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# Upper Jurassic (Malm) Shallow-Water Carbonates in the Western Gorski Kotar Area: Facies and Depositional Environments (Western Croatia)

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**Key words:** Upper Jurassic, Shallow-water carbonate facies, Biofacies, Biostratigraphy, Adriatic carbonate platform, Gorski Kotar (Western Croatia).

### Abstract

Shallow-water carbonates in the Upper Jurassic of the Gorski Kotar were deposited on a carbonate ramp, in beach-barrier island-lagoonal and peritidal environments. In the continuous sequence, more than 900 m thick, several facies have been found: (A) low-energy shallow-water wackestones/mudstones of the Lower Oxfordian, (B) high-energy shallow-water grainstones of the Middle Oxfordian, (C) low-energy, above the fair-weather wave-base packstones of the uppermost Oxfordian and transition to the Kimmeridgian, (D) shallowing-upward/coarsening-upward units formed through progradation of beach-tidal bars or barriers over the peritidal deposits of the Kimmeridgian and the beginning of the Tithonian and (E) peritidal shallowing-upward units capped by storm tidal deposits of the Tithonian and beginning of the Berriasian.

Fossil assemblages adapted to the environmental changes: maximum of their abundance, in the number of the taxa, as well as in the number of individuals, corresponds to the high-energy facies B (Oxfordian), while their minimum corresponds to the peritidal shallowing-upward units of facies E (Tithonian).

## 1. INTRODUCTION

Until recently, the facies characteristics, as well as depositional environments, of the Upper Jurassic (Malm) sediments in the Gorski Kotar area (Fig.1) have not been investigated in much detail, and there are few published reports on this topic. There are papers dealing with their paleontological and stratigraphic (biostratigraphic) characteristics, in which the description of lithological characteristics of Malm deposits are also given. These papers refer mostly to the eastern part of the Gorski Kotar area, more specifically to Mt. Velika Kapela (POLJAK, 1944; NIKLER, 1965; GUŠIĆ, 1969; MILAN, 1969; VELIĆ & SOKAČ, 1974; VELIĆ, 1977). Malm facies in western Gorski Kotar have remained almost untouched; some data can be found in a few regional geological papers (SAVIĆ, 1973; SAVIĆ & DOZET, 1985; TIŠLJAR & VELIĆ, 1991).

The analysis of the above mentioned papers, as well as our own field studies, have led us to recognize two main depositional systems in the Malm of Gorski Kotar (Fig. 2), i.e.:

(1) **a peritidal and beach-barrier island-lagoonal system** in the western part, and

(2) **a deeper water lagoonal system** of below fair-weather wave-base facies with reefal and peri-reefal facies, mostly in the eastern and southeastern part of Gorski Kotar.

The recognition of the two facies groups was the reason for this investigation in the western Gorski Kotar. This was chosen because the Malm in that area is rather poorly known, though surprisingly good outcrops (undisturbed sequences) occur NE of Rijeka, on the slopes of Mt. Platak. Moreover, the present day geographical position of the Malm outcrops is very suitable for correlation with the well investigated, corresponding Malm facies in Istria and adjacent areas.

The second facies system, i.e. the deeper lagoonal(?), below fair-weather wave-base and shoreface facies, known under the name of the Lemeš facies (well bedded limestones with nodules and/or intercalations of chert, ammonite shells and radiolarians), together with the reefal-perireefal facies in the eastern and southeastern Gorski Kotar is much more complicated and also, because of intensive tectonic disturbances, much more difficult for facies reconstructions. The investigations carried out this far have confirmed the succession consisting of the deeper water Lemeš deposits overlain by reefal-perireefal facies. Today we can speak with some certainity about the lateral position, which is characterized by gradual progradation of reefal-perireefal clinoforms toward the deeper water Lemeš deposits (Fig. 2). Such relationship certainly presents a challenge for further research, in spite of unsuitable field conditions (poor outcrops, intense tectonics). Detailed facies analysis and elaboration of mutual relationships of these Malm facies systems is yet to come.

The first, peritidal and beach-barrier island-lagoonal system, has been rather well stratigraphically investigated in the Gorski Kotar area. On the basis of the microfossil assemblages subdivision into four biostratigraphic units has been established (VELIĆ & SOKAČ, 1974, 1978; VELIĆ, 1977).

***Salpingoporella sellii* Zone** corresponds to the Lower Malm (Oxfordian and lowermost Kimmeridgian). It is characterised by the following forms: *Salpingoporella sellii* (CRESCENTI), *Gryphoporella*

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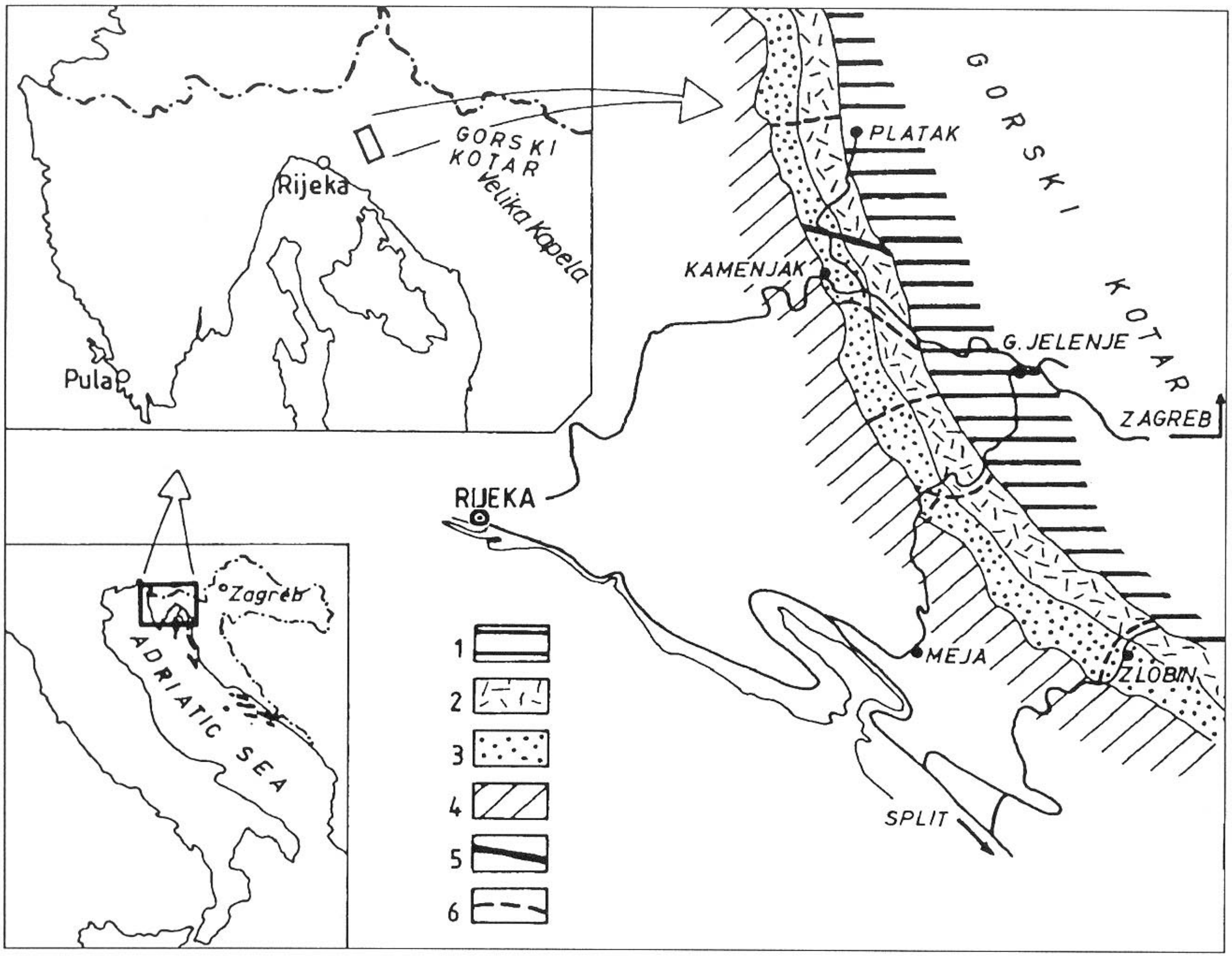



Fig. 1 Location map and geological sketch-map of the Platak-Jelenje area in the western Gorski Kotar. Legend: 1 - Middle Jurassic (Dogger); 2 - Oxfordian and Lower Kimmeridgian; 3 - Upper Kimmeridgian and Tithonian; 4 - Lower Cretaceous; 5 - the Kamenjak - Platak section; 6 - other Upper Jurassic sections in the area.

*minima* NIKLER & SOKAČ, *Kurnubia palastiniensis* HENSON, *Labyrinthina mirabilis* WEYNSCHENK, *Chablaisia chablaisensis* (SEPTFONTAINE), *Trocholina* gr. *alpina-elongata* (LEUPOLD), *Nautiloculina oolithica* MOHLER, etc.

***Heteroporella anici* Zone** in the Middle Malm (lower part of the Kimmeridgian) is characterised by an assemblage: *Heteroporella anici* (NIKLER & SOKAČ), *Pseudoclypeina cirici* RADOIČIĆ, *Kurnubia palastiniensis*, *Conicokurnubia orbitoliniformis* SEPTFONTAINE, *Alveosepta jaccardi* (SCHRODT), *Parurgonina caelinensis* CUVILLIER et al., etc.

Upper Malm (Upper Kimmeridgian and Tithonian), i.e. ***Clypeina jurassica* Zone**, has been subdivided into two subzones: the lower one is ***C. jurassica* s. str. Subzone** (Upper Kimmeridgian and the lowermost Tithonian), and the upper one is ***C. jurassica* and *Campbelliella striata* Subzone** (Tithonian). Microfossil assemblages of both subzones are predominantly algal, characterised by an abundant occurence of *C. jurassica* FAVRE and *C. striata* (CAROZZI), accompanied sporadically with *Kurnubia palastiniensis*, *Parurgonina caelinensis* and other forms of wider stratigraphic range.

## 2. THE POSITION OF GEOLOGICAL SECTIONS

The investigations of the western Gorski Kotar Malm deposits have encompassed the region extending from Zlobin to Platak in the northwest. The best outcrops are situated along the roads Zagreb-Rijeka, Jelenje-Meja and Kamenjak-Platak (Fig. 1).

Uninterrupted successions along the Bogdin ridge and the Kamenjak-Platak road have been analyzed in detail and the bulk of the results presented in this paper come from these profiles. No significant tectonic disturbances have been recorded there, which would otherwise have distorted the total thicknesses measured of the Malm deposits. Here and there minor faults have been recorded, but because of measurable throws they do not affect the continuity of the deposits. This is supported by a normal succession of the fossil assemblages characteristic of the Malm of the shallow-water Mediterranean Jurassic.

The normal succession from the underlying Upper Dogger deposits is marked by a gradual transition from thick-bedded (1-2 m thick) Callovian mudstones into somewhat thinner bedded (0.4-1 m thick), very dark coloured, kerogen-rich, fossiliferous mudstones and

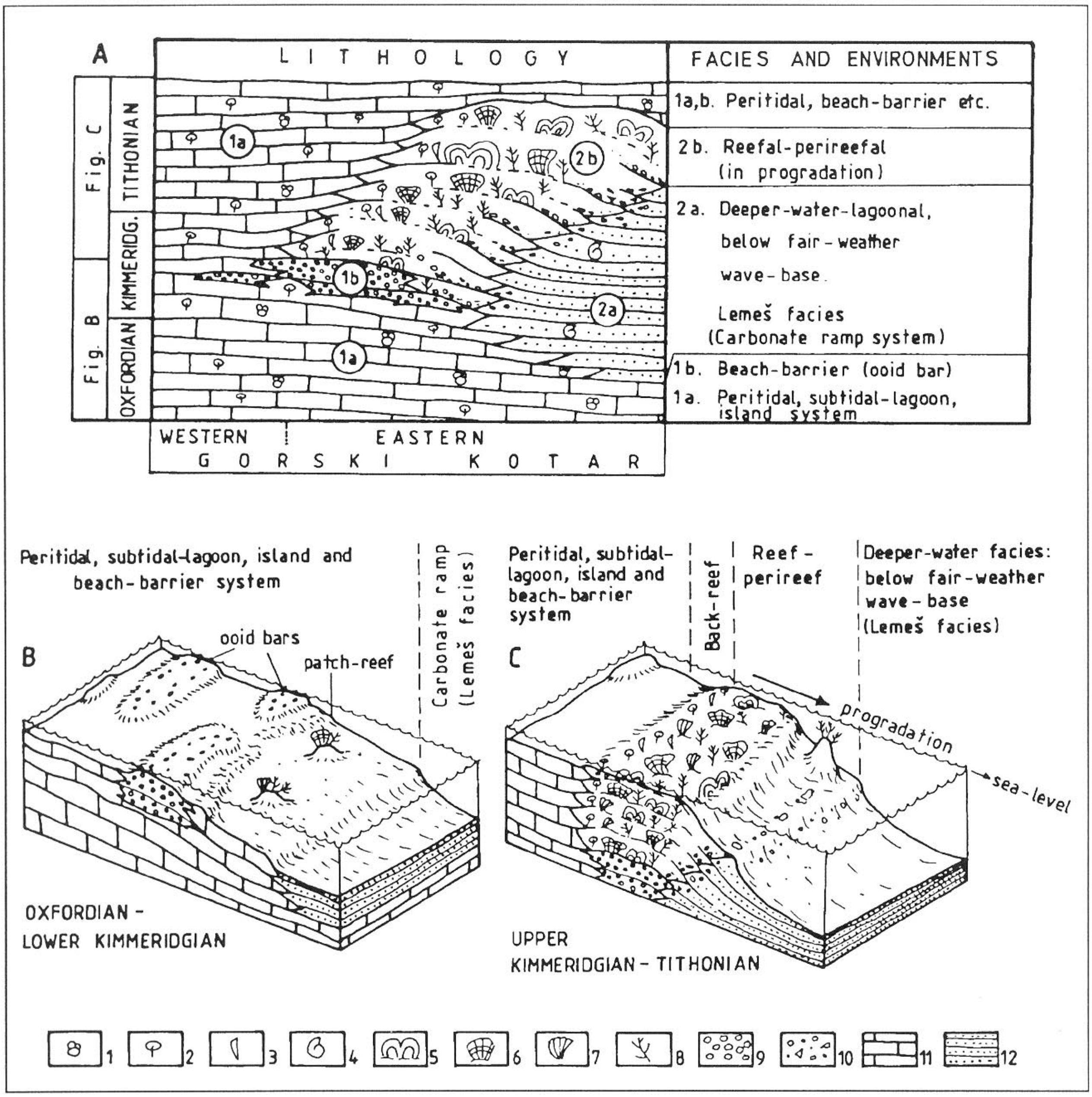



Fig. 2 Geological column of the Upper Jurassic carbonate facies and paleoenvironments in the Gorski Kotar area. Legend: 1 - foraminifera; 2 - algae; 3 - molluscs; 4 - ammonites; 5 - spongiae; 6 - hydrozoans; 7 - stromatoporoids; 8 - corals; 9 - ooid sand; 10 - bio- and lithoclasts; 11 - peritidal, subtidal-lagoon limestones; 12 - carbonate ramp facies.

wackestones of Oxfordian age. On the other hand, the transition to the overlying Lower Cretaceous beds does not show any significant sedimentological differences and cannot be clearly established by means of sedimentological criteria. The boundary has been defined on the basis of micropaleontology, within a succession of beds consisting of shallowing-upward cycles, that mark the terminal Malm (Tithonian) and the beginning of the Lower Cretaceous (Berriasian).

## 3. MALM FACIES OF THE WESTERN GORSKI KOTAR AREA

Five facies units have been distinguished within the Malm carbonates of western Gorski Kotar, each possessing distinct lithofacies, biofacies, and sedimentary features which originated under recognizable conditions and in specific sedimentary environments. These units are as follows (Fig. 3): A - Thick-bedded mudstone and wackestone facies; B - Bioclastic floatstone and grainstone/rudstone facies; C - Oncoid and pelletoid limestone facies; D - Shallowing-upward limestone facies; and E - Shallowing-upward, storm beds and vadose deposits facies.

In the investigated deposits, representatives of various fossil groups have been found. Among macrofossils, only skeletal debris occur, i.e. heavily abraded bioclasts, and most frequently of such a small grain size, that any more detailed, generic or specific, determination is impossible. These include coral, bivalve, gastro-

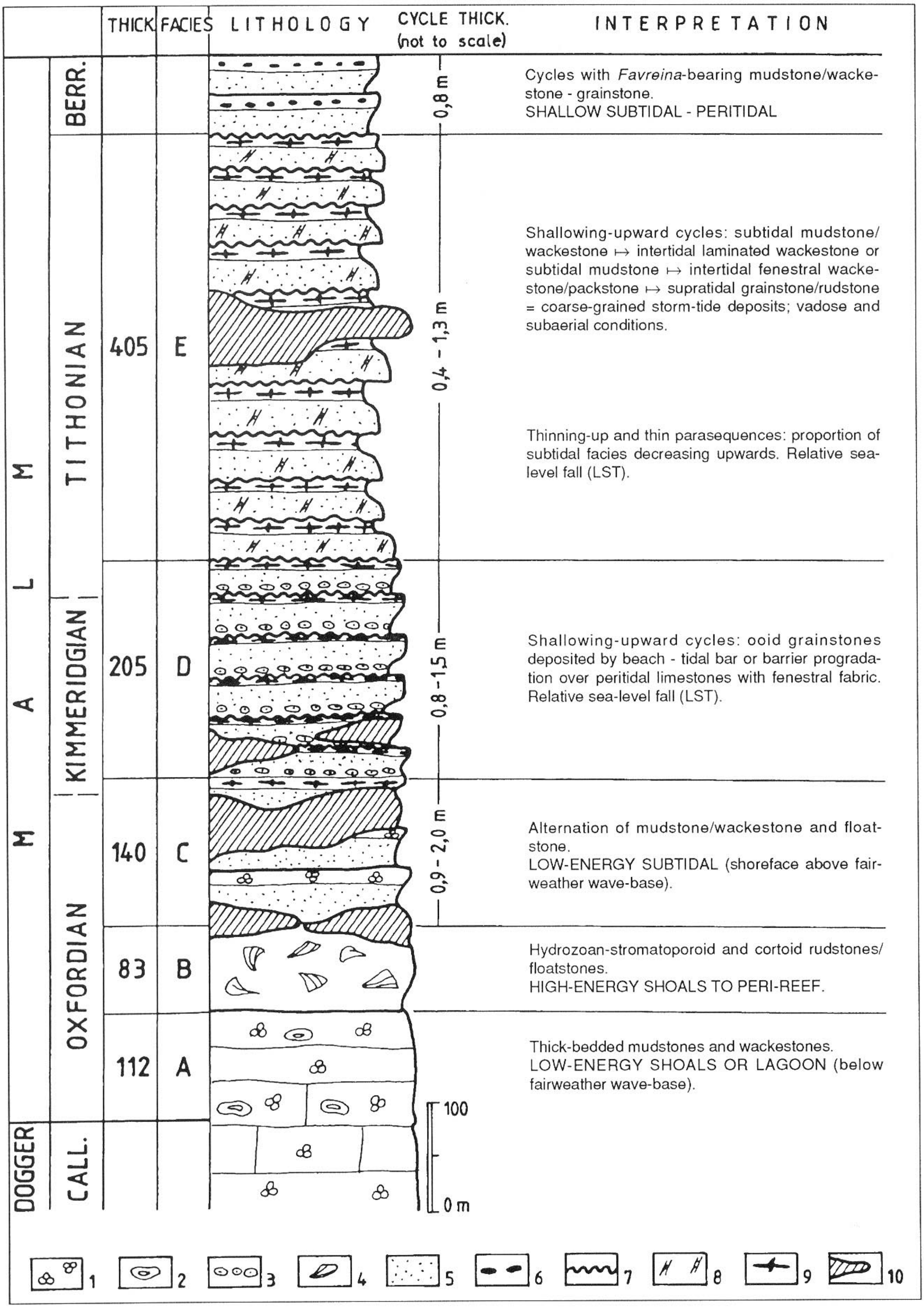



Fig. 3. Lithofacies column of the Gorski Kotar Malm carbonates. Legend: 1- benthic forams; 2 - oncoids; 3 - ooids; 4 - hydrozoan-stromatoporoid bioclasts/cortoids; 5 - pellets; 6 - carbonate clasts; 7 - erosion surface; 8 - green algae; 9 - fenestral fabric and/or intertidal features with erosion surfaces; 10 - late-diagenetic dolomites.

pod, echinoid, hydrozoan, stromatoporid, bryozoan, green algae and other debris. Therefore the emphasis of palaeontological and biostratigraphical research was on microfossil assemblages, of which benthic foraminifera and, to a lesser extent, calcareous algae, make the dominant components.

## 3.1. FACIES A: THICK-BEDDED MUDSTONES AND WACKESTONES

### 3.1.1. Lithofacies

Thick-bedded mudstones and wackestones belong to the oldest Malm sediments. Their total thickness amounts to about 112 m (Fig. 3). These are well-bedded (40-100 cm thick), in central part of the unit even thick-bedded to massive (60-200 cm thick), dark grey mudstones and, more rarely, wackestones, which in the upper part of the unit are characterized by frequent mudstone-wackestone to floatstone alternations. These limestones, rich in carbonate mud, are sporadically of a spotted appearance, due to selective late diagenetic dolomitization. Beside the carbonate mud, i.e. micrite, the dominant components are more or less numerous benthic foraminiferal tests and peloids (skeletal and/or peloid wackestones), and more rarely algal oncoids (wackestones/floatstones). Sporadically they contain also gastropod bioclasts, small-sized bioclasts and skeletons of green algae, and remains of cyanophyte filaments(?) with comparatively thick micritic envelopes. In the upper part of the unit, sporadically occur hydrozoan bioclasts and cortoids (*Cladocoropsis*), as well as cortoids of thin-shelled bivalves and echinoids. There are allochthonous carbonate skeletal components in these deposits and they make the gradual transition from these facies unit into the facies unit "B".

### 3.1.2. Biofacies

Biogenic constituents of the facies A include skeletal debris of corals, bivalves, gastropods, hydrozoans, echinoids, bryozoans, ostracodes, and algae, as well as tests of small benthic foraminifera. There is an increase in the amount of skeletal debris from older into younger deposits, so that the amount of hydrozoan and algal debris is higher in upper layers (Fig. 4).

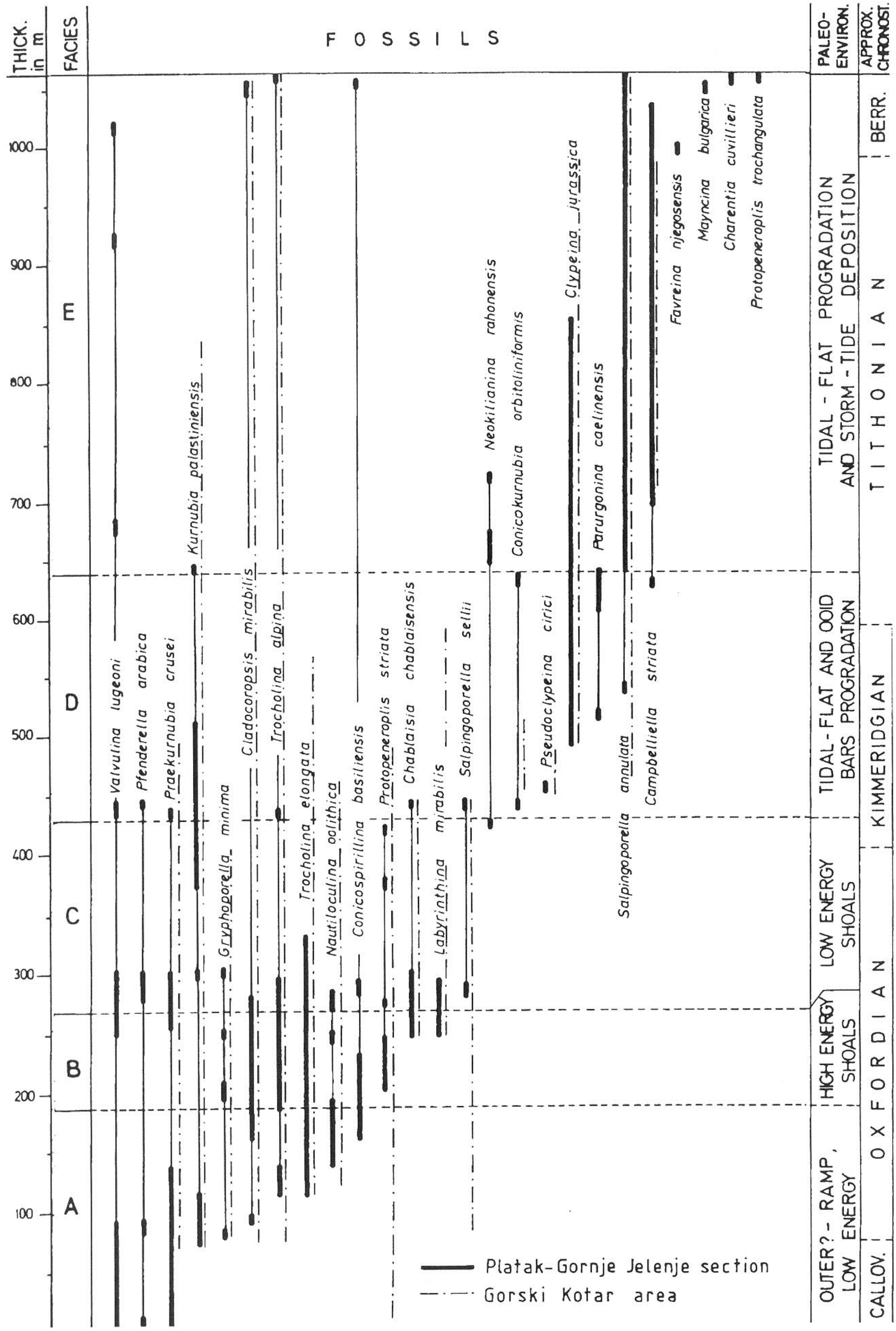
The microfossil assemblage consists predominantly of the foraminifera. *Pseudocyclammina lituus* (YOKOYAMA), *Siphovalvulina variabilis* SEPTFONTAINE, *Pfenderella arabica* REDMOND, *Valvulina lugeoni* SEPTF., and *Praekurnubia crusei* REDMOND are "inherited" from the Dogger. Foraminiferal species that appear for the first time in that facies include *Kurnubia palastininesis* HENSON, *Trocholina elongata* (LEUPOLD), *T. gigantea* PELISSIE & PEYBERNES, *T. alpina* (LEUPOLD), *Nautiloculina oolithica* MOHLER, *Conicospirillina basiliensis* MOHLER, and *Everticyclammina* sp. Algae are represented by *Bacinella irregularis* RADOIČIĆ, *Gryphoporella minima* NIKLER & SOKAČ, and debris of thaumatoporellas. The hydrozoan *Cladocoropsis mirabilis* FELIX is also present.

The order of appearance of particular taxa and assemblages points to the following biostratigraphic and paleoecologic conclusions:

1. The Callovian-Oxfordian boundary cannot be established precisely; therefore the first 170 m of thickness of the column are considered to represent transitional Dogger-Malm deposits (Fig. 4). This is an interval zone with *P. crusei, P. arabica, V. lugeoni, S. variabilis*, and *P. lituus;* all these species, however, have broader stratigraphic ranges.
2. *Kurnubia palastiniensis* is taken as an unequivocal Malm form; therefore the Dogger-Malm, i.e. the Callovian-Oxfordian boundary is placed immediately below its first appearance. Up to the end of that facies, i.e. through the following 85 m of the succession, the other forms appear (Fig. 4).
3. The facies "A" encompasses the upper part of the Callovian and the lower part of the Oxfordian (Fig. 4). In terms of lithofacies, however, there are no significant indications of changes in composition and the bio-assemblage range at the boundary between the facies "A" and "B".
4. As regards the palaeocology, the environments were predominantly protected and low-energy. Throughout most of the unit, the environment appears deprived of external influence, so that the bulk of the species can be spoken of as being autochthonous (e.g., *Praekurnubia, Kurnubia, Nautiloculina, Pseudocy-clammina).* The appearance of the genera *Trocholina, Everticyclammina* and *Conicospirillina* in the upper part of that facies indicates sporadic influence from more open shoals into the lagoonal and low-energy shoals, particularly because these species, in general, for the first time appear in stratigraphically older deposits, as distinct from here, where they first appear as late as the upper part of the Oxfordian. This is an introduction into the palaeoenvironmental changes which will mark almost the entire next facies unit, "B" (Fig. 4).

### 3.1.3. Depositional environment

The limestones composing the facies unit "A" have all the characteristics of carbonate sediments deposited in low energy shoals in the outer part of the carbonate ramp (outer-ramp?), probably mostly below the fair-weather wave-base, with constant and steady accumulation of sediment in quiet water environment. Sporadically, and particularly in the topmost part of that facies unit, under increased water energy, hydrozoa, echinoid and bivalve bioclasts were brought into the environment. They derived from the neighbouring, agitated water shoals and are the product of destruction of hydrozoan patch reef colonies and from peri-reefal environments on the ramp-margin(?). Such, different environments are the main characteristic of the next "B" facies unit in the Malm of the Gorski Kotar area.


THICK. in m
FACIES
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100
200
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B
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D
E
Valvulina lugeoni
Pfenderella arabica
Praekurnubia crusei
Kurnubia palastiniensis
Gryphoporella minima
Cladocoropsis mirabilis
Trocholina alpina
Trocholina elongata
Nautiloculina oolithica
Conicospirillina basiliensis
Protopeneroplis striata
Chablaisia chablaisensis
Labyrinthina mirabilis
Salpingoporella sellii
Neokilianina rahonensis
Conicokurnubia orbitoliniformis
Pseudoclypeina cirici
Clypeina jurassica
Parurgonina caelinensis
Salpingoporella annulata
Campbelliella striata
Favreina njegosensis
Mayncina bulgarica
Charentia cuvillieri
Protopeneroplis trochangulata
Platak-Gornje Jelenje section
Gorski Kotar area
OUTER?- RAMP, LOW ENERGY
HIGH ENERGY SHOALS
LOW ENERGY SHOALS
TIDAL- FLAT AND OOID BARS PROGRADATION
TIDAL - FLAT PROGRADATION AND STORM - TIDE DEPOSITION
CALLOV.
OXFORDIAN
KIMMERIDGIAN
TITHONIAN
BERR.

## 3.2. FACIES B: BIOCLASTIC FLOATSTONE AND GRAINSTONE/RUDSTONE FACIES

### 3.2.1. Lithofacies

The bioclastic limestone facies follows continuously upwards over the facies "A". Its thickness amounts to about 83 m (Fig. 2). In its upper part, i.e. in the terminal 20 m of thickness, the limestones of this facies unit and the lower part of the "C" unit are heavily late diagenetically dolomitized and altered into massive unbedded dolomite with xenotopic to idiotopic mosaic texture.

The bioclastic limestone facies consists of an alternation of medium (40-60 cm thick) to thick bedded (60-130 cm thick), grey, oncoid-bioclastic floatstone and bioclastic-cortoid grainstone to rudstone, and more rarely also of rhythmical alternations of wackestone, bioclastic-cortoid grainstone/rudstone and/or floatstone. Most frequent are bioclastic and bioclastic-oncoid grainstone/rudstone or floatstone, that consist of bioclasts and/or cortoids of *Cladocoropsis* and other stromatoporoids, and irregular nodular algal oncoids, with drusy calcite cement or micritic matrix in the intergranular pores. The main component in all structural types of these limestones, except in wackestones, is the rather large-sized skeletal debris. Poorly sorted, coated bioclasts or cortoids of hydrozoans (*Cladocoropsis*) and other stromatoporids and bivalves are predominant; echinoid and gastropod bioclasts, as well as algal oncoids, micritized benthic foraminiferal tests, intraclasts, and peloids are less frequent.

### 3.2.2. Biofacies

In the biofacies of this unit, foraminifera are of particular significance, in addition to the already mentioned stromatoporoids, bivalves, gastropods, echinoids and algae (Fig. 4). *Trocholina alpina* and *T. elongata*, which mostly occur in *Trocholina* grainstones, are most common. The bulk of remaining species also keeps occurring from the underlying unit: *Pseudocyclammina lituus, Praekurnubia crusei, Valvulina lugeoni, Kurnubia palastiniensis, Nautiloculina oolithica, Conicospirillina basiliensis, Cladocoropsis mirabilis*. Here however, they are joined by *Protopeneroplis striata* WEYNSCHENK, *Chablaisia chablaisensis* SEPTFONTAINE, and *Labyrinthina mirabilis* WEYNSCHENK, which appear here for the first time. The sole algal species, *Griphoporella minima*, disappears at the end of that unit (Fig. 4).

The above quoted assemblage of the "B" facies, as well as the preceding one, belongs to an Oxfordian age. Speaking of palaeoenvironments and palaeoecology, a gradual transition from protected, low energy shoals and lagoonal environments into environments characterized by clearly pronounced faunal influence from more open parts of the carbonate platform is clearly observable in the basal parts of that unit. Throughout the "B" facies there are indications of increased energy (grainstones/rudstones) and domination of taxa that are not typical of true lagoonal or low-energy environments: *Protopeneroplis, Chablaisia, Conicospirillina*, and, to some extent, *Trocholina*. The presence of *Protopeneroplis striata* is particularly interesting, as it appears only in this unit, i.e. at the middle of the Oxfordian. In other localities on the Adriatic carbonate platform (eastern Gorski Kotar, Mt. Biokovo, environs of Dubrovnik) it appears as early as Bajocian. The Dogger and Early Oxfordian lagoonal and low energy environments in this area obviously have prevented it from appearing near the beginning of its true stratigraphic range. *Chablaisia chablaisensis* was described from the Bathonian-Callovian of the French Prealps (SEPTFONTAINE, 1977), and recorded from somewhat younger deposits, Callovian and Oxfordian of SW France (PELISSIE et al., 1984) and the beginning of the Oxfordian on the Adriatic carbonate platform (Istria, Mt. Velebit). It appears here for the first time as late as middle Oxfordian, when protected lagoonal and low energy conditions and environments ceased to exist.

### 3.2.3. Depositional environments

The Facies "B" limestones are typical examples of bioclastic carbonate sediments deposited on a carbonate platform in high-energy shoals, in which large quantities of fossil debris, transported by waves and tidal currents, is being accumulated. This debris derives from the destruction of colonies of hermatypic (reef-building) organisms, that inhabited the normal salinity agitated water shoals in the form of patch reefs or larger or smaller reefs. Frequent occurrences of bioclasts of reef building organisms associated with carbonate mud, i.e. the occurrences of floatstones and wackestones within the grainstones/rudstones that predominate, indicate sporadic oscillations in water energy and current directions. Individual beds of bioclastic and/or oncoidal rudstones with more or less clearly expressed graded bedding and hummocky cross stratification (HCS) show storm-bed characteristics. That is, the concentration of large bioclasts and oncoids (rudstones/grainstones) occurred as a result of storm waves generated by high-energy currents on the shoreface, whereas the concentrations of bioclasts and carbonate mud (floatstones/wackestones) are due to decreased water energy and took place during periods in which the deposition of small-sized debris from suspension was more and more pronounced, because in strong storms the water had received large quantities of carbonate mud from peritidal shoals and possibly also from adjacent protected shoals.

The rhythmical alternation of wackestone and bioclastic grainstones/rudstones is probably more a result

Fig. 4. Microfossil range-chart in the Malm of the Platak-Gornje Jelenje section and of the Gorski Kotar area.

of periodic alternations of low- and high-energy water periods than of sea level oscillations and, in connection with that, possible changes of depositional environments. During low water-energy periods, in the shoreface type shoals, the deposition of carbonate mud and small-sized skeletal debris predominated, whereas during the periods of increased water energy large quantities of bioclasts and cortoids, as well as oncoids and intraclasts, were brought into this environment from the adjacent agitated water shoals and patch reef or from the peri-reefal environment.

## 3.3. **FACIES** C: ONCOIDAL AND PELLETAL LIMESTONES

### 3.3.1. Lithofacies

The oncoidal and pelletal limestone facies has a thickness of about 140 m and sharp contacts with the "B" and "D" facies (Fig. 3). It is characterized by light grey and grey coloured, well bedded (30-80 cm thick), at places even thick-bedded (100-150 cm thick), oncoid and pelletoid limestones, which are commonly late diagenetically dolomitized. Within the 15-20 m thick packages of dolomites with xenotopic to hypidiomorphic mosaic structure, individual relics or intercalations of the "C" facies limestones, more or less spared from dolomitization, can be found (Fig. 3).

The main characteristic of that facies is the alternation of limestone belonging to two different structural types. This alternation is mostly regular, thus producing recognizable cycles. Most commonly, mudstone occurs as the first, lowermost, member of these cycles and wackestone with benthic foraminifera and peloids, or wackestone to floatstone with benthic foraminifera, pellets, and algal oncoids as the second member. More rare are cycles in which the first member consists of foraminiferal-pelletal wackestone/packstone, and the second member of the rhythm consists of bioclastic-oncoid grainstone/rudstone to produce coarsening-upward cycles.

Wackestone/packstone consist of more or less homogeneous micritic matrix, which in places is recrystallized into microsparite, and of included micritized benthic foraminifera, peloids, algal oncoids, which sometimes can even amount to dominant component (oncoid wackestone/packstone), further on, faecal pellets, and weakly-coated bivalve, gastropod and green algae bioclasts. Individual limestone layers are bioturbated, with mostly vertical to subvertical burrowing traces.

Grainstone/rudstone, which occur as the second member of the coarsening upward cycles, contain algal oncoids (algal balls, cyanoids, composite oncoids, micritic oncoids), abraded bivalve and gastropod bioclasts, cortoids, intraclasts with micritic, pelmicritic, and oncosparitic structure, benthic foraminifera, and, locally, green algae (Dasycladaceae, Codiaceae). The sorting of bioclasts, oncoids, and intraclasts is poor. In intergranular pores, mosaic drusy calcite cement is developed, and locally variable amounts of micritic matrix can be present.

Frequently, there are grainstones and rudstones that, in addition to the drusy calcite cement, along the grain surfaces also show thin rims of early diagenetically precipitated submarine calcite cement with beach rock characteristics.

In the upper part of the "C" facies unit, the limestones are more or less intensivelly late diagenetically dolomitized. In cases where the dolomitization is not complete, all gradual transitions from pure limestones to selectively dolomitized limestones to pure dolomites with hypidiotopic and/or xenotopic mosaic structure can be found within the dolomites or dolomitized limestones. The selective dolomitization is most frequent in the wackestones and packstones: the micritic matrix is usually completely dolomitized (xenotopic, hypidiotopic or idiotopic mosaic dolomite), whereas the oncoids, bioclasts, peloids and other grains have remained, as a rule, unaltered or are only partly dolomitized. However, there are also large masses of dolomite with xenotopic to hypidiotopic mosaic structure in which only sporadically, mostly visible only in thin-sections, small, uncompletely dolomitized relics of the facies type "C" limestones can be found.

### 3.3.2. Biofacies

The biofacies of the "C" unit is characterized by small amounts of megafossil skeletons and skeletal debris and significant changes in the microfossil assemblage in the transition to the "D" facies (Fig. 4).

The benthic foraminifera are represented by "standard" forms known from earlier deposits: *Pseudocyclammina lituus, Praekurnubia crusei, Valvulina lugeoni, Pfenderella arabica, Kurnubia palastiniensis, Trocholina alpina, Conicospirillina basiliensis, Protopeneroplis striata*, and *Chablaisia chablaisensis*. The hydrozoan species *Cladocoropsis mirabilis*, that had been continuously present in older deposits, is completely absent in that unit, which is the result of palaeoecological changes. *Trocholina elongata, Nautiloculina oolithica*, and *Labyrinthina mirabilis* have been identified only in the lower parts of that unit, but because in adjacent areas they occur as late as Tithonian (BUKOVAC et al., 1974), their absence in the upper part of that facies unit, as well as in the younger units, can be explained by local palaeoecological circumstances and their migration to ecologically more suitable habitats.

Throughout the vertical range of that facies unit, *Salpingoporella sellii* (CRESCENTI) is present (Fig. 4). In the shallow-water Mediterranean Jurassic, especially in the Dinarides, this species is considered to be the index species of the Lower Malm (SARTONI & CRESCENTI, 1962; NIKLER & SOKAČ, 1968; GUŠIĆ, 1969; VELIĆ & SOKAČ, 1974; CHIOCCHINI & MANCINELLI, 1977; VELIĆ, 1977).

The composition of the microfossil assemblages as described above defines the Oxfordian age of the "C" facies unit. The somewhat lesser abundance of the forms characteristic of more open platform environments agrees with the sedimentological interpretation of the sedimentary environment, i.e. mostly protected shoals and/or lagoons.

### 3.3.3. Depositional environments

Generally speaking, the limestones making up the "C" facies unit belong the shallow-water carbonates deposited in low energy, shallow, subtidal environment (shoreface above fair-weather wave-base and/or lagoon). The rhythmical alternation of wackestone/ packstone with grainstone/rudstone is mostly the result of changing water energy, as it was explained in more detail within the "B" facies unit, and to a lesser extent of sea level oscillations and the progradation of bars. A certain shallowing influence is, however, evident also in the youngest part of the "C" facies unit. This shallowing is manifested by sporadical occurrences of the shallowing-upward cycles and frequent occurrences of fenestral fabric, dissolution vugs, and molds of shells in the top parts of the wackestones and packstones. This was a consequence of the action of the meteoric water upon the deposits that were brought into the low subtidal or intertidal zone. Afterwards they were buried under the carbonate sand deposits brought by waves and tidal currents which formed tidal bars of small thickness and local extension. This youngest part of the "C" facies unit makes a gradual transition into the "D" facies unit.

## 3.4. **FACIES D**: LIMESTONES WITH SHALLOWING-UPWARD AND COARSENING-UPWARD CYCLES

### 3.4.1. Lithofacies

The facies of limestones with the shallowing-upward and coarsening-upward cycles (facies "D") follows continuously upon the "C" facies unit. Its total thickness amounts to about 205 m (Fig. 3). The main sedimentological characteristic of that facies is the more or less clearly expressed rhythmic series of cycles consisting of three members with different composition and structure. These cycles show the shallowing-upward and thinning characteristics (TUCKER & WRIGHT, 1990).

The first, lowermost, member of the cycles is usually ooid grainstone, more rarely ooid-bioclast-intraclast grainstone to rudstone. The second one is a pelletal or oncoid wackestone or peloid-oncoid floatstone, while the third, upper member of the cycles, is the pelletal and/or oncoid wackestone/floatstone with fenestral fabric and locally with vadose features (Fig. 5). Besides such complete cycles, shallowing-upward cycles composed of only two members frequently occur. The members developed may be the second and the third or the first and the second, respectively. Sometimes, also, cycles composed of two members that instead of ooid-grainstone contain oncoid-bioclast-intraclast grainstone/rudstone, i.e. lacking the ooids, can be found.

In the lower part of the "D" facies unit, the late diagenetic dolomitization with similar relationships and structural characteristics as in the "C" facies unit frequently occurs (Fig. 3).

Grainstones, that occur as the first member of the shallowing-upward cycles, are often composed only of well-sorted ooids or crushed and regenerated ooids and drusy calcite cement (Fig. 6). Locally they show clear cross-bedding, and more rarely small-amplitude wave ripples. Ooids belong mostly to the ooids with radial microstructure and to crushed and regenerated ooids (Fig. 6). Microcrystalline cement is regularly precipitated in the intergranular pores between the ooids and the surface of the ooids is lined with early diagenetic fibrous-to-bladed crust or circumgranular crust cement (beach rock).

Some ooid grainstone beds, particularly in the lower part of bed, contain ooids that, by their internal structure and general relationship in the rock, are similar to the reworked vadose ooids or pisoids (pisoids reworked from the top of the third member of the cycles).

The upper part of the same thick-bedded ooid grainstones contains mold-ooids and early meteoric leaching oids, i.e. oomoldic and vuggy porosity.

Ooid grainstones are often affected by selective late diagenetic dolomitization: the cores of whole and/or crushed and regenerated ooids are usually dolomitized, whereas the ooid coatings and calcite cement in the intergranular pores are much less, or not at all, dolomitized.

Beside the ooid grainstones, there are commonly grainstones to rudstones that contain peloids and/or well rounded and very well-sorted micritic intraclasts, ooids with tangential microstructure, and bioclasts or micritic intraclasts with green algal skeletons (*Clypeina*), large algal oncoids (usually "composite oncoids") and benthic foraminiferal tests. Judging by their shape, dimensions and internal structure peloids indicate that they may have originated by complete micritization of the ooids. The grain surfaces are usually coated with early diagenetic cement, and in the intergranular pores the mosaic calcite cement has been precipitated so that the rocks assume structural characteristics of the beach rocks.

The wackestone and floatstone, that occur as the second members of the cycles, consist of carbonate mud - micritic matrix - and variable amount of small-sized (0.1-0.4 mm) pellets /peloids, more rarely micritized benthic foraminifera, algal oncoids, green algae bioclasts (*Clypeina*), and gastropods. Algal oncoids belong, as a rule, to micritic oncoids developed by cyanophycean encrusting processes, i.e., cyanophycean bushes. More rare are so called "spongy oncoids" and calcified cyanophycean aggregates or cyanoids (RIDING, 1983), while the C-type oncoids ("concentrical oncoids" of FLÜGEL, 1982) are extremely rare. The algal oncoids are mostly larger than 2 mm (floatstones).

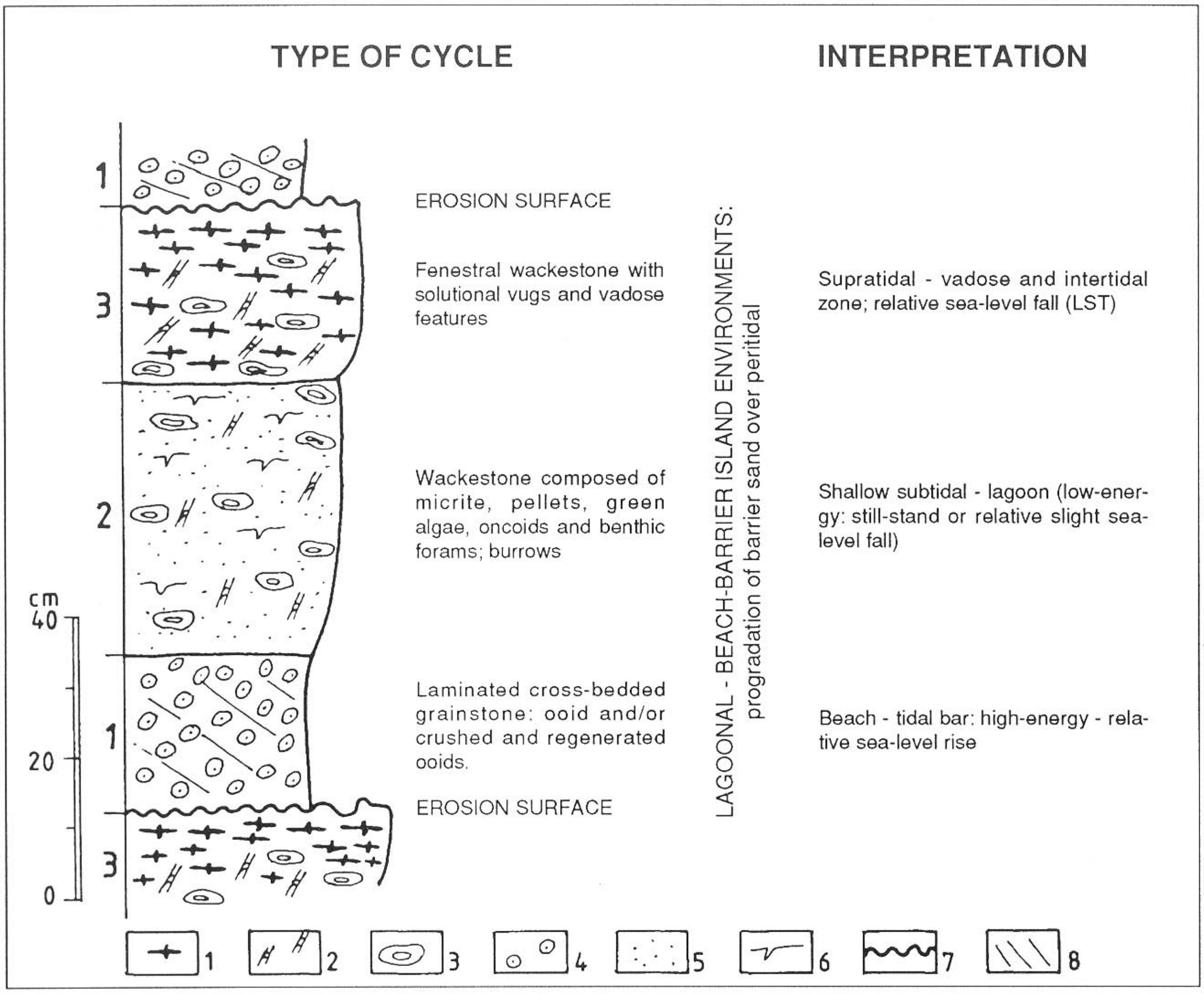



Fig. 5. Schematic model showing the basic type of the shallowing-upwards cycle of the Platak - Gornje Jelenje Malm carbonates ("D" facies). Legend: 1 - fenestral fabric; 2 - green algae; 3 - oncoids; 4 - ooids; 5 - pellets; 6 - burrows; 7 - erosion surface; 8 - cross-bedding.

The wackestones and floatstones with fenestral fabric (the third or, in the cycles consisting of only two members, the second member of the cycles) have the same composition as the above described wackestones and/or floatstones that make up the second members of the cycles, with the notable difference that they contain numerous irregular or laminoid fenestrae (Fig. 7), solution vugs, and molds of gastropod shells and green algae skeletons, and locally vadose ooids or pisoids and other vadose features. Laminoid fenestrae (= elongated fenestrae, parallel to bedding and lamination planes) and irregular fenestrae, as well as solution vugs and molds of shells, are locally roofed by precipitated gravitational or microstalactitic (vadose) cement and the remaining, larger, part is filled with drusy calcite cement. Solution vugs and molds of shells are locally, particularly in the upper part of beds, so numerous that the micritic matrix shows a "cloudy" or "brecciose" structure. That is, the wackestone or floatstone has a breccia-like appearance, as being composed of irregular micritic "fragments" (= undissolved part of rock) and sparitic cement vug and fenestral cement. In some cycles, this member contains individual, or accumulated in pockets, vadose ooids (pisoids) and/or intraclasts with pisoid coating. The contact with the first member is erosional, i.e. the third member usually terminates with an erosional plane (Fig. 5).

### 3.4.2. Biofacies

The shallowing upward cycles, which sporadically occur in the top part of the "C" facies unit, become predominant with the onset of the "D" facies. Such environmental and ecological changes have affected also the biofacies: the bulk of the "standard" taxa for habitats in the protected and/or lagoonal environments either disappear or migrate away. Therefore the very beginning of the "D" facies unit is characterized by last occurrences of *Praekurnubia crusei, Pfenderella arabica, Everticyclammina* sp., *Protopeneroplis striata, Chablaisia chablaisensis,* and *Salpingoporella sellii.* The changes did not affect *Kurnubia palastiniensis* and *Trocholina alpina*, whereas *Conicospirillina basiliensis* probably migrates away from these into more suitable environments within the range of that facies unit. From the biostratigraphic point of view, it is important to record the ranges of the two benthic foraminifera,

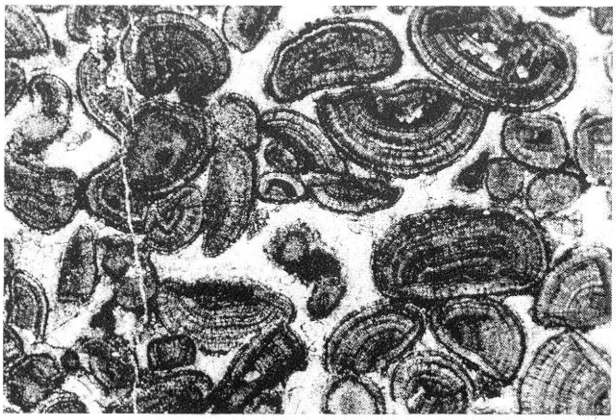


Fig. 6. Ooid grainstone composed of broken and regenerated ooid-sand ooids with radial microstructure. Facies "D" - the first member of the shallowing-upward cycles produced by progradation of ooid bar across tidal flat (thin section GJ-190). Photo lenght=17.5 mm.

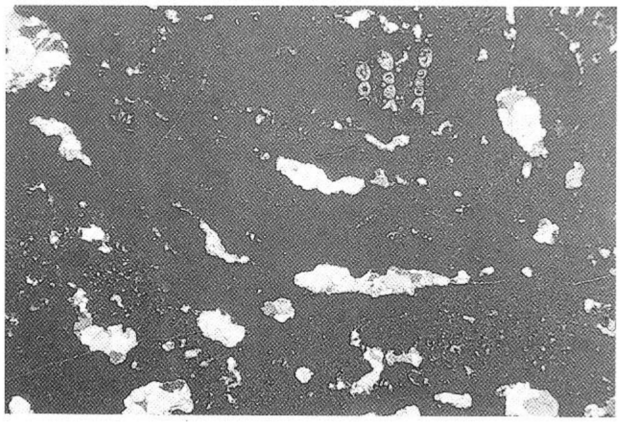


Fig. 7. Fenestral wackestone with *Clypeina jurassica* bioclasts: Facies "D" - the third member of the shallowing-upward cycles (thin section GJ-188). Photo length=7.5 mm.

*Parurgonina caelinensis* CUVILLIER et al., and *Conicokurnubia orbitoliniformis* SEPTFONTAINE (Fig. 4).

The above described relations within the fossil assemblage and the facies changes suggest the supposition that the Oxfordian-Kimeridgian boundary is situated somewhere in the basal part of that unit. The more so, since about 60 m above that, first appearances of *Clypeina jurassica* FAVRE and, somewhat higher up, *Salpingoporella annulata* CAROZZI, are situated, and between these levels *Pseudoclypeina cirici* RADOIČIĆ occurs, the species characteristic of the Dinaride Kimmeridgian (RADOIČIĆ, 1970; VELIĆ & SOKAČ, 1974).

In the upper part of that facies, isolated occurrences of *Amijiella amiji* (HENSON) have been recorded, as well as the first appearances of *Neokilianina rahonensis* (FOURY & VINCENT) and *Campbelliella striata* (CAROZZI), whose stratigraphic ranges extend into younger levels.

Based on the above described composition of the fossil assemblage, the interpretation of the age of the "D" facies unit remains, unfortunately, at the level of indirect inferences, that is, the probability level. The largest part of the "D" unit probably belongs to the Kimmeridgian. This age is indicated by *Conicokurnubia orbitoliniformis, Pseudoclypeina cirici*, and *Neokilianina rahonensis*. Also, the first appearances of *Clypeina jurassica* and *Salpingoporella annulata* fall within that range. On the other hand, the first appearances of *Campbelliella striata* near the end of that unit indicate a Tithonian age. In terms of palaeontology, there are no autochthonous fossils in the "D" facies unit: almost all forms have been brought into that unit subsequently, by tidal currents and/or waves.

### 3.4.3. Depositional environments

The limestones belonging to the "D" facies unit have been deposited in specific circumstances ranging from beach bar to lagoon and intertidal environments, as a result of ooid bar and tidal flat progradation (Fig. 2). The shallowing-upward cycles, i.e. parasequences probably of the fifth order sea-level change, begin with the ooid grainstones, and pass up into the lagoonal mudstones/ wackestones. They are capped by the fenestral tidal flat wackestones with the evidence of subaerial exposure (Fig. 5). The first member of the cycle is ooid-grainstone. Judging by the underlying erosional surface, cross-bedding, and structural characteristics, the ooid grainstones were brought onto the emergent tidal deposits from the adjacent shoals - beaches - with ooid sand bars (or ooid sand barriers) during high tidal waves and storms and/or relative sea-level rise. The bars (barriers?) were constantly changing their position, i.e. they were laterally migrating quickly shoreward over the subtidal and intertidal zone. The high-energy depositional environments of the ooid grainstones is indicated by large percentage of mechanically crushed and regenerated ooids, as well as well rounded and abraded intraclasts and oncoids derived from the reworking of subtidal limestones. Moreover, the high energy environment is indicated by the erosional surface underlying the transported ooids and by total absence of faecal pellets and micritic matrix in the grainstones and rudstones.

Fibrous-to-bladed crusts or circumgranular cements and/or microcrystalline cement indicate early cementation in the intertidal zone, and beach rock cementation in the zone of mixing of meteoric and marine waters. The oomoldic and vuggy porosity of some ooid grainstone beds is developed as a result of meteoric water influx and early meteoric leaching of the ooids.

During the influx of ooids by high tides and waves onto the deposits of the intertidal and supratidal zone that were emergent and subject to vadose diagenesis (the third member of the cycles), along with the fast lateral migration of ooid sand bars (possibly also ooid sand barriers), the high tides and waves were eroding also the subtidal deposits and semilithified sediments of the intertidal and supratidal zones. This explains the origin of the intraclasts, oncoids, and vadoids in the grainstones and rudstones, i.e. the detritus of the first member of the cycles, that contains not only ooids.

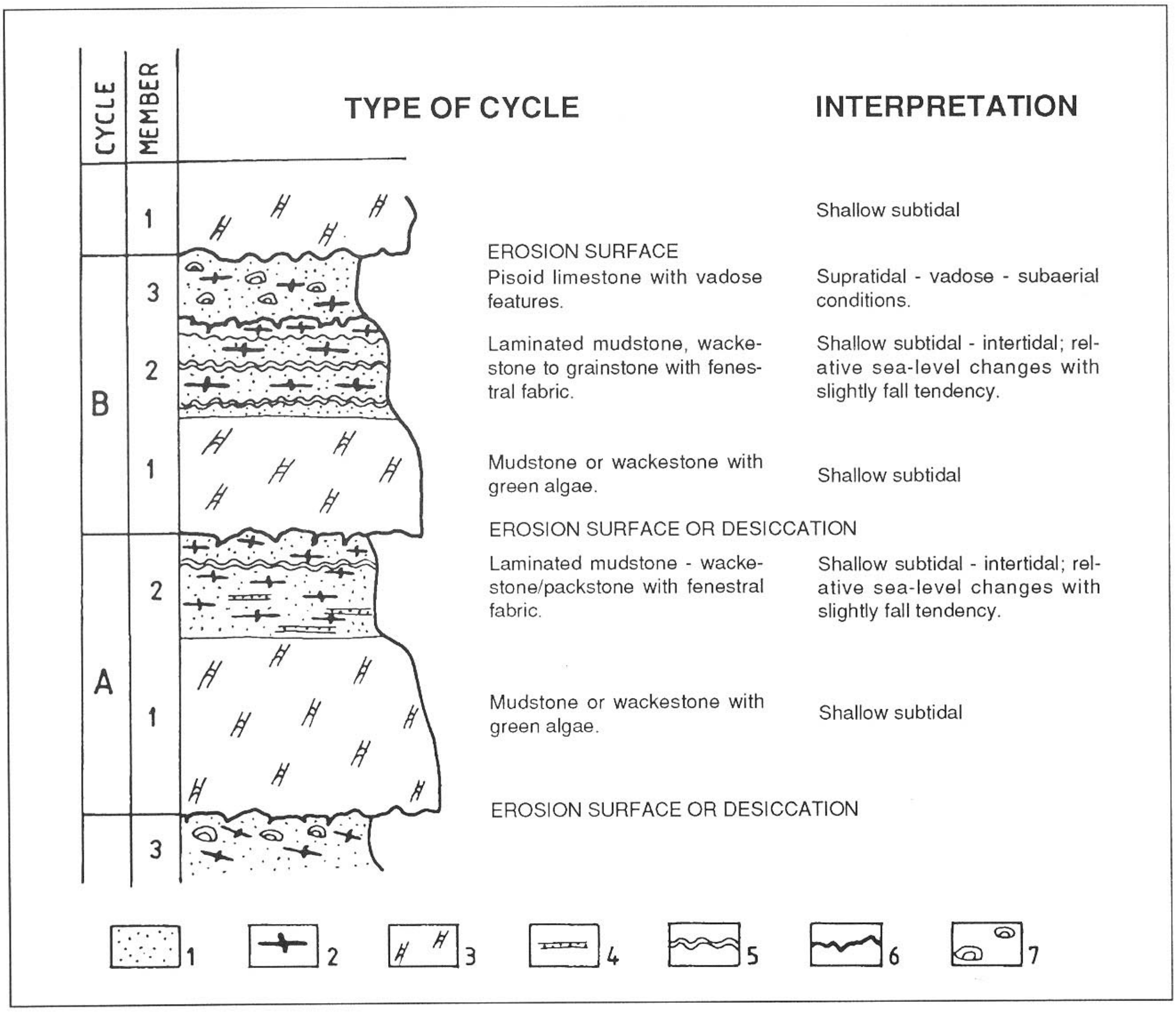



Fig. 8. Schematic model showing the two basic types of the shallowing-upward cycles (fourth/fifth order parasequences) of the Malm carbonates from Platak-Gornje Jelenje area - Facies unit "E". Legend: 1 - pellets; 2 - fenestral fabric; 3 - green algae; 4 - lamination; 5 - stromatolites; 6 -desiccations; 7 - pisoids.

The above described interpretation of the ooid grainstone and intraclastic-oncoid rudstone does not exclude the possibility that thicker ooid grainstone beds with textures and structures typical of foreshore and backshore ooid sand bars, and even ooid dunes, may sometimes be developed. Although our investigations of the western Gorski Kotar area did not reveal such cases - as distinct from western Istria where the grainstone/rudstone tidal-bar facies ("the Muča tidal bar facies" - TIŠLJAR & VELIĆ, 1987) shows all the characteristics typical of the regressive barrier depositional model - they cannot be completely excluded from the interpretation of this area either.

The second member of the cycles - wackestones/floatstones - is the product of long-lasting, slow deposition in the low-energy subtidal environment above the fair-weather wave-base (shoreface). The third member of the cycles - wackestones and floatstones with fenestral fabric and vadose features - have been deposited in the same or similar environments but with a tendency of gradual shallowing into the intertidal zone, with longer or shorter emersions and subaerial exposure, i.e. vadose diagenesis. Such shallowing is probably more a consequence of tidal flat progradation and lateral migration of adjacent ooid bars than of sea level oscillations. Shallowing conditions and subaerial exposure with vadose diagenesis are indicated by fenestral fabric, dissolution vugs, molds of shells, vadose ooids, and microstalactite cement. Such a layer, of various thickness, with more or less pronounced vadose diagenesis, and which shows, as a rule, an erosional surface, is overlain by the third, coarse-grained, member oolitic grainstone or bioclastic-intraclastic grainstone to rudstone (Fig. 5).

The shallowing-upward cycles of the facies unit D are parasequences produced by the fourth or fifth order relative sea-level changes (see: TUCKER, 1993). Generally, they are characterized by the thinning-upward parasequences, i.e. proportion of subtidal members decreasing upward. Their stacking pattern shows characteristics of deposition during the LST - lowstand systems tract, i.e. by relative sea-level fall.

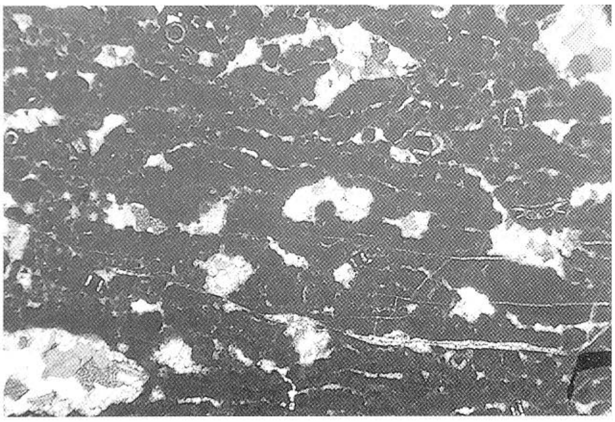


Fig. 9. Typical fenestral wackestone - the second member of the shallowing-upward cycles of Facies "E", composed of pellets and green-algae bioclasts in carbonate mud characterized by fenestral fabric (thin section GJ-205), crossed-nichols. Photo length=7.5 mm.

Fig. 10. Laminated bioclastic and intraclastic grainstone with *Campbelliella striata*. Facies "E" - lamina in the second member of the shallowing- and coarsening-upward cycles (thin section GJ-229). Photo length=7.5 mm

## 3.5. FACIES E: SHALLOWING-UPWARD CYCLES, STORM-TIDE AND VADOSE CARBONATES

### 3.5.1. Lithofacies

The "E" facies, consisting of shallowing-upward cycles, storm-tide and vadose deposits, follows gradually over the "D" facies, amounting to an average thickness of about 405 m, and is overlain, with a comparatively sharp contact, by micritic, favreina-bearing lagoonal to shallow-subtidal Lower Cretaceous limestones (Figs. 3 and 4).

The main sedimentological characteristic of the "E" facies is rhythmical sedimentation: shallowing-upward cycles, between 40 and 130 cm thick, composed of two or more members (Fig. 8). In the lower part of that facies unit, shallowing-upward cycles composed of only two main members commonly occur: the first member is a 40-80 cm thick mudstone and/or pelletal wackestone and the second member is a 20-40 cm thick bed composed of a mm-cm-scale alternation of laminae and intercalations of mudstones, LLH-stromatolites, and pelletal wackestones to grainstones. This laminated bed contains fenestral and vadose features (Fig. 8, cycle A).

More commonly, however, are cycles consisting of three members (Fig. 8, cycle B):

- **The first member** of the sequence is usually a 50 to 100 mm thick layer of mudstone, more rarely wackestone, consisting of micrite with sporadic bioclasts and green algal skeletons (mostly *Clypeina*), pellets, and, very rarely, benthic foraminifera.

- **The second member** of the shallowing-upward cycles shows a somewhat greater variability as regards its composition and structure, i.e. it has not always the same structure and composition in all sequences. Most commonly it is a 20-30 cm thick limestone layer composed of mm-cm-scale alternation of mudstone and pelletal wackestone to grainstone with clear fenestral fabric (Fig. 9). It always contains two types of fenestrae: thin laminoid fenestrae that strictly follow the lamination, and larger, irregular fenestrae and/or dissolution vugs filled up by drusy calcite cement. In addition to the micrite in the pelletal laminae and sparite in the grainstone-type laminae, both types contain large amount of spheroidal, small-sized (0.08-0.4 mm in diameter faecal pellets, and sporadically also green algae and small algal oncoids. Beside this lithological type, the second member of the cycles often may be a fenestral wackestone with grainstone intercalations that contain numerous algal bioclasts (*Clypeina* and/or *Campbelliella* - Figs. 10-12). Bioclasts usually have micritic coatings (Figs. 11 and 12); the intraskeletal cavities, as well as molds of shells, are lined along their walls by fibrous and drusy calcite cement. Some larger cavities show geopetal fabric with internal sediment consisting of vadose crystal silt.

More rare are bivalve and echinoid bioclasts, as well as micritized benthic foraminifera. In this limestone type, the internal sediment occurs more rarely. The grain surfaces are usually coated by precipitated, early diagenetic fibrous cement and the remaining pore spaces are filled up mostly by drusy calcite cement, though locally small amounts of micritic matrix are present.

The second member of the shallowing-upward cycles commonly contains a thinner or thicker intercalation of pisoid wackestone with clear erosional surface. Larger intergranular pores and dissolution vugs often are roofed by gravitational or microstalactite cement indicating the vadose zone diagenesis.

- **The third member** shows the greatest variability with regard to composition, structure, and limestone type. Most frequently, this is the pisoid-intraclast grainstone-rudstone, rather conmmonly rudstone/floatstone with vadose features. The third member of the shallowing-upward cycles follows, as a rule, above the erosional surface of the second member, and more rarely above a surface with desiccation cracks or above an intercalation of the desiccation breccia, on the second member (Fig. 8).

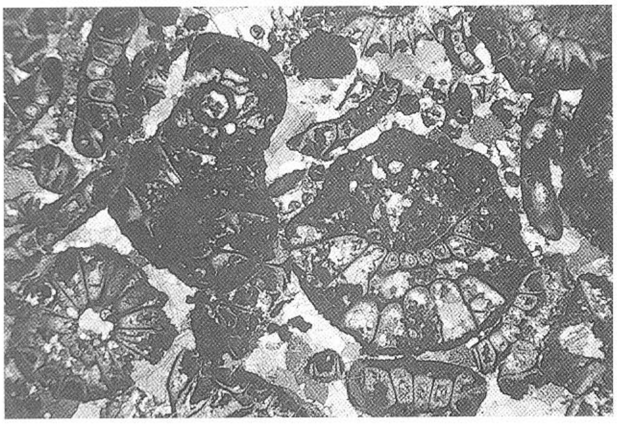


Fig. 11. Intraclastic-bioclastic grainstone/rudstone with *Clypeina*-bioclastics and intraclasts composed of *Clypeina*-wackestone transported onto tidal-flat. Facies "E" - the second member of the shallowing- and coarsening-upward cycles (thin section GJ-204). Photo length=7.5 mm.

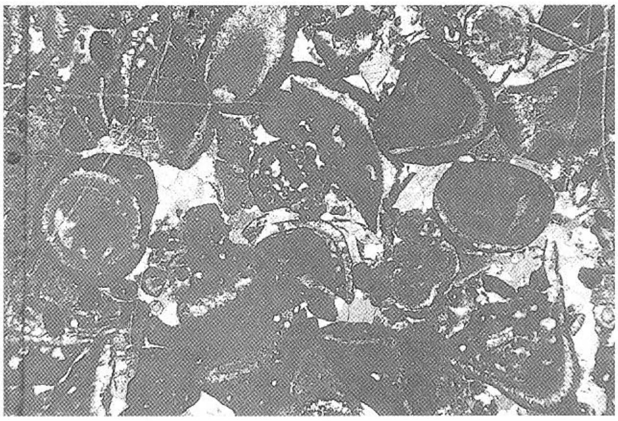


Fig. 12. Storm-tide deposit: intraclastic-bioclastic grainstone with *Campbelliella*-bioclasts and rounded intraclasts composed of *Campbelliella*-wackestone transported onto tidal-flat. Facies "E" - the second member of the shallowing-upward cycles (thin section GJ-232), crossed-polars. Photo length=7.5 mm.

Pisoid-intraclast grainstone/rudstone is composed of large (0.5-7 mm in diameter), irregularly intraclasts which often contain pisoid crustose envelopes, and rather sizeable amount of internal sediment - vadose pelletal and crystal silt - and calcite cement (Fig. 13). The pisoids belong mostly to the micritic type or composite-grains type. Intraclasts of mudstone or wackestone type, with or without fenestral fabric, serve as a nuclei to the pisoid, and in some cycles they are enveloped by crustose pisoid coatings. Some cycles contain calcrete lamination with pisoids (Fig. 13) and microstalactitic or meniscus cement. Vadose pelletal or crystal silt in these limestones always occurs as internal sediment, commonly showing inverse grading and geopetal fabric (Fig. 13).

### 3.5.2. Biofacies

The main biofacies characteristic of the "E" facies unit is even abundant occurrence of green algae skeletal debris and strikingly scarce remains of benthic foraminifera (Fig. 4).

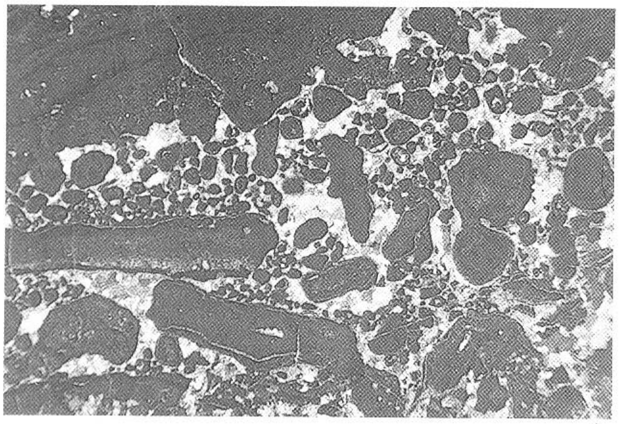
*Conicokurnubia orbitoliniformis, Parurgonina caelinensis* and *Kurnubia palastiniensis* disappear in the beds that mark the transition from the "D" into the "E" facies unit, and *Neokilianina rahonensis* disappears only slightly later, i.e. after the first 80 m of the column. *Pseudocyclammina lituus* and *Valvulina lugeoni* occur throughout various levels of the "E" facies unit, but very rarely. Dasyclad species behave variously: while *Salpingoporella annulata* occurs throughout the range of that unit, *Clypeina jurassica* disappears in about the middle and *Campbelliella striata* at the very top of the "E" facies unit (Fig. 4). The age of that unit in continuous Upper Jurassic section of Mt. Platak is Tithonian in its entire range.

Generally speaking, the termination of that unit is of particular importance for stratigraphy, because it coincides, approximately, with the Tithonian-Berriasian boundary. Because the sequence is represented by carbonate deposits with rhythmic sedimentation and shallowing-upward cycles and due to the fact that characteristic forms occur extremely rarely, there is no way to establish that boundary more precisely. However, the disappearance of *Campbelliella striata* and first appearances of the foraminifera *Charentia cuvillieri* BERNIER & NEUMANN, *Mayncina bulgarica* LAUG et al. and probably *Protopeneroplis trochangulata* SEPTFONTAINE, along with the sporadically abundant occurrence of *Favreina njegosensis* BRONNIMANN, prove that a part of that continuous sequence belong to the Lower Cretaceous (Berriasian).

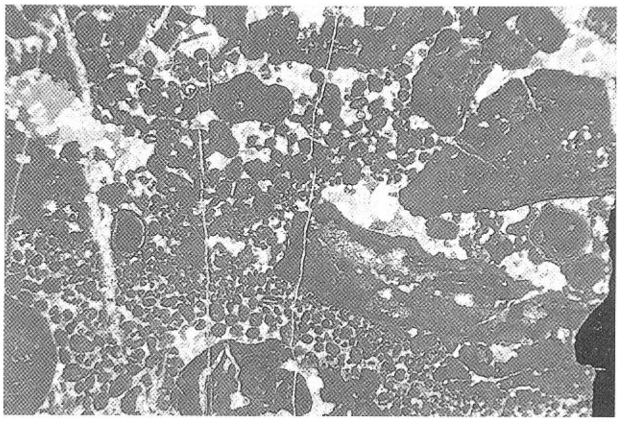
From the palaeoecological point of view, the reappearance of *Cladocoropsis mirabilis, Conicospirillina basiliensis*, and *Trocholina alpina* near the end of that unit - which means, about the end of the Tithonian and the beginning of the Berriasian - is of particular significance. These taxa have not been recorded throughout the largest part of the "D" and "E" facies units (Fig. 3). Obviously, these intervals are characterized by extremely unfavourable ecological conditions for these species: isolated protected shoals with increased salinity were probably dominant. The bulk of benthic foraminifera, as well as abundant algal skeletal debris and algal-bearing intraclasts in the storm-tide beds, have been splashed into the low energy tidal flat environment by storm-tide or waves, along with bioclasts and other carbonate detritus (Fig. 8).

### 3.5.3. Depositional environments

The limestones of the "E" facies unit, i.e. the facies of shallowing-upward cycles, storm-tide and vadose deposits, have been deposited under specific conditions of periodical - rhythmical - repeated deposition of two or three main lithologic members, resulting in vertical piling of more or less lithologically monotonous shallowing-upward and coarsening-upward cycles. The first member of the cycle, mudstone/wackestone, was deposited in shallow subtidal environment of restricted shoal and/or lagoon, under low-energy conditions and predominant accumulation of carbonate mud. Sporadically,



A



B

Fig. 13. Intraclastic and pisoid grainstone - the third member of the shallowing-upward cycles in Facies "E". A - ill-sorted intraclasts with pisoid crustose envelopes. B - inverse grading of vadose pelletal silt subsequently deposited between coarse pisoid-intraclasts and pisoids (thin section GJ-227). Photo length=7.5 mm.

particularly in the beginning phase of deposition of that facies unit, such deposition of mud was interrupted by gradual shallowing processes reaching the lower intertidal zone with the formation of microbial mats, i.e. LLH-stromatolites, and the influx of pellets and skelets (laminae and intercalations of packstones to grainstones - Figs. 10-12). Gradual shallowing was probably caused by different processes, among which the autocyclicity and the progradation of the tidal and supratidal zones toward the protected shoals and lagoon were surely the most important. It caused repeatedly emergence of the muds that had been deposited below the low tide (shallow subtidal) for shorter or longer periods. Here, under subaerial conditions of the vadose zone, they have been subjected to vadose diagenetic processes (fenestrae, formation of dissolution vugs, formation of pisoids, deposition of internal sediment, erosional surfaces) as shown by the limestones belonging to the second member of the shallowing-upward cycles (Fig. 8). The third member of the cycles is the product of influx of coarse-grained carbonate detritus by the storm-tide and waves onto the second member deposits that had been emerged into the intertidal, supratidal, or vadose zone. Consequently, the deposits of the third member are interpreted as storm-tide deposits, transported onto the underlying deposits that had been emerged above the mean tide level. The variability in the composition of that coarse-grained detritus in individual cycles and its diagenetic characteristics indicate that detritus was mainly being brought and accumulated onto the tidal or supratidal, more rarely the upper part of the subtidal zone. That is, the most frequent succession of the diagenetic processes in these limestones is the following: first subaerial and/or vadose diagenesis (equant, microstalactitic and meniscus cement, calcrete lamination), followed by the submarine diagenesis, meaning that the sediment was first exposed to diagenetic processes in the vadose conditions (above mean sea level and groundwater level) and only afterwards was flooded by the seawater. Here the probable depositional environment was the sand beaches accumulated by storms - spit beach, or small sized sandy storm beaches. In such environments, the carbonate detritus could be exposed, for shorter or longer periods, to both subaerial and submarine diagenesis, depending on the carbonate platform subsidence rate, duration of fair- vs. storm-weather periods, sea level oscillations, autocyclicity, and progradational processes.

Accordingly, the sequences of the "E" facies unit have the characteristics of the shallowing-upward and coarsening-upward cycles, just as the facies "D" cycles. However, they substantially differ from the latter by the fact that the facies "E" cycles are not begun with ooids but instead commonly topped, with coarse-grained detritus that had been subjected to subaerial and vadose diagenesis (Figs. 8 and 13).

The shallowing-upward cycles of the facies unit E correspond to the parasequences (fourth/fifth order changes of the relative sea-level curve; 10 to 100 thousand years).

Parasequences are predominantly thin and characterized by tidal flat facies, while some, especially in the lower part of this unit, have an obvious thinning-upward trend. Such a pattern indicate on deposition during the low-stand system tract (LST), when the third-order sea-level curve was falling.

## 4. DISCUSSION AND CONCLUSION

The "A", "B" and "C" facies of the western Gorski Kotar area (the Platak-Grobnik region) - which are Oxfordian in age - correspond, by their sedimentological characteristics, to the carbonate ramp depositional model in which the sea-level rise exceeds the sediment accumulation. In the Kimmeridgian and at the beginning of the Tithonian (the "D" facies) the sedimentary conditions changed greatly, and shoals with characteristics of the beach - barrier island - lagoonal environment system with progradation of the ooid sand bars (and/or barriers) over the subtidal (shoreface and foreshore) to intertidal-supratidal zone (backshore), have been formed.

The dark colour of the Platak-Grobnik Malm facies (the "A", "B", and "C" facies units) agrees with the above mentioned sedimentary environments and conditions in the Oxfordian. These limestones are grey to dark grey, at places even almost black, rich in organic matter ("euxinic"). The dark colour in the lower part of the similar sediments of the Oxfordian - Smackover Formation in Mexican Gulf, has been explained as a consequence of deposition in carbonate ramp marine environments that were deprived of dissolved free oxygen and enriched in organic matter due to the relative sea-level rise. This rise overtook the sedimentation rate and caused the keeping up of the long-lasting carbonate ramp depositional regime (MOORE, 1984, 1989).

The general vertical facies succession in the Oxfordian and Kimmeridgian of the western Gorski Kotar region shows also some other similarities with the above mentioned Smackover Formation in Oxfordian carbonates of Texas, Louisiana and Arkansas, that served as a prototype for establishing the carbonate ramp sedimentation model. The Smackover Formation contains five shallowing-upward cycles composed of mudstone/wackestone → pelletal-ooid packstone → pelletal-ooid grainstone → ooid grainstone. These cycles indicate the following depositional environments order: "offshore below fairweather wave-base through shoreface to intertidal and reflect the upward growth of sand bars into beach-barrier bars and their lateral migration" (HARWOOD & MOORE, 1984). The Smackover Formation of the northeast Texas area was interpreted by McGILLIS (1984) as follows: "a shelf-break is postulated for this area contrasting with the ramp setting of other parts and ooid shoals and bars prograded landwards by spillover lobe sedimentation into the shelf lagoon, where pelleted muds were accumulating".

In western Gorski Kotar during the Malm there is an uninterrupted shallow-marine carbonate sedimentation with the formation of shallowing-upward cycles as a result of barrier ooid sand progradation over the peritidal deposits (Fig. 5). In the Late Tithonian, the general depositional succession show a clear difference with regard to the Kimmeridgian and early Tithonian environments and conditions. Namely, peritidal environments with long-lasting subtidal-intertidal sedimentation predominate, giving rise to shallowing-upward cycles due to progradation of tidal flats and autocyclicity. The shallowing-upward cycles are topped by coarse-grained detritus splashed by tidal waves and high storm-tides onto the intertidal and tidal flat, mainly emerged above sea-level (third member of the shallowing-upward cycles in the "E" facies unit).

Sedimentary succession of the Upper Jurassic carbonates in the western Gorski Kotar show generally-shallowing carbonate ramp environment, from low-energy shoals below fair-weather wave-base (the Late Dogger and Oxfordian age), passing into high-energy shoals and peri-reefal areas, to low-energy subtidal above fair-weather wave-base, and finally to the tidal flat facies during the Kimmeridgian and Tithonian age (Fig. 3).

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