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Correlation of Carbonate Strata in Gorski Kotar Area (Karst Dinarides, Croatia), An Example of Adriatic Carbonate Platform Environmental Diveristy During the Late Jurassic

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Abstract

Adriatic Carbonate platform environmental diveristy as observed within the carbonate strata in Gorski kotar area (Karst Dinarides, Croatia) was caused by synsedimentary tectonics when the hitherto uniform platform area was partly differentiated into two different sedimentary environments. In Jasvina zone an uninterrupted shallow-water platform succession occur, indicating shallow subtidal and peritidal environmental conditions. On the other hand, the Breze zone is characterised by the presence of deeper-water pelagic influenced carbonate succession, clearly evidencing the sunken intraplatform trough of unknown dimensions, which was possibly connected with the open basin area. Correlation of carbonate strata of the studied sections allows the reconstruction of sedimentary dynamics and events that led to such diversified environment which represent the inner part of the Adriatic Carbonate Platform.

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Introduction

The area of Gorski Kotar (Karst Dinarides, Croatia) is characterised by significant Upper Jurassic carbonate facies variability, thus it is very interesting for the interpretation of palaeogeographic events in this part of former Adriatic Carbonate Platform area during the Late Jurassic, e.g. [1-4]. In the broader Gorski kotar area the Late Jurassic is partly characterised by the occurrence of so-called "Lemeš deposits"[5] with cherts and ammonites that indicate deeper-water environments connected with the open basin (Tethys) realm. In the same stratigraphic level one can observe a sedimentary signature of huge platform area with constant shallow-water conditions ranging from subtidal to supratidal in which different facies in mutual exchange originated. These two depositional systems observed in the Gorski kotar area were studied separately in detail by previous researchers, e.g. [1-4], but compared and correlated still represents an interesting though not a new topic of research. So in this compiled paper that is based on the results of previous research, the lithostratigraphic column from each site is presented due to its detailed facies characteristics; one from the Jasvina zone and the other from the Breze zone. These two columns were correlated (Figure 1) which enabled the comparison of simultaneous but laterally distant and quite different platform environments, providing an interesting comparative study to the existing knowledge of the environmental diversity in this part of Adriatic Carbonate platform realm.

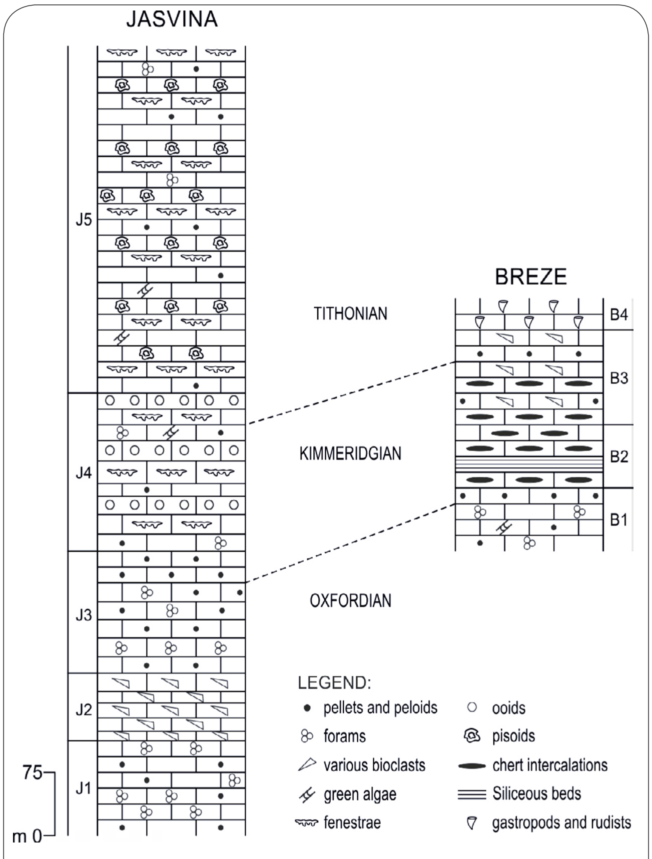

Figure 1: Correlation of studied lithostratigraphic columns.

Materials and Methods

Two sections were investigated for this study and a total of 98 samples were collected and analyzed. The first succession (Jasvina zone) is situated NE from town of Rijeka, and the second one (Breze zone) is situated NE from town of Novi Vinodolski (Figure 2). Both successions are uninterrupted and have been analysed in detail. Here and there in the field minor faults have been recordered, but because of measurable throws they do not affect the continuity of the succession. This is supported by a normal succession of the microfossil assemblages characteristic for the Late Jurassic. A thin sliver of rock was cut from the rock sample with a diamond saw and ground optically flat. It was then mounted on a glass slide and grounded smooth using progressively finer abrasive grit until the sample was only 30 μm thick. In order to define the depositional environments, microfacies features including a description of lithology, texture, sedimentary structures

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and skeletal content, thin-sections were investigated in laboratory under petrographic microscope. The microfacies types were identified and described according to the Dunham and Folk classifications [6, 7].

Geological Setting

Contrary to the underlying Lower and Middle Jurassic carbonates, the Upper Jurassic carbonates of the Karst Dinarides comprise more different facies types, originating in more heterogeneous platform environments. Thus, in the area of the Adriatic Carbonate platform it can be distinguished three texturally different sedimentary developments of the Upper Jurassic that were formed in different platform areas: (1) shallow-water platform carbonates; (2) shallow-water platform carbonates, but partly with pelagic, deeper-water characteristic; (3) shallow-water platform carbonates, interrupted by an emersion.

(1) Shallow-water platform carbonates are the most common and typically exposed in the western Gorski kotar area, e.g. [1, 2]. The boundary between the lower and upper portion of the Upper Jurassic succession is marked by the first appearance of *Clypeina jurassica* Favre. The lower portion of the Upper Jurassic carbonates is predominantly mud-rich, whereas its higher portion is built of more grained facies types. Thus, the Upper Jurassic levels consist of successive series of shallowing/coarsening-upward cycles with ooidal/pisoidal lower/upper cycle members and common emersion features.

(2) The eastern and southeastern Gorski kotar, Lika and Dalmacija are regions where shallow-water lower parts of Upper Jurassic carbonates are overlain with deeper-water intraplatform trough carbonates, ending the Upper Jurassic succession with overlying shallow-water carbonates again. These deeper-water intraplatorm trough carbonates are well-known by the name "Lemeš beds", after their type locality the Lemeš Pass on the Mt. Svilaja [5, 8, 9].

(3) The third Upper Jurassic development outcrops in Istria and in southern Dalmatia area [10]. It begins similarly as in the western Gorski kotar Upper Jurassic succession: mud-rich carbonates are overlain by successive series of coarsening-upward cycles. However, contrary to the Upper Jurassic shallowing/coarsening-upward cycles from the western Gorski kotar area, these cycles consist of thicker upper cycle members with ooidal-bioclastic architecture and distinct sedimentary textures. Additionally, in Istria, the upper cycle members contain a considerably richer macrofossil assemblage, with frequent fragments of Cladocoropsis, various mollusk debris and large hydrozoans and coral "heads". Starting from the middle part of the Late Jurassic (Early Kimmeridgian), a regressive tendency began so terrestrial conditions, marked with regressive breccias and sporadically bauxite deposition (Istria), took place. Afterwards, i.e. during upper part of Late Jurassic (Late Tithonian), the oscillating transgressive events started and shallow-water conditions were re-established when successive series of peritidal shallowing-upward sequences were formed [10].

Description of the Studied Sections

Jasvina zone: In the Jazvina zone, five litostratigraphic units were recognized [1, 2] as follows: (1) the J-1 unit, with mudstones and peloidal wackestones; (2) the J-2 unit, with bioclastic wackestone/floatstones and grainstone/rudstones; (3) the J-3 unit, with peloidal-bioclastic wackestones and packstones; (4) the J-4 unit, composed of shallowing and coarsening-upward cycles with mudstones or peloidal wackestones as the lower cycle members, fenestral mudstones or peloidal wackestones as the middle cycle members, and ooidal grainstones as the upper cycle members; and (5) the J-5 unit, composed of shallowing- and coarsening-upward cycles, which differ from the underlying J-4 unit by the presence of the pisoidal-intraclastic grainstone/rudstones as the upper cycle members.

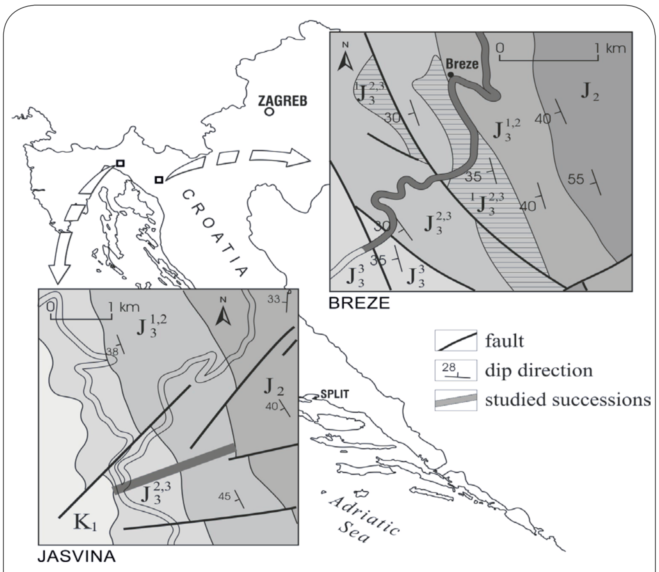

Figure 2: Geographical location and geologic background of studied successions area (Jasvina - according to Basic Geological Map 1:100 000, sheet Delnice [28]; Breze - according to Basic Geological Map 1:100 000, sheet Crikvenica [29] (all modified). Legend: J_2 - Middle Jurassic, $J_3^{1,2}$ - Oxfordian-Early Kimmeridgian, $^1J_3^{2,3}$ - Late Kimmeridgian-Early Tithonian ("Lemeš deposits"), $J_3^{2,3}$, J_3^3 - Middle Kimmeridgian- Tithonian.

Mudstone and peloidal wackestones of the J-1 unit mostly contain variable amounts of foraminifera and peloids in carbonate mud. Among the foraminifera, *Kurnubia palastiniensis* Henson (Figure 3), *Pseudocyclammina lituus* (Yokoyama), *Redmondoides lugeoni* (Septfontaine), *Praekurnubia crusei* Redmond and *Trocholina elongata* (Leupold) have been determined. Sporadically, tiny molluscan fragments, algal oncoids, and cyanophyte filaments with thick micritic envelopes can also be found. Bioturbation occurs locally. Coarse-grained, coated Cladocoropsis, echinoderm, and molluscan fragments occur more frequently in the upper part of this unit. This indicates a gradual transition into the overlying J-2 unit.

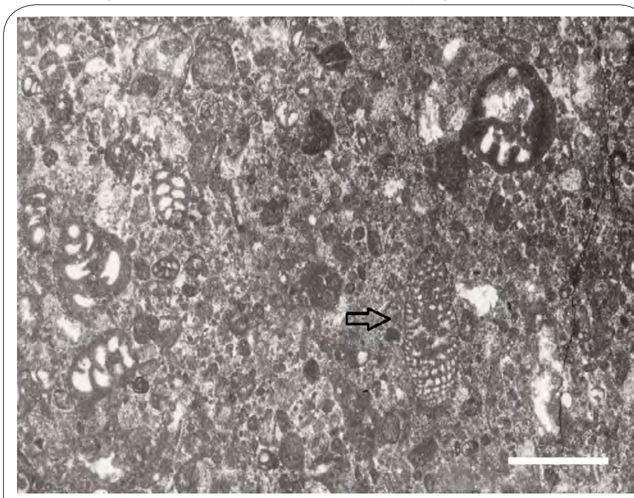

Figure 3: Peloidal wackestone of the J-1 unit with *Kurnubia palastiniensis* Henson. Scale bar 0.8 mm.

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Rhythmical alternations of the bioclastic wackestone/floatstones and bioclastic grainstone/rudstones is the main characteristic of the J-2 unit. Both facies types are 0.2-0.6 m thick and contain various coarse-grained molluscan and hydrozoan skeletal debris (Figure 4). Besides the above mentioned allochems, peloids, subspheroidal micritic intraclasts, and algal oncoids occur very rarely. Foraminifers keep occurring; in addition to those from the underlying unit, *Nautiloculina oolithica* Mohler, *Labyrinthina mirabilis* Weynschenk, *Chablaisia chablaisensis* Septfontaine, and *Mohlerina basiliensis* (Mohler) appear.

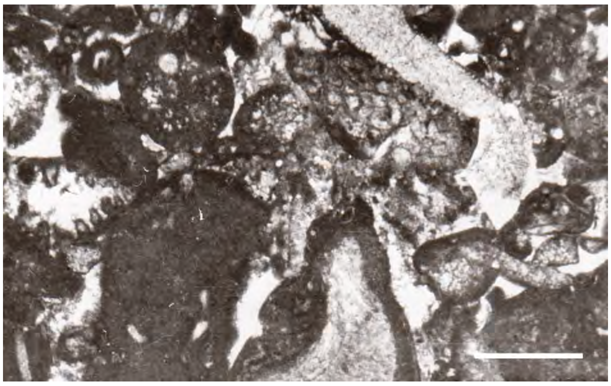

Figure 4: Bioclastic grainstone/rudstone of the J-2 unit. Scale bar 0.8 mm.

Poorly sorted and locally bioturbated, peloidal-bioclastic wackestone of the J-3 unit predominantly contain typical shallow-water allochems that include pellets, peloids, and benthic foraminifera well-known from the underlying units. However, contrary to the underlying units, this whole unit is additionally characterized by the presence of the algal species *Salpingoporella sellii* (Crescenti) (Figure 5). Algal oncoids, tiny molluscan fragments, and angular to rounded micritic intraclasts also occur in variable proportions. Algal oncoids and/or coarser intraclasts may be the dominant component in a few places inside this unit, thus forming individual beds of oncoidal-intraclastic wackestone/floatstones or grainstone/rudstones.

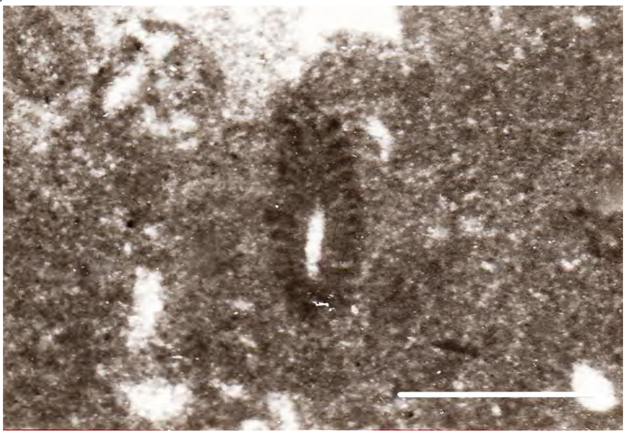

Figure 5: Peloidal wackestone of the J-3 unit with *Salpingoporella sellii* (Crescenti). Scale bar 0.8 mm.

Shallowing- and coarsening-upward sequences of the J-4 unit consist of three texturally and compositionally different members. The thickness of the lower cycle members ranges from 0.4-1.2m, whereas the thicknesses of the middle and upper cycle members are frequently equal, amounting to 0.15-0.2 m. Mudstone or peloidal wackestone beds are usually 0.2-0.6 m thick and contain peloids, and foraminifera. In these members, rare algal oncoids and fragments of *Clypeina jurassica* Favre (Figure 6) and/or *Salpingoporella annulata* Carozzi are also present. Less common allochems are mainly tiny molluscan and echinoderm fragments. Middle cycle member begins with the appearance of the irregular fenestrae, molds of bioclasts, and/or dissolution vugs filled by drusy calcite (Figure 7). Ooidal grainstones are composed of well sorted ooids with peloidal and, much more rarely, bioclastic nuclei, surrounded by a microcrystalline envelope. Within the individual ooids radial-fibrous fabric is clearly visible. Numerous ooidal grainstone members contain only crushed and/or regenerated ooids (Figure 8).

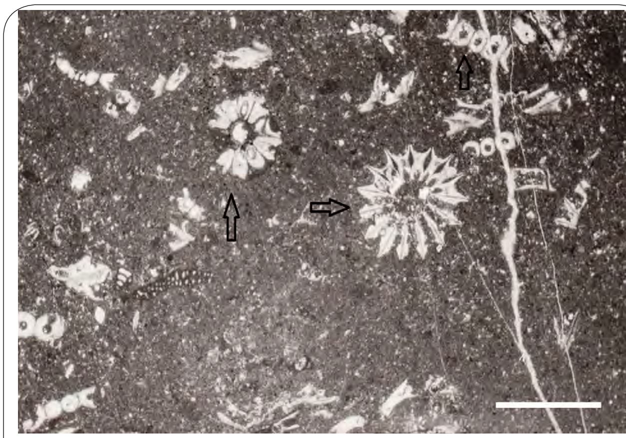

Figure 6: Peloidal wackestone with *Clypeina jurassica* Favre. J-4 unit. Scale bar 1.6 mm.

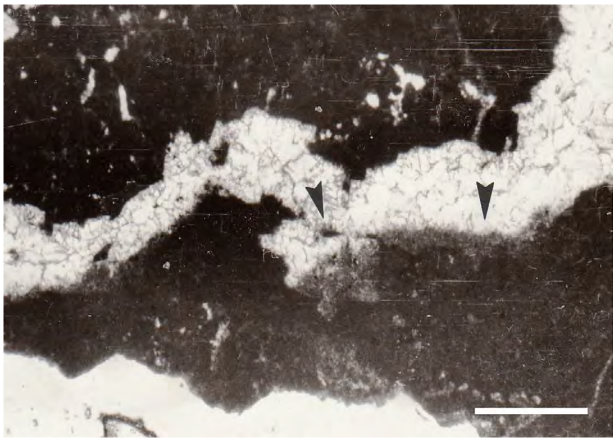

Figure 7: Fenestrae is lined at its bottom with crystal silt showing geopetal fabric. J-4 unit. Scale bar 0.4 mm.

Figure 8: Crushed and/or regenerated ooids within the J-4 unit. Scale bar 0.8 mm.

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A distinct cyclic pattern of three cycle members can also be observed in the J-5 unit. The first two members of these shallowing- and coarsening-upward cycles are characterized by the same compositional and textural features as the first two members from the underlying J-4 unit. However, the middle, fenestral, member is frequently capped with bioclastic-intraclastic grainstones containing abundant *Clypeina jurassica* Favre and/or *Campbelliella striata* (Carozzi) fragments (Figure 9) and micritic intraclasts. In a few places, the bioclastic grainstones contain variable amounts of molluscan and echinoderm fragments, cortoids, and foraminiferal tests. The thicknesses of these first two members are frequently equal, amounting to 0.35-0.5 m. The third members are always 0.1-0.15 m thick pisoidal-intraclastic grainstone/rudstones. They contain angular to rounded micritic-pelletal intraclasts (sometimes with fenestral fabric), with or without pisoidal envelopes (Figure 10). Intergranular pores commonly contain variable amounts of crystal and pelletal silt; this internal sediment frequently shows grading and geopetal fabric. Meniscus and microstalactitic cements occur only sporadically. Beside sporadic findings of the foraminifera *Redmondoides lugeoni* (Septfontaine) and *Pseudocyclammina lituus* (Yokoyama), this unit contains abundant fragments of the dasyclad species *Clypeina jurassica* Favre and *Campbelliella striata* (Carozzi).

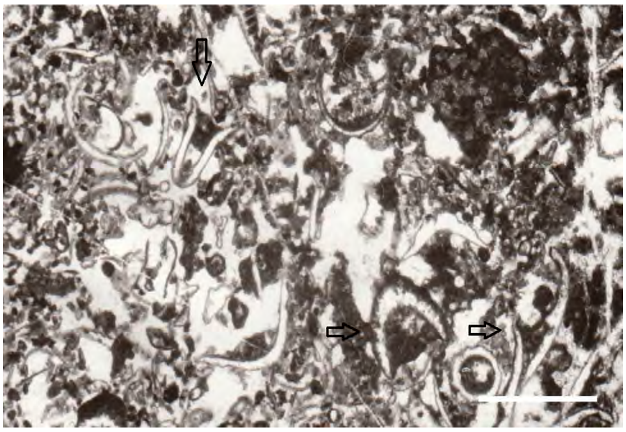

Figure 9: Bioclastic-intraclastic grainstone with *Campbelliella striata* (Carozzi). J-5 unit. Scale bar 1.6 mm.

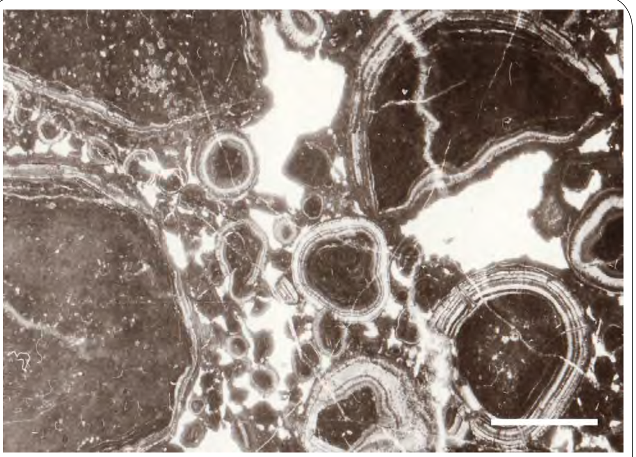

Figure 10: Pisoidal-intraclastic grainstone/rudstone of the J-5 unit. Scale bar 1.6 mm.

Interpretation: (according to Bucković 2004): The depositional environment for the J-1 unit is interpreted as a shallow, low-energy lagoon below the fair-weather wave-base, situated in the inner platform region. [1] consider this unit to be 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 a quiet water environment. However, the increasing amount of coarse-grained fragments in the upper part of this unit suggests stronger influence of adjacent environments, inhabitated by molluscs, echinoderms, and hydrozoans. These could be reef mounds or patch-reefs build-up of various coarser skeletal organisms. These organic structures could be formed on lagoonal floor irregularities providing hard substrate, where bottom currents provide oxygen and nutrients. Their growth was due to local accumulation of skeletal material and to the baffling and trapping of finer sediment by lagoonal organisms (e.g. fleshy algae). As a result of destruction of these structures by currents and waves during major storms, coarse-grained skeletal fragments were spread throughout the lagoon, sporadically initiating formation of additional lagoonal floor irregularities which became nuclei for new organic structures. When reef mounds or patch-reefs, in such a way, spread (prograded) and occupied more space, the J-2 unit, composed solely of coarse-grained skeletal fragments, began to be deposited during major storms. These 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, have been accumulated [1]. Rhythmical alternation of wackestone/floatstones and grainstone/rudstones indicate oscillations in water energy; wackestone/floatstones were deposited when waves began to calm down. High carbonate mud content within the J-3 unit suggests a subtidal depositional environment (shoreface above fair- weather wave-base and/or lagoon - [1]). Contrary to the depositional environment of the J-1 unit, rich foraminiferal content (particularly in the packstones) indicates better water circulation above the fair-weather wave-base and thus more favourable ecological conditions than those in the J-1 unit. Packstone beds suggest sporadic higher energy environments, triggered by periodical storms which winnowed the muddy foraminiferal material. During sporadic major storms, carbonate mud was washed out and neighbouring reef mounds or patch-reefs were eroded, giving rise to bioclastic-intraclastic grainstone/rudstone beds. Within the J-4 unit, three sedimentary environments with different depositional styles can be recognized. Periodically changing conditions, ranging from shallow subtidal to oolite shoals, have produced a series of shallowing- and coarsening-upward sequences. Gradual transition of the mudstones and pelletal wackestones to those with fenestral fabric, as well as molds of bioclasts and/or dissolution vugs, clearly indicate shallowing-upward evolution, with sporadic subaerial exposure as a consequence of tidal-flat progradation or aggradation in the subtidal zone of maximum carbonate productivity [1]. Oolite shoals from adjacent areas, which constantly changed their position during periodic storms and/or higher tidal currents, capped the underlying intertidal-supratidal fenestral deposits, thus forming the third, ooid grainstone member of the shallowing- and coarsening-upward sequences. During stormy periods, ooids were thrown by waves onto the vadose zone, and thus subjected to desiccation and vadose diagenesis, producing vadose features (microstalactitic and meniscus cement, crystal and pelletal silt). Triggered by periodical storms and/or high tides, several episodes of re-deposition took place, when ooidal deposits were transported from the vadose to the subtidal zone and back, which caused their partial cracking and multiphase regeneration. [1] consider this unit to be deposited in specific cumstances ranging from beach bar to lagoon and intertidal environments as a result of ooid bar and tidal flat progradation, so their interpretation of this unit is rather different. They interpreted these shallowing-upward sequences as beginning with the ooidal grainstones, and passing up into the lagoonal mudstones/wackestones (for such a model see also [11, 12]). They are capped by the fenestral tidal flat wackestones with the evidence of subaerial exposure. The first two facies types of the J-5 unit originated under similar conditions as the first two facies types of the underlying J-4 unit. However, after the final emergence of the second member, carbonate detritus (mainly intraclasts), thrown onto the emergent surface from the adjacent subtidal environments by action of storm waves and high tides, was exposed to vadose diagenesis. During these periods, some intraclasts developed pisoidal envelopes, and internal sediment was produced (for a more complex and different interpretation of this unit, see [1] .

Breze zone: In the Breze zone, four distinct litostratigraphic units which originated under different conditions and in different environments were distinguished as follows: (1) the B-1 unit, with peloidal wackestone/packstones; (2) the B-2 unit, with pelletal-bioclastic wackestones and sporadic intercalations and nodules of chert (in irregular alternation with siliceous beds); (3) the B-3 unit, with normally graded bioclastic packstone/floatstones; (4) the B-4 unit, bioclastic-peloidal wackestone/packstones with rare floatstones and sporadic grainstones.

Grey-coloured beds of the B-1 unit belong to the lowest level of the investigated succession. The dominant component of these peloidal wackestone/packstones are tiny oval to suboval pellets between 0.02-0.1 mm in size and more frequent oval peloids up to 2 mm in size. The skeletal debris are represented by numerous benthic foraminiferal species; *Kurnubia palastiniensis* Henson, *Praekurnubia crusei* Redmond, *Pseudocyclammina lituus* (Yokoyama), *Valvulina lugeoni* Septfontaine and debris of Thaumatoporella. Small echinoderm and larger gastropod bioclasts are also often found. *Salpingoporella sellii* Crescenti is very common throughout this unit. Rarely large-sized *Cladocoropsis mirabilis* Felix can be found in growth position (Figure 11 and Figure 12).

The deposits of the B-2 unit continuously overly the B-1 unit and two parts of this unit can be distinguished: a lower one is represented by pelletal-bioclastic wackestones with rare intercalations and nodules of chert and an upper one where pelletal-bioclastic wackestones and siliceous beds occur in irregular alternation. In this upper part of B-2 unit the intercalations and nodules of chert are very frequent (Figure 13). The pelletal-bioclastic wackestones contain dominantly oval to

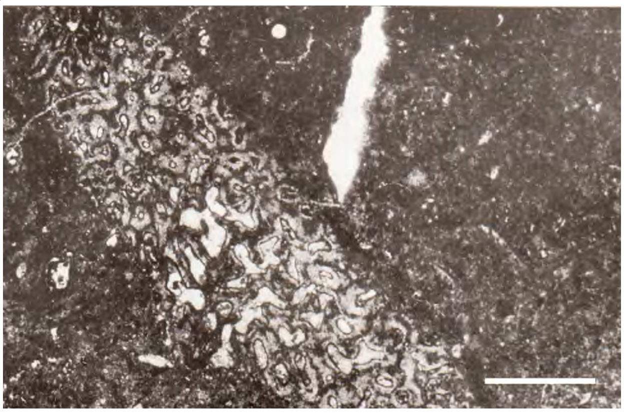

Figure 11: Peloidal wackestone with *Cladocoropsis mirabilis* Felix. B-1 unit. Scale bar 1.6 mm (taken from [2, 3]).

Figure 12: *Cladocoropsis mirabilis* Felix inside the limestones of the B-1 unit (taken from [2, 3]).

Figure 13: Intercalations of chert inside the limestones of the B-2 unit (taken from [2, 3]).

suboval pellets up to 0.06 mm in diameter, echinoderm fragments between 0.02-1 mm and rarer calcified radiolarian tests as well as sponge spicules suspended in the carbonate mud. Frequently tiny echinoderm fragments (0.02-0.06 mm) are the dominant component of this facies and, more rarely, small-sized hydrozoan and gastropod debris can be found (Figure 14). However, no regular pattern can be observed in this allochem content. In the upper part of this unit the limestones irregularly alternate with greyish-green siliceous beds. The slaty textured to sporadically thin-bedded (0.05-0.15 m) siliceous intervals vary in thickness from 0.4-3 m. Easy cleavage and poor consolidation are the main characteristics of these slaty textured siliceous beds (Figure 15). These siliceous beds belong to very fine-grained vitric pyroclastics that have been devitrified and secondarily altered in varied proportions ranging from chert to clayey alteration products [13]. These altered pyroclastics usually contain a large amount of the quartz-skeletal biota such as radiolarians and spicules of siliceous sponges [13]. Also, in chert intercalations and nodules within the interbedded limestones, [13] observed the relics of calcitic allochems (pellets, bioclasts, calcitised radiolarians and sponge spicules), indicating partial alteration of these limestones by chalcedony and quartz.

Within the B-2 unit one thin-bedded interval (0.1 m thick) of bioclastic packstone/floatstone can be observed (Figure 16). After this first appearance, in the next 11 m of the succession, bioclastic packstone/floatstones appear again as 0.08-0.25 m thick intervals. The main textural characteristic of these bioclastic intervals is a more or

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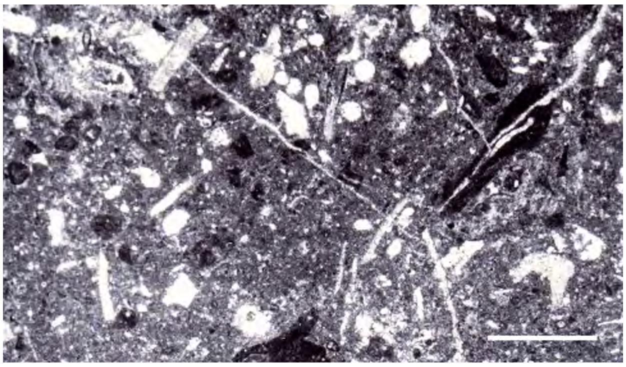

Figure 14: Pelletal-bioclastic wackestones with rare calcitised radiolarian tests as well as sponge spicules. B-2 unit. Scale bar 0.4 mm (taken from [2, 3]).

Figure 15: Slaty textured to thin-bedded siliceous intervals within B-2 unit (taken from [2, 3]).

Figure 16: The first bioclastic interval (bioclastic packstone/floatstone) indicates the beginning of the B-3 unit (taken from [2, 3]).

less clearly expressed normal grading of bioclasts and their frequent orientation parallel to bedding. The first appearance of bioclastic packstone/floatstones interval inserted within the facies types of the B-2 unit, we consider as the beginning of the B-3 unit. These intervals of bioclastic packstone/floatstones are composed of poorly sorted, abraded and broken echinoderm and hydrozoan fragments predominantly 2-3 mm in diameter as well as variously sized angular micritic intraclasts (Figure 17). Smaller bioclasts of indeterminable bivalves, gastropods, green and red algae are rarely present. Intergranular pores are filled with carbonate mud often enriched with oval pellets, but locally irregular drusy calcite has been developed as a result of partial recrystallisation. [13] labelled above described successions with intercalations and nodules of chert (here called the B-2 and B-3 units) as the "Lemeš beds" according to lithologically equivalent deposits on Mt. Svilaja (central Dalmatia) where its stratigraphic range was determined as Upper Kimmeridgian-Lower Tithonian [5, 8, 9, 14].

The studied succession ends with a thick package of the B-4 unit rich with various bivalve and gastropod fragments. In these bioclastic-peloidal wackestone/packstones with rare floatstones and grainstones, oval peloids (1-2 mm in diameter), echinoderm cortoids, micritic intraclasts and rare benthic foraminifera (e.g. *Pseudocyclammina lituus* (Yokoyama) are the predominant components. Large diceratid shells are also present here (Figure 18). [15, 16] determined here 13 Tithonian gastropod species of the genera Nerinea, Cryptoplocus, Ptygmatis, Iteria, various Tithonian hydrozoan species and a very rich microfosil assemblage with *Clypeina jurassica* Favre, *Salpingoporella anullata Carozzi*, *Pseudocyclammina lituu*s (Yokoyama) etc.

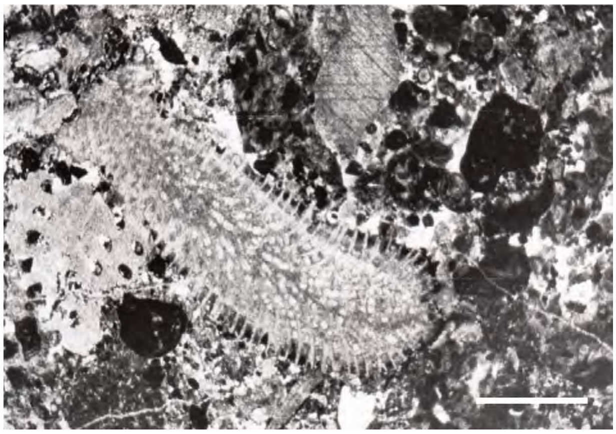

Figure 17: Bioclastic packstone/floatstone of the B-3 unit. Scale bar 0.8 mm (taken from [2, 3]).

Figure 18: Diceratid shells inside the limestones of the B-4 unit (taken from [2, 3]).

Interpretation: (according to Bucković 1995): The characteristics of the B-1 unit indicate deposition in low-energy platform shoals and/or lagoons, probably mostly below the fair-weather wave-base, with calm water and a low, constant rate of sediment accumulation. Under such

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environmental conditions a large amount of carbonate mud has been deposited. Rather frequent finds of radiolarian tests in the overlying deposits of the B-2 unit indicate a pelagic influence. Additionally, the complete absence of benthic biota with only tiny echinoderm fragments, sponge spicules and pellets within the carbonate mud indicates a quiet, low-energy depositional environment influenced by the open sea. Furthermore, [1, 17] presumed that such "Lemeš" limestones of Velika Kapela with chert intercalations and nodules were deposited in the deeper-water (lagoonal ?) environment below the fair-weather wave-base. The very low rate of carbonate accumulation in such an environment enabled the preservation of the pellets that were slowly litified. Also, the low rate of sedimentation enabled considerable accumulation of vitroclasts derived from distant volcanic eruptions and transported by the wind. Here, this pyroclastic material was devitrified and altered ranging from chert to clayey alteration products, thus, enriching the water with SiO_2 [13]. Therefore, intercalations and nodules of chert within B-2 unit resulting mostly from the dissolution of volcanogenic silica, although, the presence of calcitised radiolarians and sponge spicules indicates considerable biogenic source of silica. A much higher rate of carbonate accumulation in the surrounding shallow platform environments [18,19], relative to the slow and almost insignificant contribution of the aeolian pyroclasts, is the main cause of their non-appearance in contemporaneous, adjacent shallow-water carbonates. However, they are probably present but difficult to observe. Sedimentary characteristics of the intercalated bioclastic deposits within the B-3 unit indicate allochthonous sediments representing gravity displaced coarser carbonate material deposited along an inclined slope. Since the majority of this material consists of angular echinoderm and hydrozoan bioclasts, a contemporaneous perireefal/reefal hydrozoan environment must have existed locally and somewhat deeper down the slope an environment with echinoderm (crinoid ?) "meadows". Processes of bioerosion, supported by wave and current activity, enhanced the accumulation of carbonate debris in the perireefal/reefal area. When the equilibrium between these two processes was disturbed by periodic storms, smaller earthquakes, etc., carbonate material was displaced down the slope sweeping up the deeper living echinoderms to be deposited with definite textural characteristics as bioclastic intercalations within the sedimentary deeper-water environment. Successive infilling of this inclined deeper-water environment with bioclastic material resulted in progressive shallowing of the depositional environment, particularly when the displacement of bioclasts down the slope became more pronounced (thicker bioclastic intervals within the B-3 unit). This led to a gradual decrease in water depth and a transition into a higher energy shallow subtidal environment, above the fair-weather wave-base, that facilitated the renewed development of the large benthic foraminifera, calcareous green algae and other platform biota as well as shallow-water allochems (peloids, cortoids) of the B-4 unit. A high rate of carbonate accumulation in such a shallow-water environment was very favourable for local formation of the rudistid (*Diceras* sp.) buildups observed in the uppermost part of the B-4 unit and identified as biostromes by [16].

Discussion

Due to the lithostratigraphic framework established for both successions, important differences in the nature of environmental conditions can be perceived. These differences are consequence of different sedimentary events that took place at two distant Adriatic Carbonate platform areas, representing today's Jasvina and Breze zones.

Starting from the beginning of the Oxfordian, sedimentation within the investigated platform area took place in a lagoonal or shallow subtidal platform environment below and/or above the fair-weather wave-base, with predominant accumulation of carbonate mud and micritic allochems (pellets and peloids), into which, from time to time, fine-grained skeletal debris was derived from adjacent reef mounds and/or patch-reefs. This is clearly recorded inside the whole J-1 and B-1 units (Figure 19a). During the Middle Oxfordian, sedimentary environments began to diversify and each investigated area assumed its own evolution up to the end of the Late Jurassic. At Jasvina, the reef mounds and/or patch-reefs spread and occupied broader lagoonal area, so that the coarse-grained skeletal detritus was predominantly deposited within the J-2 unit. By gradual shallowing of this lagoonal environment, subtidal areas above the fair-weather wave-base existed in the Late Oxfordian. This shallowing event had a negative effect on the growth of sediment trappers and, consequently, the growth of reef mounds and/or patch-reefs was markedly reduced. On the other hand, however, these environments were very favourable for foraminifers and dasyclads, as well as the development of various coated grains (oncoids, peloids) observed within the J-3 unit (Figure 19a). In the Early Kimmeridgian, the

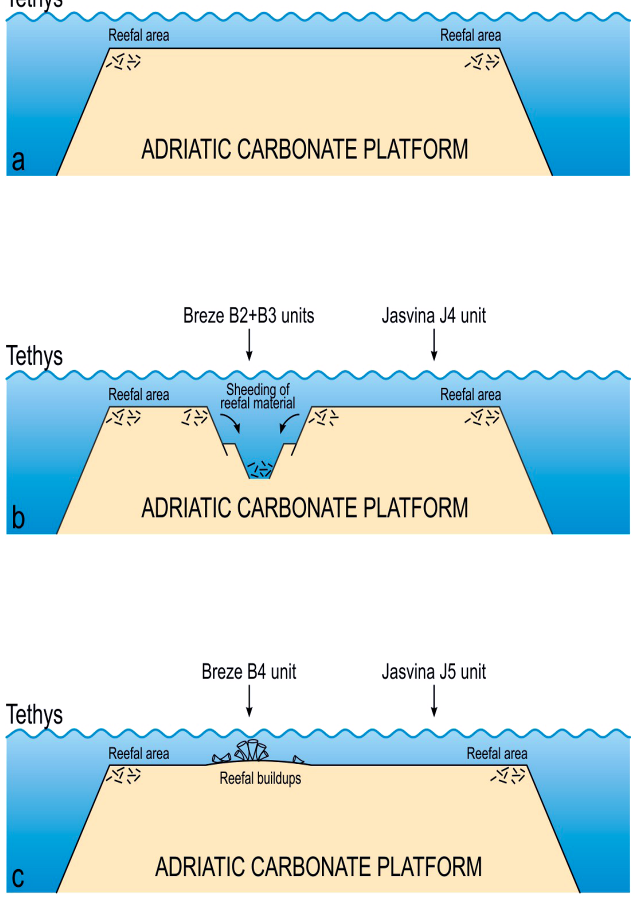

Figure 19: Simplified schematic geodynamic interpretation: a) from the Oxfordian to earliest Kimmeridgian deposition took place within Adriatic Carbonate platform subtidals and/or peritidals; b) from the Middle to Late Kimmeridgian and up to the end of Early Tithonian deposition took place within intraplatform trough and/or peritidals; c) from the Late Tithonian platform subtidals were re-established above the former intraplatform trough area, occupied by diceratid reefal buildups (not to scale).

gradual shallowing progressed and oolite shoals, surrounded by lagoons and tidal flats, came into existence when J-4 unit originated (Figure 19b). This sedimentary system gradually prograded seaward and in the Tithonian was replaced by a peritidal sedimentary system of the J-5 unit (Figure 19c), indicating continuous regression. Both sedimentary systems gave rise to high-frequency relative sea-level fluctuations. However, besides certainly active the autocyclic processes of progradation of the oolite shoals or tidal flat or aggradation in the subtidal zone of maximum carbonate productivity, allocyclic influence on these relative sea-level fluctuations cannot be excluded. It is possible, that the two sets of processes (autocyclic and allocyclic, respectively) jointly produced a synergistic effect, though, for the time being, their share in the total process cannot be reliably determined because we cannot, as yet, measure the duration of our sequences in the J-4 and J-5 units.

During the deposition of J-4 unit in the Jasvina zone, intensive synsedimentary tectonics markedly affected some parts of the Adriatic Carbonate platform. In many places, there are deeper-water, locally ammonite-bearing, carbonates and cherts intercalated inside the Upper Jurassic shallow-water carbonate successions[5, 8, 9, 14, 17, 18, 19, 20]. One of those pelagic-influenced successions is recorded in the Breze zone. Therefore, it can be assumed that starting sometime in Early Kimmeridgian some internal parts of the Adriatic Carbonate platform subsided and became connected with the open Tethys realm, thus forming an intraplatform trough with pelagic deposition when B-2 unit originated (Figure 19b). Comparing the composition of these pelagic sequences from the various Adriatic Carbonate platform localities, the existence of two main intraplatform troughs is supposed where in so called “Lemeš deposits” originated [5, 19]. One can be traced from western Croatia (Karlovac region) towards the south and southeast, with typical outcrops between Mt. Svilaja and Mt. Kozjak, while the other occupies the central part of the Gorski kotar area. They differ from each other by the more pronounced pelagic influences in the first one. Contrary to that, in the Gorski kotar area, medium to thick-bedded dark limestones with sporadic slaty textured siliceous beds occur, with rarer chert intercalations and much rarer pelagic fauna. It can be assumed that these troughs were very similar to the recent Bahamas "Tongue of the Ocean", as it has been envisaged by [21] for the Belluno Trough in the Venetian Alps (Italy). Since the majority of allochthonous bioclastic layers within the bioclastic intervals of the B-3 unit consist of hydrozoan, molluscan, and echinoderm bioclasts, a contemporaneous peri-reefal environment must have existed at the margin of the Gorski kotar trough. Disturbed by periodic storms, peri-reefal debris was displaced down the slope, sweeping up the deeper living echinoderms (crinoids), to be deposited in the elongated lagoon or intraplatform trough (Figure 19b). Successively repeated, this process progressively filled up the Gorski kotar trough and, consequently, in the Late Tithonian, reefal buildups and shallow subtidal to peritidal environment capped the former deeper-water lagoon area when B-4 unit originated (Figure 19c).

Conclusion

The major influence on the complex palaeogeographical and depositional relationships in the Kimmeridgian may be attributed to synsedimentary tectonics [22-26]. A major part of the platform remained within shallow-water environments as in the area of today's Jasvina zone, but some areas of the platform were subjected to drowning event when somewhat deeper depositional areas were formed as relatively shallow intraplatform troughs, as in the area of today's Breze zone. Therefore, the facies diversity observed during Kimmeridgian within two selected successions from Gorski kotar area (Jasvina and Breze zone) was certainly the consequence of a tectonic regime that represents the beginning of the period characterized by inverse tectonics, since existing lineaments began to reactivate in order to adjust to the new conditions of compression/ transpression [26, 27]. This resulted in sporadic formation of small pull-apart basins, i.e. the intraplatform troughs where the "Lemeš deposits" originated. During the Tithonian, former intraplatform troughs were completely filled by progradation from the surrounding reefs and a shallow-water depositional system was re-established above. Thus, in the Late Tithonian the whole platform area of today's Gorski kotar area became a shallow-water subtital environment again.

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