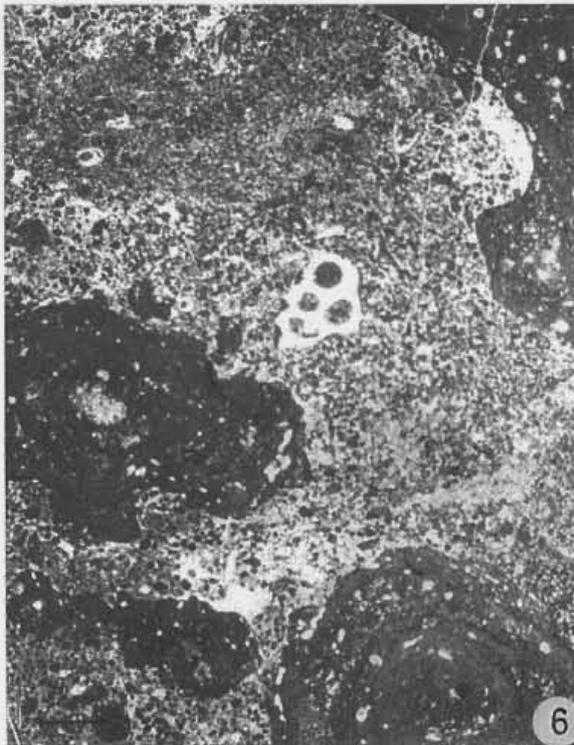
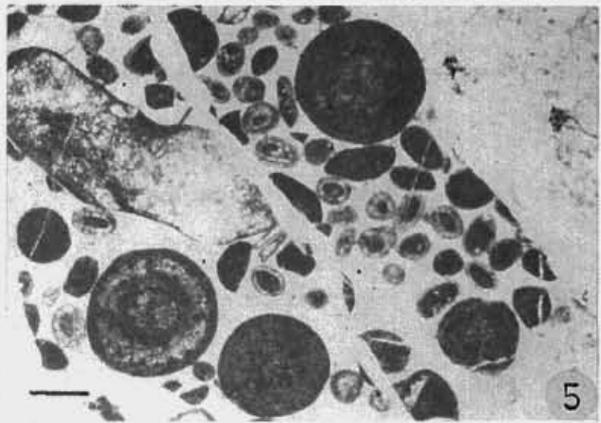
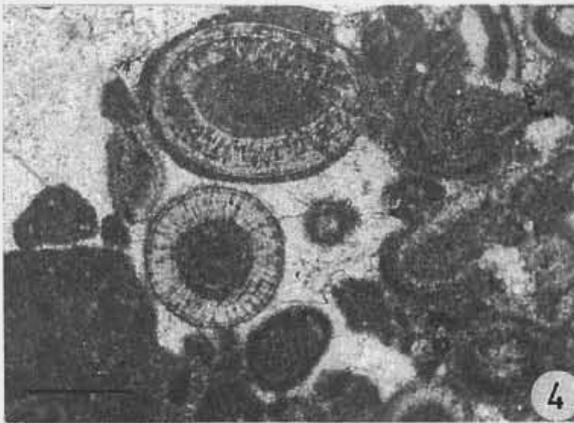
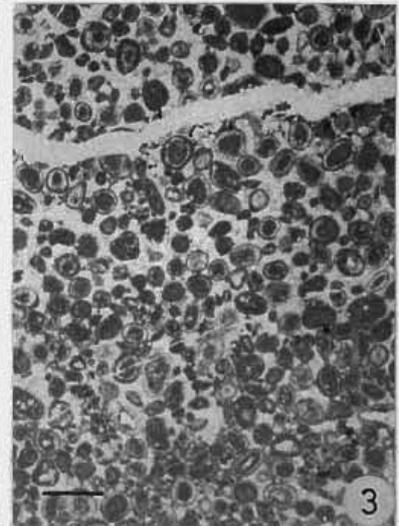
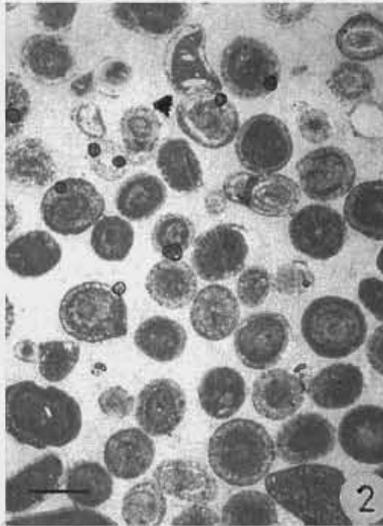
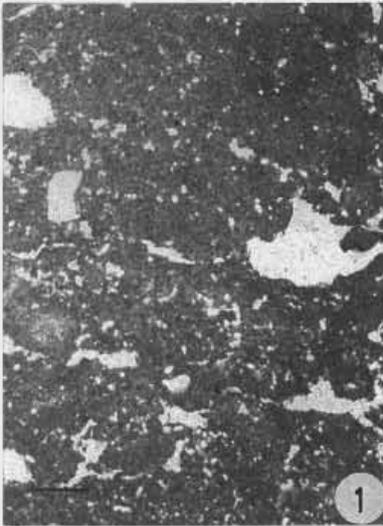


PLATE II

Microfacies types of Oxfordian and Kimmeridgian

- Fig. 1 — Framestone of Kimmeridgian age with different sections of *Tubiphytes obscurus* MASLOV, representing MF 7/2.
- Fig. 2 — Magnified view of a turbiditic layer with crinoids, corals, lamellibranchs and cyanophycean-fragments together with *Tubiphytes obscurus* MASLOV, all yielding an unsorted structure of MF 5/1.
- Fig. 3 — Lower part of a turbidite layer cutting with sharp, erosional base into the underlying pelagic micrite, MF 5/1.
- Fig. 4 — Bafflestone with sclerocrinian corals, partly encrusted by algae and *Baccinella* sp., MF 7/1.
- Fig. 5 — Red algal oncomicrite, with bryozoans and echinids as nuclei, MF 6/2
- Fig. 6 — Single oncolite, the encrusting alga shows a fine network and irregularly arranged sparitic tubes.
- Fig. 7 — Biointramicrite with ruditic clasts, grapestones, agglutinated foraminifera, ostracodes and fragments of hexactellinid sponges MF 8/2.
- Fig. 8 — Foraminiferal micrite with *Trocholina* sp. (lower right), *Thaumatoporella* sp. (middle) and different bioclasts of MF 9.
- Fig. 9 — Tuberosolithic micrite with sponge spicules of MF 8/1.

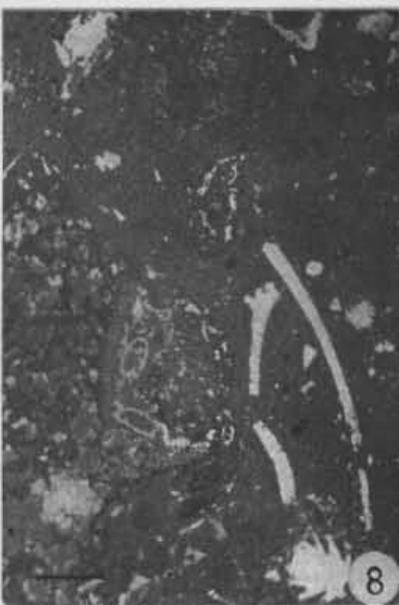
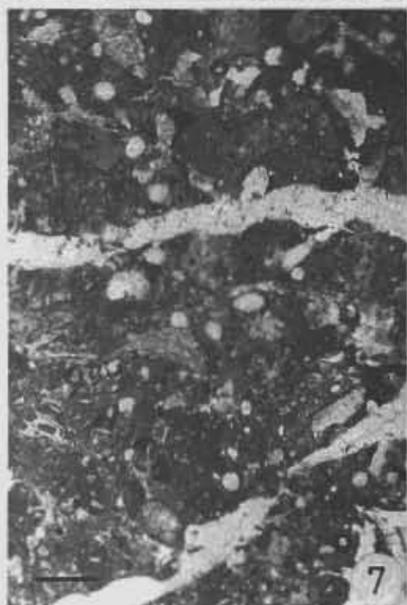
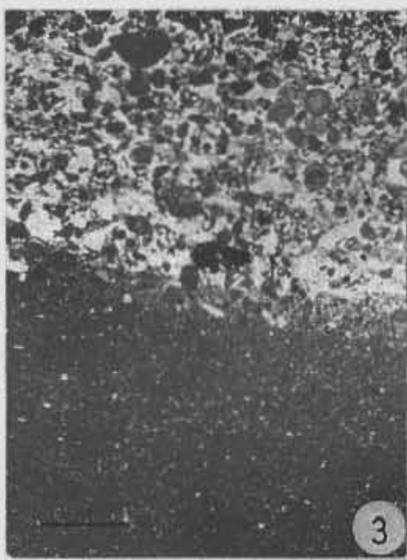
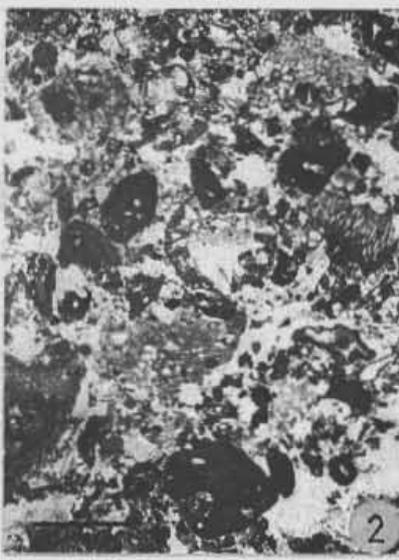
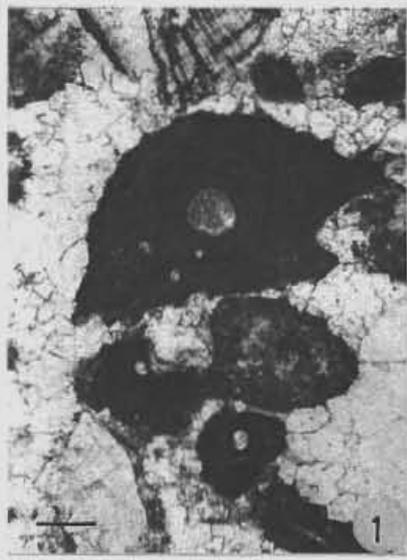


PLATE III

Bathonian foraminifera

- Fig. 1, 2 — Foraminifera of type 1.
- Fig. 3, 4 — Micritized *Involatina* sp.
- Fig. 5 — *Pseudocyclammina* sp.
- Fig. 6 — *Nodosaria* sp.
- Fig. 7 — Encrusting *Planimolata* sp.
- Fig. 8 — *Haplophragmoides* sp.
- Fig. 9 — *Placopsilina* sp.
- Fig. 10 — *Reophax* sp.
- Fig. 11, 12, 13 — *Dictyoconus cayensis* LUCAS.
- Fig. 14, 15 — Foraminifera sp. indet.

Foraminifera of the Oxfordian and Kimmeridgian

- Fig. 16 — *Nubecularia* sp.
- Fig. 17 — *Placopsilina* sp.
- Fig. 18 — *Pseudocyclammina* sp.
- Fig. 19, 20 — *Anchispirocyclina lusitanica* EGGER.
- Fig. 21 — *Nodophthalmidium* sp.
- Fig. 22 — *Nantiloculina oolitica* MOHLER.
- Fig. 23 — *Quinqueloculina* sp.

Bathonian algae

- Fig. 24, 25, 26 — *Caryocia* sp.
- Fig. 27 — *Clypeina* sp.
- Fig. 28, 29 — *Terquemella* sp.

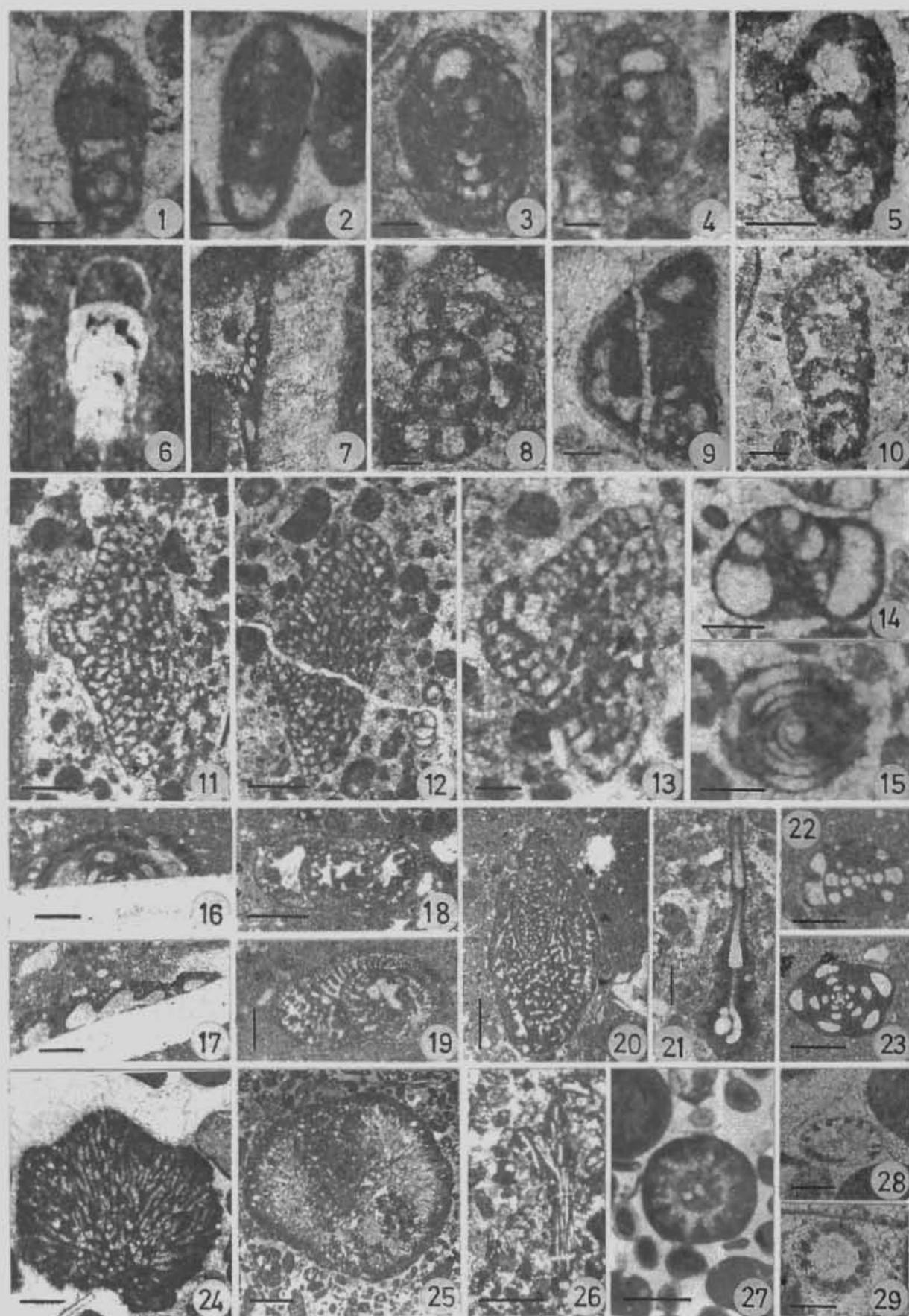


PLATE IV

Different types of oncoids and microproblematica

- Fig. 1 — Oncoid type II, characterized by a single nucleus and laminated, concentric arrangement of sparitic tubes.
- Fig. 2 — Oncoid type V, with different, partly reworked nuclei (themselves encrusted by oncooid crusts of type II).
- Fig. 3 — Oncoid type IV with a central network of large, drusy sparitic eyes in the centre.
- Fig. 4 — Different sections of *Tubiphytes obscurus* MASLOV within an extraclast.
- Fig. 5, 6 — *Bacinella irregularis* RADOICIC with typical network structures in detail (fig. 5) and as single clast (fig. 6).
- Fig. 7 — Oncoid type I with a simple micritic coating and concentrically arranged limonitic particles.
- Fig. 8 — Oncoid type II with a micritic cortex and small bubble-like structures. The second encrusting generation consists of dome-shaped encrustation with *Tubiphytes* sp.
- Fig. 9 — Problematicum sp. 2 SENOWBARI-DARYAN.
- Fig. 10, 14 — Problematicum A, characterized by a halfmoon vug and a thick microgranular crust.
- Fig. 11 — Network of *Thaumatopora parvovesiculifera* RAINERI encrusting different clasts.
- Fig. 12 — Problematicum C, consisting of a micritic/sparitic intercalation.
- Fig. 13 — Problematicum B «Kettenalge».

