Lower Jurassic carbonate succession between Predole and Mlačevo, Central Slovenia

Spodnjejursko karbonatno zaporedje med Predolami in Mlačevim, osrednja Slovenija

STEVO DOZET[1]

[1]Geološki zavod Slovenije, Dimičeva ulica 14, SI-1000 Ljubljana, Slovenija

*Corresponding author. E-mail: stevo.dozet@geo-zs.si

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Abstract: The paper deals with Lower and Middle Jurassic carbonate succession sotheasterly of Ljubljana in the area belonging to the northern margin of the Dinaric Carbonate Platform. The Lower Jurassic carbonate succession between Predole and Mlačevo is composed of five lithostratigraphic units that in view of biostratigrafy belong to the cenocona *Palaeodasycladus mediterraneus* (Pia). In the topmost part of the Lower Jurassic stratigraphic sequence there is an unfossiliferous interval zone of the platy Spotty Limestones. The considered rocks are developed in a shallow-water carbonate facies lying conformably upon the Norian-Rhaetian variously grey bedded dolomite in Lofer development, the Main Dolomite respectively. The passage of the micritic Lower into oolitic Middle Jurassic limestones is gradual. In the Lower Jurassic carbonate sequence, where limestones strongly prevail over dolomites, occur thinner and thicker sedimentary rhythms of subtidal and intertidal environments. The first and especially the last unit of the Lower Jurassic carbonate succession between Predole and Mlačevo are poor in fossils. In central more or less fossiliferous unit play most important role alga *Palaeodasycladus,* benthic foraminifer *Orbitopsella*, lithiotid bivalves and corals. Important are also megalodontid bivalves that appear already in the Rhaetian and Lowermost Jurassic part of the Mesozoic stratigraphic sequence. Lithiotid and megalodontid bivalves occur in the form of

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lumachelles composing biostromes, whereas the corals build minor mud mounds. Nonfossiliferous dark platy Spotty Limestones were deposited in restricted parts of shelf, where there were no favourable conditions for greater diversity of organisms. In geotectonic regard is the investigated area a part of External Dinarides.

Povzetek: Članek obravnava spodnje in srednjejursko karbonatno zaporedje plasti jugovzhodno od Ljubljane na ozemlju, ki pripada severnemu robu Dinarske karbonatne platforme. Spodnjejursko karbonatno zaporedje med Predolami in Mlačevim je sestavljeno iz petih litostratigrafskih enot, ki biostratigrafsko pripadajo cenoconi *Palaeodasycladus mediterraneus* (Pia). Prav na vrhu je nefosiliferna intervalna cona ploščastih marogastih apnencev. Obravnavane kamnine so razvite v plitvovodnem karbonatnem faciesu. Leže konkordantno na norijsko-retijskem, različno sivem plastnatem dolomitu v loferskem razvoju oziroma na Glavnem dolomitu. Prehod mikritnih spodnjejurskih v oolitne srednjejurske apnence je postopen. V karbonatni spodnjejurski skladovnici, v kateri močno prevladujejo apnenci nad dolomitom, se pojavljajo tanjši in debelejši ritmi sedimentov podplimskega in medplimskega okolja. Prva in še zlasti zadnja enota spodnjejurskega karbonatnega zaporedja med Predolami in Mlačevim sta revni s fosili, v osrednjih fosilifernih plasteh pa igrajo pomembno vlogo alga *Palaeodasycladus*, bentična foraminifera *Orbitopsella* in litiotidne školjke. Zelo opazne so tudi megalodontidne školjke, ki se pojavljajo že v retijskem in spodnjejurskem delu mezozojske skladovnice. Litiotidne in megalodontidne školjke se pojavljajo v obliki lumakel ozorima horizontov, korale pa ponekod tvorijo manjše kopaste grebene. S fosili revni, temni, ploščasti marogasti apnenci so nastajali v zatišnih delih šelfa, kjer ni bilo ugodnih pogojev za večjo raznolikost organizmov. V geotektonskem pogledu je raziskano ozemlje del Zunanjih Dinaridov.

Key words: stratigraphy, shallow marine carbonate rocks, litho- and biostratigraphic subdivision, Lower and Middle Jurassic, External Dinarides, Slovenia

Ključne besede: stratigrafija, plitvomorske karbonatne kamnine, lito- in biostratigrafska razdelitev, spodnja in srednja jura, Zunanji Dinaridi, Slovenija

Introduction

In this article are applied data obtained during geological mapping for elaboration of Geological Map of Slovenia on the scale of 1:50 000 on the Map Sheet Grosuplje performed in the years 2005 to 2007 by Stevo Dozet.

With our research work we intend to define, above all, the stratigraphy of the Lower Jurassic sedimentary succession and to carry out lithostratigraphic and biostratigraphic subdivision in formations, unit, cenocones and subcones, what will be useful for elaboration of the geologic formation-map of this ter-

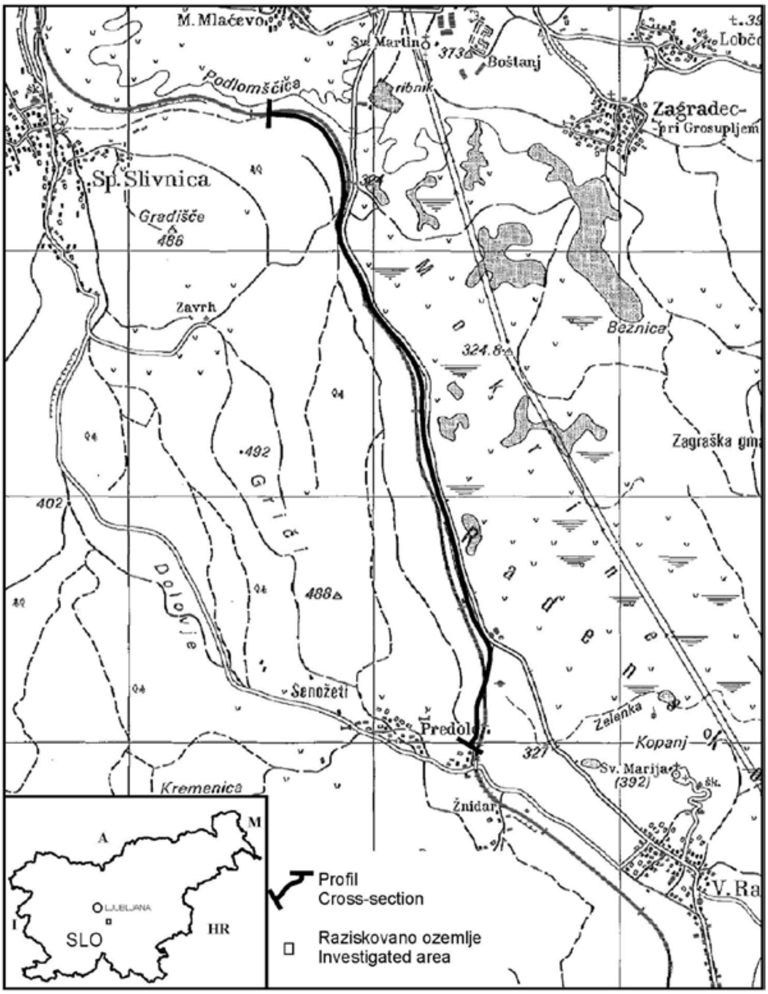

Figure 1. Location map of the investigated area

ritory. Next to the Lower Jurassic carbonate sequence we intend to research more in detail also rocks and their fossil contents at the lower and upper boundary of the discussed stratigraphic sequence.

Geological setting. The mapping area (Figure 1) lies on the Map Sheet Grosuplje on the scale of 1:25 000 (N°136) southeast of Ljubljana respectively on the western border of Radensko polje extending on the distance of 3.5 kilometers in the area between Spodnja Slivnica, Mlačevo and Predole at Račna. The Lower Jurassic carbonate rocks build smaller hills Gradišče (486 m) and Griči (492 m and 488 m) extending continually in NW-SE direction.

In structural respect the investigated area represents one of smaller tectonic units of External Dinarides defined by northwestern-southeastern (NW-SE) faults (BUSER, 1974; PLACER, 1998) belonging to the northern margin of Dinaric Carbonate Platform (BUSER, 1989).

Previous investigations. The oldest registered data on geologic structure of the considered area could be found in works of M. V. LIPOLD (1858), who in the Dolenjska and Notranjska regions attributed a greater part of Jurassic beds to Triassic. KERČMAR (1961) researched Jurassic beds in the area between Krka, Videm and Ilova gora. In the Explanatory text of the Map Sheet Ribnica BUSER (1969, 1974) described principal geological mapping lithostratigraphic units of this area. Tectonically he ranged the investigated area to the Dolenjska-Notranjska Mesozoic Blocks, paleogeographically however, to the Dinaric Carbonate Platform (BUSER, 1989). ŠRIBAR and coworkers (1966) investigated Jurassic sediments between Zagradec and Randol in the Krka valley. Within the framework of geologic investigation for his doctor's degree STROHMENGER (1988) carried out under the guidance of his comentor DOZET sedimentological and geochemical investigations in the cross-sections Kompolje (Mala gora) and Krka-Mali Korinj in Suha krajina (STROHMENGER & DOZET, 1991; STROHMENGER et al., 1987 a, b). DOZET (1993) recorded the complete Lofer cyclothems in lower part of the Lower Jurassic beds in the Krka area that compose the slovenian part of External Dinarides. BUSER and DEBELJAK (1994/95) determined rich findings of lithiotid bivalves. DEBELJAK & BUSER (1998) added the lithiotid horizon to Pliensbachian respectively Domerian. DOZET & ŠRIBAR (1981, 1997) and DOZET (1990 a) recognized and proved almost all litho- and biostratigraphic units applied for subdivision of the Jurassic stratigraphic sequence in Dinarides. Dozet (1999 a, b) explored and described Lower Jurassic shallow-water carbonate succession with coal on the Dinaric Carbonate Platform in Southern Slovenia. The coal occurs in the form of lenses and thin seams among the limestone and dolomite beds of middle part of the Lower Jurassic age. Miler and Pavšič (2008) described the development of the Triassic and Jurassic beds in the Krim Mountain area. The Jurassic stratigraphic sequence involves Lower and Middle Jurassic shallow marine carbonate rocks.

Materials and methods

This work is based on data, obtained during the systematic regional geologic mapping in the field on the Map Sheet Grosuplje for elaboration of Geologic Map of Slovenia on the scale of 1 : 50 000, performed by Geological Survey of Slovenia. During geologic mapping of Central Slovenia we were focused on stratimetric researches in the field and systematic labor examinations. For planning of geologic mapping on the Map Sheet Grosuplje the Basic Geologic Map of SFRJ – Map Sheet Ribnica on the scale of 1:100 000 and its Explanatory text has been applied. For formation analaysis the cross-section Spodnja Slivnica-Predole has been chosen (Strohmenger & Dozet, 1991). Around 150 samples of carbonate rocks have been collected along the road on the southeastern border of Radensko polje and another 65 rock samples in the cross-section Ilova gora-Čušperk for micropaleontological analyses carried out by Rajka Radoičić and S. Dozet.

Carbonate rocks are classified according to Folk's (1959) practical petrographic classification of limestones and Dunham's (1962) classification of carbonate rocks according to depositional texture.

Results of the research work

Lower Jurassic

In the area between Spodnja Slivnica and Račna (Figure 2) five litostratigraphic units of the Lower Jurassic age is separated. Superpositionally from bottom to top they follow one other like that: 1 – bedded micritic and oolitic-oncolitic limestones, 2 – bedded *Orbitopsella* Limestones, 3 – bedded *Lithiotis* Limestones, 4 – bedded to massive oolitic and reef limestones, 5 – platy Spotty Limestones.

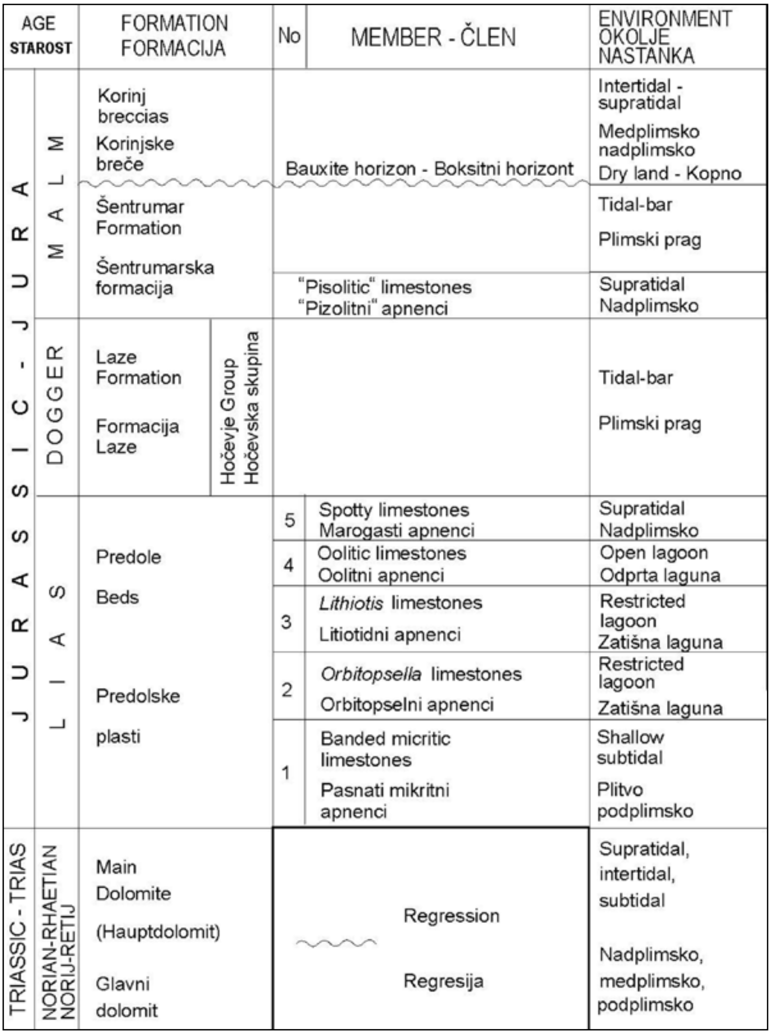

Figure 2. Stratigraphic position and environment of the Predole Beds and "pisolitic" horizon

Distribution: The Lower Jurassic limestones can be followed along the Dolenjska railway in the Spodnja Slivnica-Račna section, but Jurassic beds are, however, exposed also along the roads Mlačevo-Račna and Ilova gora-Čušperk; further on, they build the smaller hills Gradišče (486 m) and Griči (495 m and 488 m) that pass in the NW-SE direction as far as Račna. Similar limestone development is exposed also in the Krka area (Dozet & Strohmenger, 2000), where these carbonate rocks compose Podbukovje Formation respectively Krka Limestones. Also isolated small hill Kopanj (392 m) and solid bedrock of the southern part of Radensko polje are built of Lower Jurassic carbonate rocks.

Stratigraphic position. We already mentioned, that about 325 m thick succession of limestones and to much minor extent of dolomites that compose Lower Jurassic carbonate succession lies conformably between the underlying Main Dolomite and overlying Laze Formation (Figure 2). Conformably upon the Main Dolomite repose bedded micritic and biomicritic limestones with algae *Palaeodasycladus*, that together with other fossils prove the Lower Jurassic age of the limestones. Platy and thin-bedded Lower Jurassic Spotty Limestones pass gradually upward into dark grey to grayish black oolitic limestones with Middle Jurassic diagnostic foraminifer *Gutnicella (Dictyoconus) cayeuxi* Lucas and *Spiraloconulus giganteus* Cherchi & Schroeder as well as alga *Holosporella siamensis* Pia. Dark oolitic limestones overlying the Lower Jurassic sequence correspond accordingly to the Laze Formation from Hočevje Group (Dozet, 2000 b). Also the upper boundary of the Lower Jurassic sequence is conformable, since the Lower Jurassic Spotty Limestones pass gradually into the dark oolitic limestones of Middle Jurassic age. Quite other case is with the Lower Jurassic carbonate sequence of Podbukovje Formation (Dozet & Strohmenger, 2000) where erosional discordance between the Lower Jurassic and Middle Jurassic sequences have been recorded and the relatively small thickness (only 15 m) of the Lower Jurassic dark platy limestones is explained, that greater part of Spotty Limestones was eroded.

Description of lithostratigraphic units

1st Unit – Bedded micritic (mudstone) limestones, Hettangian and Sinemurian

The oldest unit of Lower Jurassic limestones is represented by a carbonate succession (Figures 3, 5) in which prevail variously grey, bedded and occasionally banded (Figures 6, 7) micritic limestones containing in spots fragments of benthic foraminifers and molluscs (wackestone). Bedded micritic limestones contain sporadic interbeds of oosparitic (ooid grainstones), intraoosparitic, bioosparitic, biosparitic, biomiciritic and oncomicritic limestones, that alternate rhythmically. In the thick-bedded oosparitic limestones (ooid grainstones: Pl. 1, Fig. 6) are to be found intraclasts (intraclastic grainstones) and bioclasts (bioclastic grainstones). Intraclasts are subangular to poorly rounded and up to one centimeter in size. They belong to micritic, biosparitic, intrasparitic and laminated limestones. Bioclasts are represented by more or less rounded and micritized

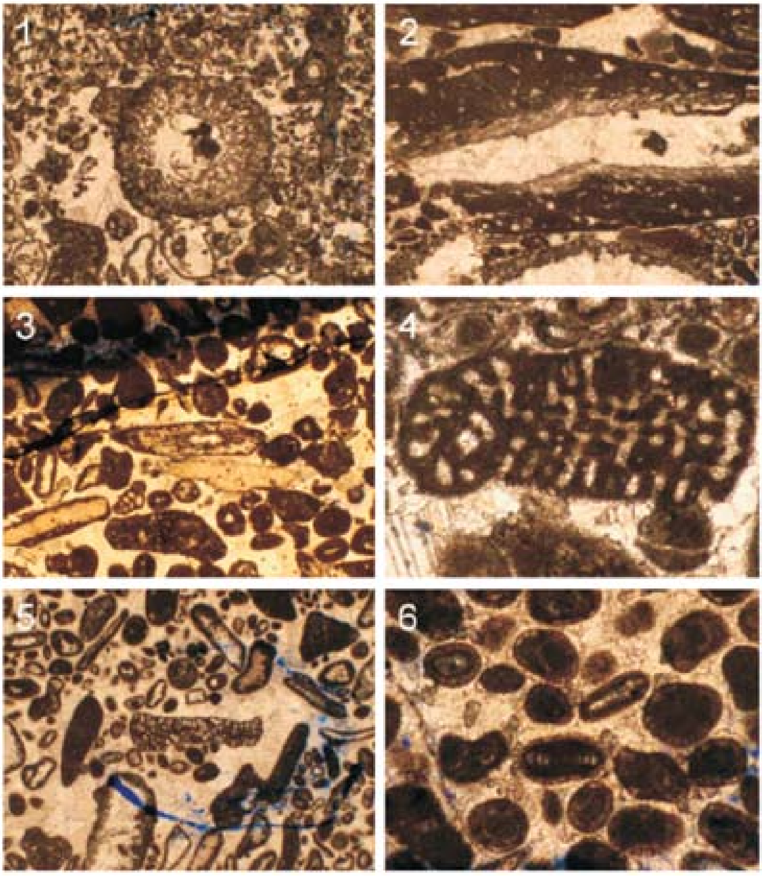

Plate 1. Fig. 1. Bioclastic packstone with algae *Palaeodasycladus mediterraneus* (Pia) and strongly changed (micritized) *Thaumatoporella parvovesiculifera* (Raineri) as well as foraminifers Textulariidae and Trochaminidae, Lower Lower Jurassic, Predole at Račna; **Fig. 2.** Strongly recrystallized mollusc fragment and alga *Palaeodasycladus elongatulus* Praturlon coated with algal or cyanobacterial crust as well as foraminifers Textulariidae, Lower Lower Jurassic, Predole at Račna; **Fig. 3.** Bioclastic-ooid grainstone with alga *Palaeodasycladus elongatulus* Praturlon and foraminifers *Orbitopsella praecursor* (Gumbel), Verneuilinidae, Textulariidae, Trochaminidae and echinoderms, Middle Lower Jurassic, Predole at Račna; **Fig. 4.** Foraminifer *Lituosepta recoarensis* Cati, Middle Lower Jurassic, Predole at Račna; Fig. 5. Foraminifers *Orbitopsella* sp. and *Trocholina* sp. in the bioclastic-intraclastic grainstone Lower/Middle Lower Jurassicsic, Predole at Račna; **Fig. 6.** Ooid-grainstone with foraminifer *Agerina* sp., Middle Lower Jurassic, Predole at Račna.

fragments of algae, molluscs and foraminifers (Pl. 1, Fig. 5). Some beds of the lower part of the Lower Jurassic carbonate succession were subjected to selective late diagenesis. Dolomitization affected especially coarse-grained sparitic limestones (grainstones), so that the limestones pass in spots into coarse-grained respectively coarse-crystalline dolomite. There are also pretty much strongly dolomitized limestones. The intergranular pores in the limestones of the grainstone type are filled with fibrous calcite cement A and/or mosaic sparry cement B.

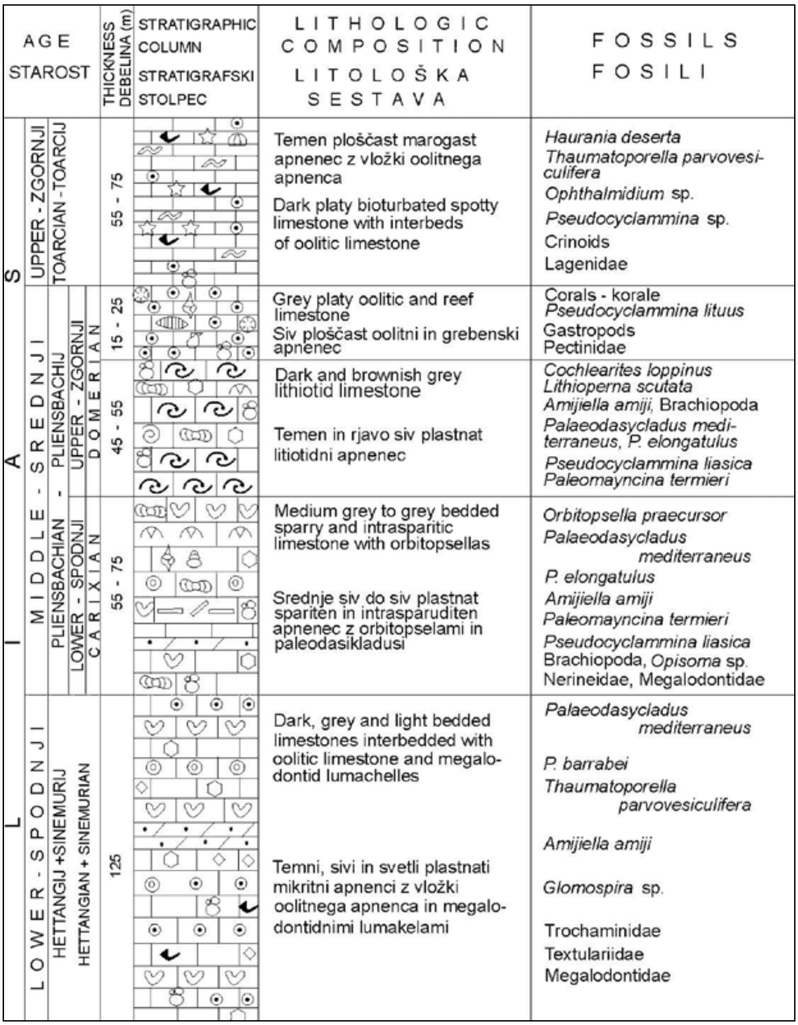

Figure 3. Stratigraphic column of the Lower Jurassicsic Beds in Predole at Račna area (Dolenjska)

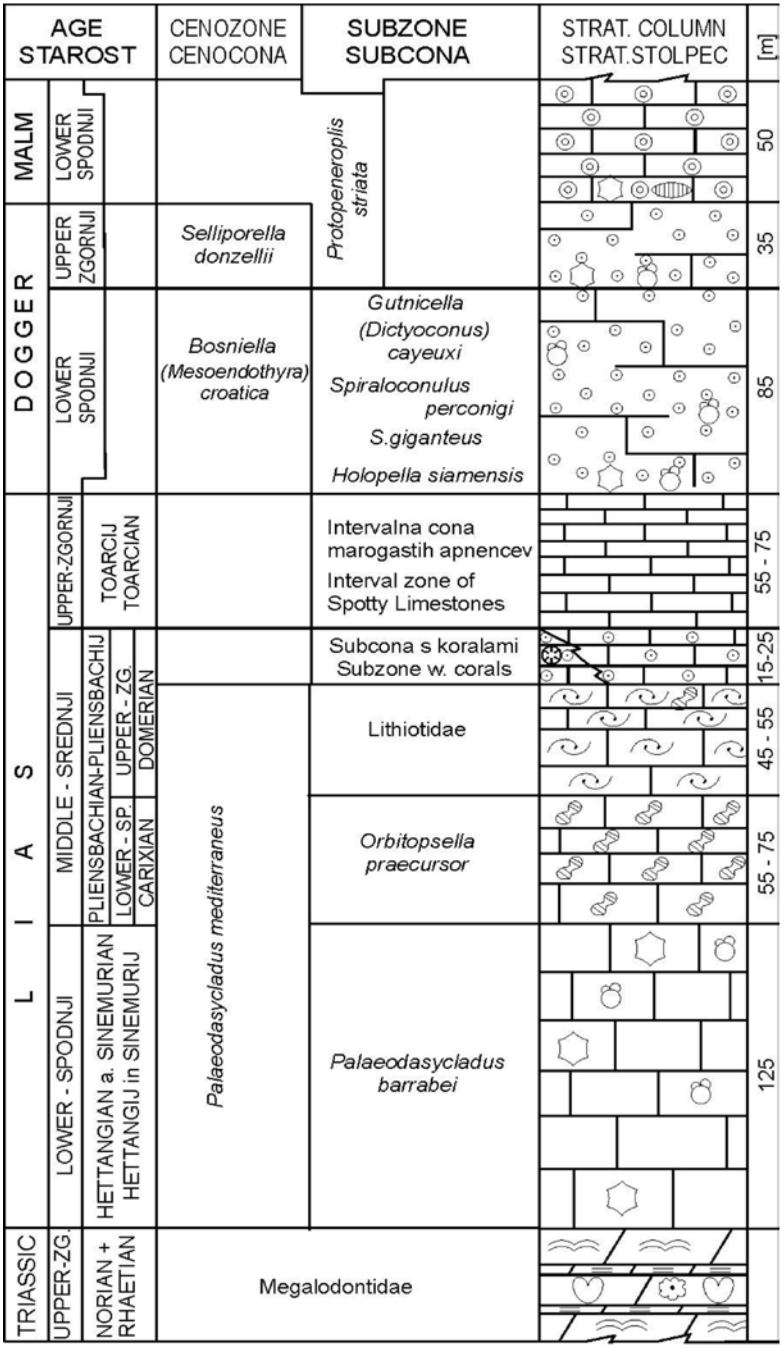

Figure 4. Biostratigraphic subdivision of Jurassic beds on the northern margin of Dinaric Carbonate Platform

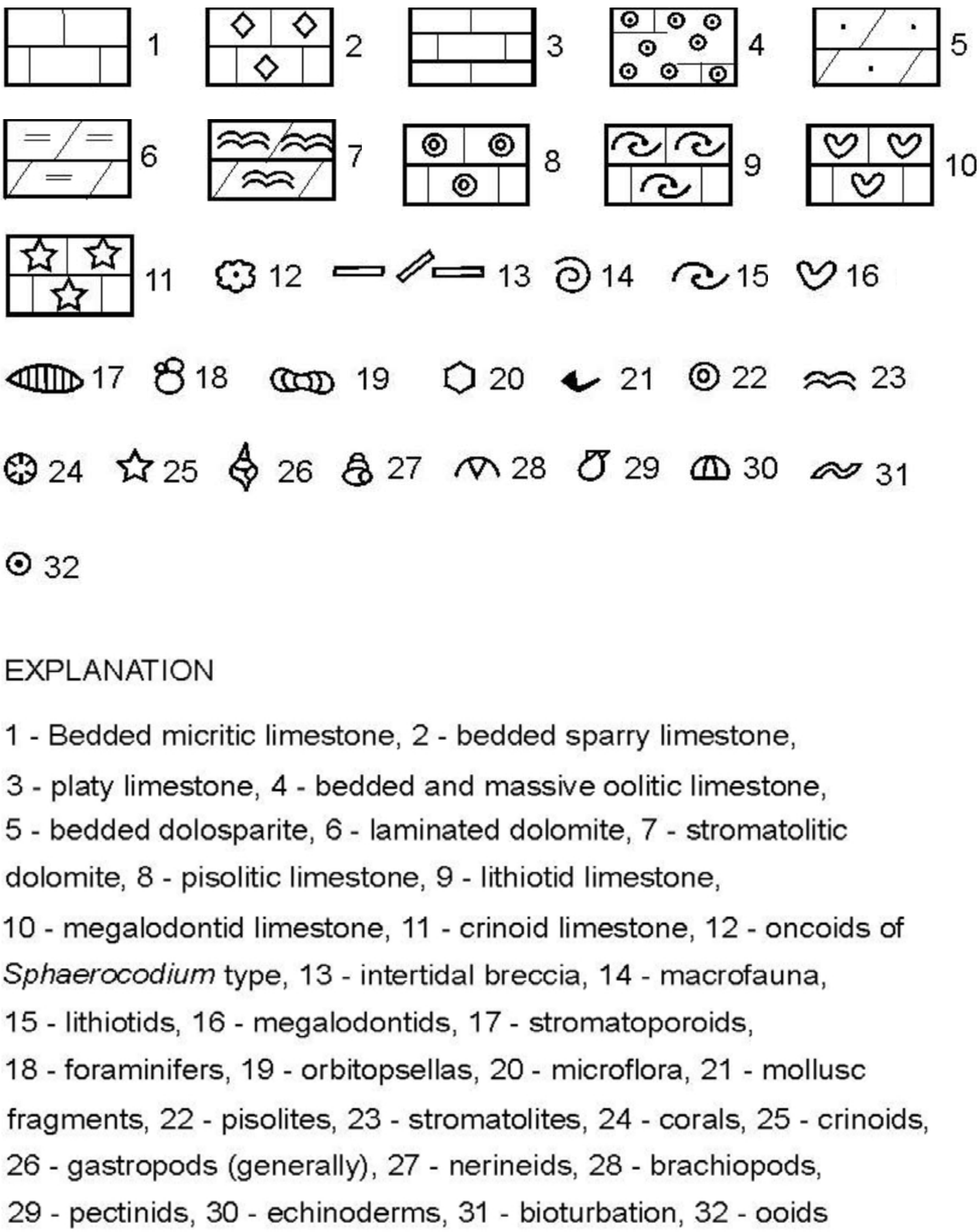

Figure 5. Explanation

Figure 6. Grey bedded Lower Lower Jurassic micritic limestone

Figure 7. Bedded and banded Lower Lower Jurassic micritic limestone

Oolitic limestone interbeds are composed of ooids with radial microstructure and micritic ooids. They are bound with fibrous and mosaic calcite cement. The oolitic limestones with radial ooids originated in shoals with moderately agitated water (TIŠLJAR & VELIĆ, 1991). Micritic ooids are the result of diagenetic changes, chiefly due to micritization by *Cyanophiceae* and cryptocrystalline recrystallization.

Limestones of wackestone and mudstone type were deposited in a shallow subtidal environment in a restricted part of lagoon, while coarse-grained sparitic limestones originated in an intertidal belt, what is proved by erosional surfaces, stromatolitic belts, fenestral structures and textures, intraclasts, shrinkage pores and intertidal breccias.

The lower unit of Lower Jurassic carbonate sequence is relatively poor in fossils, what point at unfavourable life conditions for the then fauna and flora. Important characteristics of the oldest unit is especially an absence of echinoderms and rarity of foraminifers and molluscs (Figure 8). Limestones of the lowermost unit of Lower Jurassic succession contain the following fossils:

Figure 8. Black bedded limestone with megalodontid lumachelles, Lower Lower Jurassic, Radensko polje

Palaedasycladus mediterraneus (Pia) (Pl. 1, Fig. 1), *P. elongatulus* (Pratur-

Figure 9. Medium light grey massive limestone with interbeds of fine-grained intraformational breccia, Middle Lower Jurassic

Figure 10. Medium grey *"Megalodon"* Limestone, Middle Lower Jurassic

lon) (Pl. 1; Fig. 2, 3), *Palaeodasycladus* sp., *Sestrosphaera Lower Jurassicina* Pia, *Thaumatoporella parvovesiculifera* (Raineri), Codiaceae, *Cayeuxia*, *Amijiella amiji* (Henson), *Lituosepta recoarensis* Cati (Pl. 1, Fig. 4), *Haurania* sp., *Glomospira* sp., *Everticyclammina* sp., *Trocholina* sp., Textulariidae, Verneuilinidae, Trochaminidae, *Paleomayncina termieri* (Hottinger), Nerineidae and *Favreina salevensis* Parèjas. With reference to above listed fossil contents the lowermost limestones are ranged in the Hettangian and Sinemurian stages of the Lower Jurassic series.

The thickness of the first unit of the Lower Jurassic carbonate succession is estimated on around 125 m.

2nd Unit-Orbitopsella sparitic Limestones, Lower Pliensbachian (Carixian)

In the second lithostratigraphic unit predominate thick-bedded, medium grey, grey, dark grey and very dark grey prevalently sparitic limestones containing benthic foraminifer *Orbitopsella*; and that is why we designated them as ***Orbitopsella*** **Limestones** (Figures 3, 5). In considered limestones occur sporadic interbeds of breccia (Figure 9), oncoid (Figure 11), gastropod and megalodontid limestones (Figure 10). In this unit can also be seen a certain rhythmism of sedimentation, since there is present an alternation of micritic sediments (mudstone/wackstone) with sediments of packstone/floatstone and grainstone/rudstone type that contain oncoids, intraclasts, small megalodontids, gastropods (Figure 13) and horizons of oolitic limestones, benthic foraminifers and green algae, above all dasyclads. The rhythmic sedimentation is a consequence of sea-level oscillation.

Figure 11. Medium light grey oncolitic limestone, Middle Lower Jurassic

Figure 12. Medium light grey biomicritic limestone with small brachiopods, Middle Lower Jurassic

Figure 13. Medium grey biooncomicritic limestone with small gastropods, Middle Lower Jurassic

In the *Orbitopsella* Limestones the following fauna and flora have been determined: *Orbitopsella praecursor* (Gümbel) (Pl. 2, Fig. 1), *Lituosepta recoarensis* Cati, *Planisepta compressa* (Hottinger), *Involutina farinacciae* Bronnimann & Zaninetti (Pl. 2; Fig. 2, 3), *Thaumatoporella parvovesiculifera* (Raineri), *Paleomayncina termieri* (Hottinger), *Haurania deserta* Henson, *Agerina martana* (Farinacci), *Glomospira* sp., *Pseudocyclammina liassica* Hottinger, *Palaeodasycladus mediterraneus* (Pia), *Aeolisaccus dunningtoni* Elliott, *Linoporella (Tersella ?) lucasi* Cross & Lemoine (Pl. 2, Fig. 4), Codiaceae, *Cayeuxia* sp.and *Favreina salevensis* Parèjas, *Lenticulina* sp., gastropods *Opisoma* sp. and Nerineidae, as well as pelecypods Megalodontidae and Pectinidae. Above-enumerated fossil fauna and flora as well as the stratigraphic position range this unit of considered sediments in the Lower Pliensbachian stage (VELIĆ, 1977).

Orbitopsella Limestones were formed in a restricted shallow-marine environment with periodically agitated water, lagoon and shallow-subtidal environments respectively.

The thickness of the second unit of the Lower Jurassic carbonate succession (prevalently limestones with dolomite interbeds) ranges from 55 m to 75 m.

3rd Unit – *Lithiotis* Limestones, Upper Pliensbachian (Domerian)

Limestones with rock-building shells of Lithiotidae bivalves represent one of most characteristic and important facies in the Jurassic carbonate succession on the Dinaric Carbonate Platform (Figures 3, 5). The main particularity of this facies are bivalves of the family Lithiotidae, which are accumulated in carbonate sediments in the form of more or less thick lumachelles. The horizontal respectively parallel orientation of lithiotid shells in lumachelles indicates a transport of broken lithiotids from adjacent patch-reefs and shoals. Next to lithiotids, that are most important constituent part of these limestones, contribute to their composition also brachiopods (Figure 12), that appear in the lowermost and topmost part of the third unit. In the lower part of this unit there is also several lumachelles with megalodontids (Figure 14). The *Lithiotis* Limestones are grey, dark grey, dark brownish grey to grayish black, thick-bedded micrites (mudstones), biomicrites (wackstones) or biosparites (packstones, grainstones). Intermediate beds between lumachelles belong to biosparitic, biomicritic and biointrasparitic limestones. Some lithiotid and intermediate coarse-grained beds are more or less late diagenetically dolomitized. The considered limestones are medium to thick-bedded. Various textural types of limestones alternate rapidly having in spots interbeds of coarse-grained dolomite. Very rarely they are fine-laminated or even poorly stromatolitic.

Figure 14. Around 0,75 m thick "*Lithiotis*" lumachelle within the Middle Lower Jurassic grey bedded dolomitic limestone

Figure 15. Lumachelle from lithiotid genera *Cohlearites* and *Lithioperna* in the grey bedded Middle Lower Jurassic limestone

Lithiotis Limestones contain the following fauna and flora: *Cochlearites loppianus* (Tausch) and *Lithioperna scutata* (Dubar) (Figure 15), Brachiopoda, Megalodontidae (see Buser & Debeljak, 1994/95 and Debeljak &

BUSER, 1997), *Palaeodasycladus mediterraneus* (Pia), *Amijiella amiji* (Henson) and *Pseudocyclammina liassica* Hottinger. Concerning the collected fossils and with regard to stratigraphic position the *Lithiotis* Limestones belong to the Upper Pliensbachian, Domerian respectively.

During the early and middle Lower Jurassic the depositional environments were marked by continuous deposition of sheltered subtidal and intertidal zones, where periodically occurred suitable conditions for an extensive growth of calcareous algae, foraminifera, lamellibranches (especially lithiotids and megalodontids), gastropods and brachiopods.

The thickness of the third unit of Lower Jurassic lithologic column ranges from 45–55 meters.

4th Unit – Oolitic Limestones, Uppermost Pliensbachian

Above the beds with lithiotid bivalves known under the name *Lithiotis* Limestones lies a packet of thick-bedded and rarely platy or massive oosparitic (ooid grainstone), bioosparitic, intraoosparitic and intrabiosparitic, medium to dark grey, medium-grained limestones, we denoted as Oolitic Limestone unit (Figures 3, 5). Concordantly over the Oolitic Limestone unit repose the Spotty Limestones.

The Oolitic Limestone unit consists of pretty pure oosparitic limestones (ooid grainstones). Fragments of fossils occur in these limestones as a rule in ooid cores. Ooids reach the size no more than 1 milimeter. There are ooids with radial and concentric structure. Some ooids are tectonically deformed and more or less micritized, so that the inner structure is in greater or minor extent rubbed out. There are also ooids that were broken off and anew overgrown; on the other hand, some ooids are recrystallized so much, that only outer envelope is still preserved. Pretty frequent are also so-called composed ooids. Ooids and intraclasts are bound in medium-grained sediment with fibrous and mosaic calcite cement and they are more or less late diagenetically dolomitized. The oolitic limestones exibit occasionally a well-developed cross-stratification and contain thin horizons of superficial oolites. They look like pellets and are built of micritic mud enclosed by microsparitic envelope.

In the oolitic limestones rare larger fragments of algae and molluscs can be obtained as well. Recognized are also well-preserved prints of pectinids. In the Oolitic Limestone unit a late diagenesis is often present so that these limestones can pass in places into more or less dolomitized oolitic limestones, and somewhere even into coarse-grained respectively coarse-crystallized dolomite.

The described oolitic limestones were formed in an evironment with high-water energy, in shoals and bars respectively.

In the limestones of the Oolitic Limestone unit sections of alga *Palaeodasycladus mediterraneus* (Pia), rare foraminifers *Pseudocyclammina liassica* Hottinger and *Haurania deserta* Henson, pointing at upper part of middle Lower Jurassic (Domerian) as well as rare fragments of crinoids, molluscs, corals, stromatoporoids and pelecypod *Pecten* sp. were found.

The Oolitic Limestone unit is found in several places of central and southern Slovenia. In the oolitic-bioclastic limestones, that lie above the *Lithiotis* Limestone and are accordingly an equivalent of the Oolitic Limestone unit of the Lower Jurassic stratigraphic sequence, a corral patch reef with rich associations of corals and stromatoporoids were detected on Krim (Turnšek & Košir, 2000) and Trnovski gozd (Turnšek et al., 2003). Turnšek and Košir (2000) described systematically seven coral species, from which three species are new: *Thecactinastraea krimensis* Turnšek, *Siderosmilia perithecata* Turnšek and *Cuifastraea lopatensis* Turnšek. Turnšek et al. (2003) found in Trnovski gozd in the Lower Jurassic patch reef, lying upon the *Lithiotis* Limestone, a finding of Lower Jurassic corals. Systematically were determined and described 12 coral species belonging to eight genera. Four species were new: *Protoheterastraea trnovensis* Turnšek, *Apocladophyllia gozdensis* Turnšek, *Phacelophyllia bacari* Turnšek and *Heterostraea angelae* Turnšek. Corals built at least 70 meters long and 4 meters large patch reef, that grew on the northern border of the Dinaric Carbonate Platform. The corals range the Lower Jurassic reef limestone of the Trnovski gozd in Upper Pliensbachian, Domerian respectively.

The Domerian Oolitic Limestone originated in shallow and open parts of the Dinaric Carbonate Platform.

The thickness of Uppermost Pliensbachian oolitic limestones ammounts from 15 to 25 meters.

5th Unit – Spotty Limestones, Toarcian

The youngest unit of considered carbonate sequence (Figure 16) is composed of medium dark grey, dark grey and grayish black, platy (predominate) and bedded prevalently micritic (mudstone) and pelmicritic bioturbated limestones, which are due to activity of numerous organisms, that ate mud, became spotty. For the Spotty Limestones (Figures 3, 5) is also pretty characteristic that they are poor in fossils. They contain only rare remains of algae, benthic foraminifers and echinoderms. According to texture they are mostly micritic, oomicritic and biomicritic limestones. In the limestones of the fifth unit locally a gently lamination can be observed. The stratigraphic sequence of Spotty Limestones include sporadic thinner interbeds of oolitic and bioclastic limestones (crinoid limestones: Pl. 2, Fig. 5).

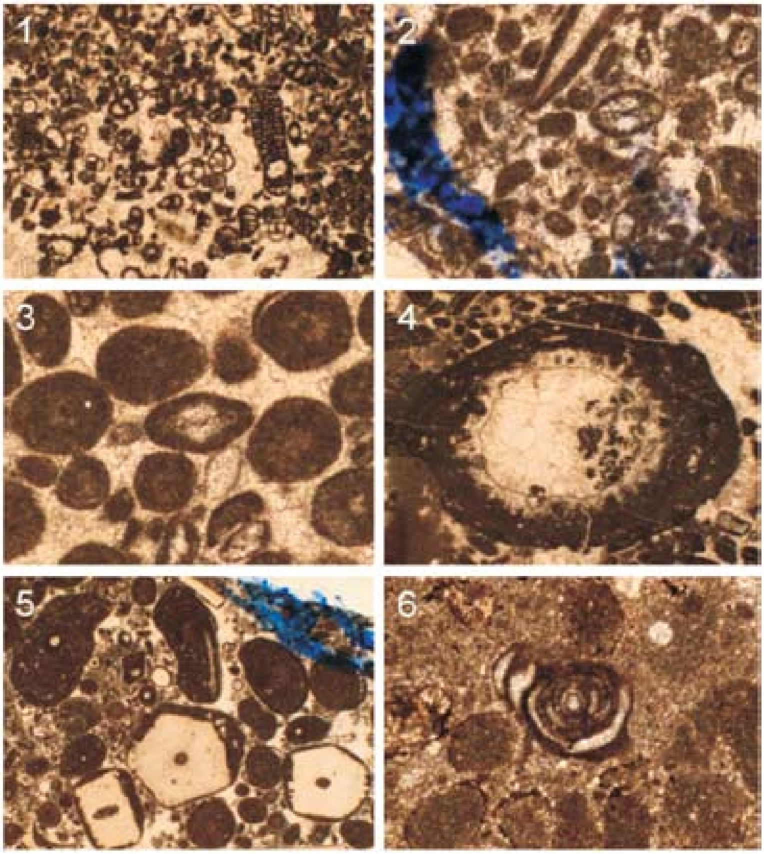

Plate 2. Fig. 1. Bioclastic-peloid packstone to grainstone with foraminifers *Orbitopsella praecursor* (Gümbel) Trochaminidae and Textulariidae, Middle Lower Jurassic, Predole at Račna; **Fig. 2.** Foraminifer *Involutina farinacciae* Bronnimann & Zaninetti in an intrasparitic packstone, Middle Lower Jurassic, Predole at Račna; **Fig. 3.** Ooid grainstone with foraminifer *Involutina farinacciae* Bronnimann & Zaninetti, Middle Lower Jurassic, Predole at Račna; **Fig. 4.** Alga *Linoporella (Tersella ?) lucasi* Cross & Lemoine coated with algal (cyanobacterial) envelope, Middle Lower Jurassic, Predole; **Fig. 5.** Crinoid limestone: bioclastic-intraclastic packstone, Upper Lower Jurassic, Predole at Račna; **Fig. 6.** Recrystallized ooid mudstone with foraminifer *Ophthalmidium* sp., Upper Lower Jurassic/ Dogger, Predole at Račna.

Figure 16. The contact between the underlying medium grey massive Middle Lower Jurassic oolitic limestone and the verlying dark platy Upper Lower Jurassic Spotty Limestone

Upper part of the Lower Jurassic limestones contain rare foraminifers *Haurania deserta* Henson, *Ophthalmidium* sp. (Pl. 2, Fig. 6), *Pseudocyclammina* sp., crinoids, small gastropods as well as algae *Aeolisaccus dunningtoni* Elliot and *Thaumatoporella parvovesiculifera* (Raineri).

The age of considered carbonate rocks is defined also by their stratigraphic position, since they lie between the Lower Jurassic biostromal (coral) beds and dark oolitic limestones with diagnostic Middle Jurassic fossils, so that they are surely of Toarcian age.

According to dark colour, abundant bituminous organic matter, structures and texture and regarding the fauna (ostracods, molluscs with thin shells) and flora can be concluded that the Spotty Limestones were deposited in restricted parts of shelf, where there were no favorable conditions for greater diversity of organisms.

The thickness of upper part of the Lower Jurassic limestones varies from 55 m to 75 m.

Midle Jurassic

Hanging wall of the considered carbonate succession is represented by a stratigraphic sequence (Figure 4, 5) of dark brownish grey to grayish black oolitic limestones (ooid grainstones) that are an equivalent of the Middle Jurassic Laze Formation (Dozet, 2000 a). They are overlain by around 50 meters thick horizon of "pisolitic" limestones (pisolite grainstones).

Around 85 meters thick Middle Jurassic lithologic column is composed of thin- and thick-bedded, well-sorted, prevalently medium-grained ***oolitic limestones*** (Figure 17). In the considered carbonate sediments predominate from 0,5 mm to 0,75 mm large ooids, but there are also more or less rounded intraclasts, bioclasts, pellets and pelletoids. In the field can be followed oosparitic (ooid grainstones), oointrasparitic, intrasparitic (intraclast grainstones), biosparitic (bioclast grainstones) as well as smaller patches of oomicritic and pure micritic limestones. In the composition of oolitic limestones strongly prevail medium-

Figure 17. Medium grey massive Dogger oolitic limestone

Figure 18. Grey to medium grey platy or bedded Lowermost Malm "pisolitic" limestone

grained well-sorted radial ooids bound with mosaic calcite cement, here and there with isopach granular cement A as well.

Among organogenic remains prevail foraminifers (Textulariidae, Trochaminidae and Verneuilinidae), that represent mostly cores of ooids. Paleontologically and biostratigraphically significant (RADOIČIĆ, 1987) for these carbonate rocks are Aalenian alga *Holosporella siamensis* Pia (Pl. 3; Fig. 1, 2, 3, 4) as well as foraminifers *Spiraloconulus giganteus* Cherchi & Schroeder (Pl. 3; Fig. 5, Fig. 6) and *Gutnicella (Dictyoconus) cayeuxi* Lucas. Oolitic limestones contain also greater or minor fragments of molluscs, echinoderms, pretty rare sections of stromatoporoids, alga *Thaumatoporella parvovesiculifera* (Raineri) and corals, that represent free clasts in sparitic cement.

Interbeds of micritic and sparitic limestones in the considered oolitic complex speak for subtidal to intertidal sedimentary environment in close vicinity of tidal channels. The isopach granular cement A indicates an episodic meteoric influence.

Upward follows 50 m thick lithologic interval (Figure 4, 5) represented by platy and bedded medium dark grey ***"pisolitic" limestones*** (Figure 18) composed of 1 cm to 2,5 cm large concentric pisolites, bound with coarse-crystallized (sandy) greatly dolomitized sparitic cement. Late diagenesis usually did not embrace pisolites. It took only sparitic cement, and in spots it changes the rock in a pure dolosparite. Similar "pisolitic" horizon is also found along the road between Vrhnika and Logatec, on Hrušica, at Vodice and to the east of Col (BUSER, 1978), This horizon within the Middle and Upper Jurassic oolitic limestones has been up to then ranged to Middle Jurassic, but BUSER

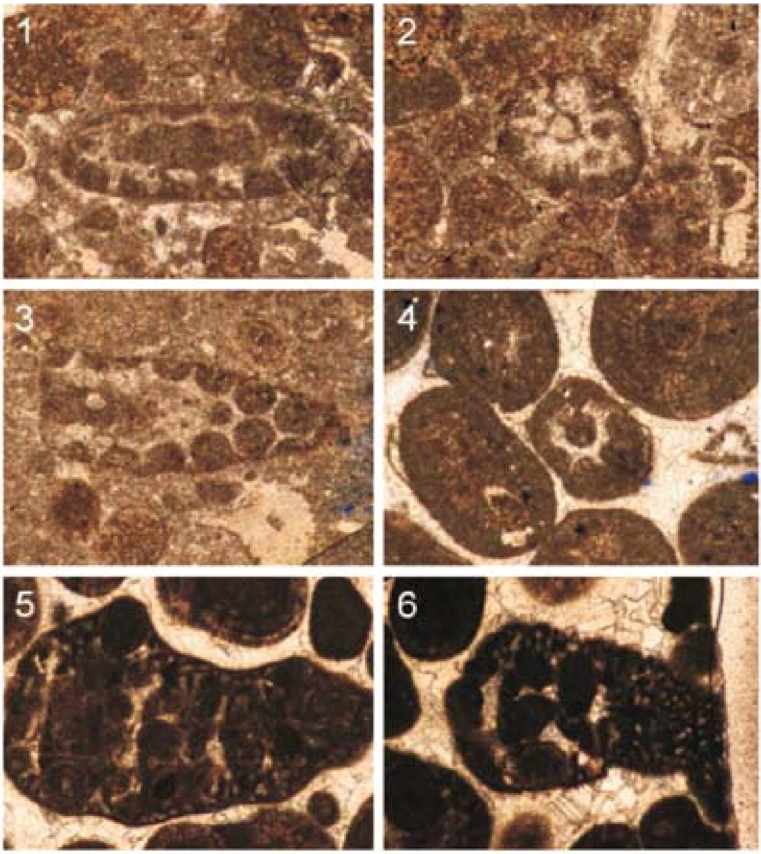

Plate 3. Fig. 1. Ooid wackstone-packstone with alga *Holosporella siamensis* Pia, Lower Dogger (Aalenian), Predole at Račna; **Fig. 2.** Ooid packstone with a section of alga *Holosporella siamensis* Pia, Lower Dogger (Aalenian), Predole at Račna; **Fig. 3.** More ore less recrystallized ooid-wackestone with section of alga *Holosporella siamensis* Pia, Lower Dogger (Aalenian), Predole at Račna; **Fig. 4.** Ooid grainstone with alga *Holosporella siamensis* Pia, Lower Dogger (Aalenian), Predole at Račna; **Fig. 5.** Foraminifer *Spiraloconulus giganteus* Cherchi & Schroeder in a coarse-grained ooid grainstone, Dogger, Predole at Račna; **Fig. 6.** Foraminifer *Spiraloconulus giganteus* Cherchi & Schroeder in a coarse-grained ooid grainstone, Dogger, Predole at Račna.

(1978) found bellow that horizon corals and hydrozoans, that proved the "pisolitic" horizon belongs already to the lowermost (basal) part of Upper Jurassic.

The "pisolitic" limestone at Predole contains the following fauna and flora: *Trocholina alpina* (Leupold), *Clado-*

coropsis mirabilis Felix, *Aeolisaccus dunningtoni* Elliott and *Cayeuxia* sp.

In the succession of oolitic limestones, that lie above the Lower Jurassic beds, we found and determined the following fossils: *Trocholina elongata* (Leupold), *Salpingoporella annulata* Carozzi and *Kurnubia palastiniensis* Henson.

On the basis of determined fauna and flora as well as considering correlation of the "pisolitic" limestones at Predole and "pisolitic" horizons on Hrušica, at Vodice, between Vrhnika and Logatec as well as east of Col (BUSER, 1978) the 50 meters thick succession of "pisolitic" limestones at Predole is attributed to Upper Jurassic, to the lowermost part of Upper Jurassic more precisely, that is overlain by the Upper Jurassic oolitic complex corresponding to the Šentrumar Formation (DOZET, 2000 b) or to the upper part of the Verd Oolitic Complex (DOZET, 2000 a).

PALEOGEOGRAPHIC EVOLUTION AND CORRELATION OF UPPER TRIASSIC TO MIDDLE JURASSIC SEDIMENTATION

This chapter deals with sedimentation and paleogeography in the Predole area on the northern margin of the Dinaric Carbonate Platform.

In the Norian and Rhaetian periods originated in the Predole area and the whole southern Slovenia on the stable Dinaric Carbonate Platform the well-known 900 to 1300 meters thick formation of Main Dolomite. It was formed in pretty shallow restricted environment, where supratidal, intertidal and subtidal conditions alternated. The most typical for the Main Dolomite is so-called Lofer facies (SANDER 1936, FISCHER, 1964) respectively cyclic alternation of red or green residual sediments (supratidal unit A), fenestral and stromatolitic dolomites, breccias (intertidal unit B) and micritic dolomites with megalodons – subtidal unit C (OGORELEC, 1988; DOZET, 1990 b, 1991; OGORELEC & ROTHE, 1992). The Rhaetian-Lower Jurassic development in the Krim Mountain area is interpreted (MILER & PAVŠIČ, 2008; MILER et al., 2007) as a consequence of short-termed marine regression that was also evidenced in the Northern Calcareous Alps (MC ROBERTS et al, 1997; KRYSTYN et al., 2005).

The sea-level changes in the Northern Calcareous Alps are explained as a consequence of a short-termed tectonic uplift, possibly a regional thermal uplift connected to the activity in the Central North Atlantic Magmatic Province, and slow rebound within a locally or regionally limited area (KRYSTYN et al., 2005). In the Lower Jurassic the sea was deepened and a sedimentation of variously grey, bedded micritic limestones interbedded with rare oolitic ones in prevalently quiet-water of restricted and episodically open lagoon followed. The deepening of the environment is interpreted as a consequence of global sea-level rise (Hallam, 1997; Mc Roberts et al, 1997; Miler & Pavšič, 2008).

In the Predole area the variously grey bedded micritic (mudstone), sparitic, oncolitic, laminated and stromatolitic dolomites of the Main Dolomite Formation pass upwards directly into the bedded prevalently micritic (mudstone) Lower Jurassic limestones so that the geological relations at the Triassic/Jurassic boundary were normal. Namely, in the Predole area the Rhaetian-Lowermost Jurassic breccia unit occurring in central Dolenjska (Buser, 1974; Dozet 2003 and Miler et al.) is not developed, what testifies that in the Uppermost Rhaetian and Lowermost Jurassic there were no larger tectonic movements in this area.

Sedimentologic particularities, fauna and flora show that the Lower Jurassic Krka Limestones in central Dolenjska (Dozet & Strohmenger, 1993) originated in similar sedimentary conditions as Dachstein Limestone and Main Dolomite in Northern and Southern Calcareous Alps. All three formations are namely characterized by typical Lofer rhythmic sedimentation.

The Lower Jurassic epoch is marked by lithiotid limestones. Lithiotid bivalves formed in southern Slovenia in prevalently quiet water environment of the restricted shelf sea-bottom mats or biostromes. Their shells can be only rarely found in their growth position (Buser & Debeljak, 1994/1995). The up to 75 m thick horizon with lithiotid bivalves is attributed to Pliensbachian. At high tides and storms the fresh water overflowed the adjacent barring "oolitic sand". Consequently, inside the former lagoon with lithiotid biostromes, dark oolitic limestones can be found as well.

Uppermost part of the middle Lower Jurassic is represented by a horizon of oolitic limestones originated in high energy open shallow-water environment (Dozet & Šribar, 1997; Dozet & Strohmenger, 2000).

The upper part of the Lower Jurassic intensively bioturbated Spotty Limestones with high organic contents were formed in a low-energy restricted lagoon environment. The Spotty Limestones contain rare interbeds of oolitic limestone that indicates an alternation with episodic high energy open shallow-water environment (Orehek & Ogorelec, 1981; Dozet & Šribar, 1997) The high organic contents in the Spotty Limestones is explained as a consequence of Toarcian Ocean anoxic event (Hallam, 1986; Jenkyns, 1998;

Miler & Pavšič, 2008).
During the Lower Jurassic epoch in the region of Tethys vivaceous tectonic movements occurred. In northern Slovenia area a short land phase took place, and afterwards it rapidly subsided and disintegrated (Buser, 1989). These events reached also the Dinaric Carbonate Platform. In the Stična, Šentvid, Radohova vas, Trebnje, Veliki Gaber and Valična vas areas the Upper Jurassic beds transgressively overlie the middle Lower Jurassic ones. In central Dolenjska numerous coal occurrences are known (Buser, 1974; Dozet, 1999 a, b). All this may be understood as an evidence of an uplift of the area after the deposition of the Lower Jurassic sediments with bivalves. The same tectonic activity was reported also from the neighbouring Italy. On the Trento Carbonate Platform the shallow marine beds with bivalves are overlain by deep marine limestone of the ammonitico rosso type (Bosellini & Broglio Loriga, 1971).

During the Middle Jurassic the paleoeogeography of southern Slovenia was marked by high-energy environments especially on the northern margin of the Dinaric Carbonate Platform.

Jurassic rocks and fossils from the cross-section Krka-Mali Korinj in Suha krajina (Strohmenger & Dozet, 1991) clearly indicate a smaller stratigraphic gap during the Middle Jurassic epoch. The identified index fossils indicate an age older than Callovian or older than Upper Callovian respectively. Perhaps the break in sedimentation coincides with the assumed fall of sea-level during the Callovian or at the end of the Bathonian (Hallam, 1987, 1997; Bosellini et al., 1981).

Conclusions

- The considered territory is situated in the southeastern border of Radensko polje (southeasterly of Ljubljana) comprising smaller hills Gradišče (486 m) and Griči (492 m and 488 m). From the palaegeographic point of view the area in question belongs to the Dinaric Carbonate Platform (Buser, 1989), geotectonically however, to the macrotectonic unit of External Dinarides (Placer, 1998).
- According to the mineral composition monotonous, and with reference to texture pretty diverse carbonate succession, consisting prevalently of various limestones with some dolomite interbeds and lying conformably upon the Main Dolomite and conformably (gradual transition) under the dark oolitic limestones of Laze Formation (Dozet, 2000 b), is considered as an equivalent of the Podbukovje Formation (Dozet & Strohmenger, 2000) .

- The discussed stratigraphic sequence between Predole and Mlačevo is composed of five lithostratigraphic units:
- 1 – Micritic and oolitic-oncolitic limestones, 2 – *Orbitopsella* Limestones, 3 – *Lithiotis* Limestones, 4 – Oolitic and reef limestones and 5 – Spotty Limestones.
- The first Jurassic lithostratigraphic unit is composed of bedded micritic (mudstone) limestones interbedded with oolitic (ooid grainstones) and oncolitic ones. The considered limestones are of Lower Jurassic (Hetangian a. Sinemurian) age (*Palaeodasycladus mediterraneus* Pia, *Sestrosphaera liasina* Pia). The limestones of mudstone type were deposited in a shallow subtidal environment in a restricted part of lagoon. The thickness of the first unit is about 125 m.
- In the second Lower Jurassic lithostratigraphic unit predominate thick-bedded variously grey prevalently sparitic limestones containing benthic foraminifers *Orbitopsella.* They are known under the name *Orbitopsella Limestones* and are ranged according to microfauna and microflora in the Lower Pliensbachian. The *Orbitopsella* Limestones were formed in a restricted shallow-marine environment with periodically agitated water, lagoon and shallow-subtidal environments. The thickness of the second unit ranges from 55 m to 75 m.
- Limestones with rock-bulding shells of Lithiotidae represent the third unit of the lower Lower Jurassic sequence. The main characteristic of this facies are bivalves of the family Lithiotidae that form lumachelles. According to the fossils *Cochlearites loppianus* (Tausch), *Lithioperna scutata* (Dubar) and *Palaeodasycladus mediterraneus* (Pia) they belong to the Upper Pliensbachian, Domerian respectively. During Middle and Lower Jurassic the depositional environments were marked by continuous deposition of sheltered subtidal and intertidal zones with suitable conditions for an extensive growth of calcareous alga, foraminifers, lamellibranchs, gastropods and brachiopods. The thickness of the third unit ranges from 45 m to 55 m.
- The fourth lithostratigraphic unit, lying concordantly between the *Lithiotis* Limestones and Spotty Limestones and consisting of grey massive, bedded and platy oolitic limestones is denoted as Oolitic Limestones. The Oolitic Limestones pass horizontally into reef limestones containing corals that range both facies into the Upper Pliensbachian, Domerian respectively. The Oolitic Limestones originated in an environment with high energy, in tidal channels respectively. The thickness of Uppermost

Pliensbachian Oolitic Limestones unit varies from 15 m to 25 m.

- The fifth Lower Jurassic unit is composed of prevalently dark, micritic (mudstones), bioturbated, so-called Spotty Limestones, with rare interbeds of oolitic and crinoid limestones that are all added to Toarcian. Spotty Limestones were deposited in restricted parts of shelf. The thickness of this unit varies from 55 m to 75 m.
- The Predole area and wider environs lie in southern Slovenia territory belonging paleogeographyically to the northern margin of Dinaric Carbonate Platform (BUSER, 1974), geotectonically however, to External Dinarides (BUSER, 1989; PLACER, 1998). It is built of Upper Triassic and Jurassic carbonate rocks. Upper Triassic sedimentation is represented by the Main Dolomite Formation composed of cyclic Lofer facies (SANDER, 1936; FISCHER, 1964) and originated in a shallow lagoonal subtidal, intertidal and supratidal environments. In the Predole area sediments of the Main Dolomite Formation pass upwards continually without any interruption in sedimentation directly into bedded, micritic Lower Jurassic limestones. The geological relations at the Triassic/Jurassic boundary were normal. Consequently, there were no larger tectonic movements in that time.
- The Lower Jurassic sedimentation is exclusively lagoonal and carbonate by character. In the lower part variously grey bedded prevalently micritic (mudstones) limestones with interbeds of oolites and dolomites occur. The middle part of the Lower Jurassic stratigraphic sequence consists of *Orbitopsella* and *Lithiotis* Limestones as well as Oolitic and Reef Limestones at the top. The above-enumerated carbonate sediments were formed in alternating restricted and open lagoonal environments. They coreespond to the outer part of the inner platform environments, proximal to the northern margin of Dinaric Carbonate Platform (BUSER, 1989; BUSER & DEBELJAK, 1996; TURNŠEK & KOŠIR, 2000; MILER & PAVŠIČ, 2008). Uppermost Lower Jurassic bioturbated Spotty Limestones have high organic contents. They were formed in high energy open shallow-water envioronment (DOZET & ŠRIBAR, 1997; DOZET & STROHMENGER, 2000). Oolitic limestones interbeds in the Spotty Limestones indicates an alternation with episodic high energy open shallow-water environment (OREHEK & OGORELEC, 1981; DOZET & ŠRIBAR, 1997). The high organic contents in the Spotty Limestones is explained as a consequence of Toarcian Ocean anoxic event (HALLAM, 1986; JENKYNS, 1998; MILLER & PAVŠIČ, 2008).

- The described stratigraphic sequence is of Lower Jurassic age. Bedded, prevalently banded micritic limestones with oolitic-oncolitic interbeds (1) belong to Hettangian and Sinemurian, the *Orbitopsella* Limestones (2) to the Lower Pliensbachian (Carixian), *Lithiotis* Limestones (3) to the Upper Pliensbachian (Domerian), oolitic and coral reef limestones (4) to the Uppermost Pliensbachian, and the Spotty Limestones to Toarcian.
- Biostratigraphically, in the Lower Jurassic carbonate sequence are recognized: the cenocona *Palaeodasycladus mediterraneus* (Pia), subzones *Palaeodasycladus barrabei* (Lebouche & Lemoine), *Orbitopsella praecursor* (Gümbel) and Lithiotidae, subzone with corals, as well as the interval zone of Spotty Limestones (Figure 7).
- The Middle Jurassic stratigraphic sequence in the Predole area is composed of various dark oolitic limestones of grainstone type that contain the Middle Jurassic diagnostic foraminifers: *Spiraloconulus giganteus* Cherchi & Schroeder and *Gutnicella (Dictyoconus) cayeuxi* Lucas as well as alga *Holosporella siamensis* Pia.
- The beds with above-mentioned fossils in the Predole area correspond to the beds of Laze Formation representing the lower part of Hočevje Group (Dozet, 2000 b) and are quite comparable with Muča ooid-bioclastic unit in Croatia (Velić & Tišljer, 1988). Muča ooid-bioclastic Limestones are in fact positioned within the Lim unit. The shallow-water limestones of the Muča unit are typical tidal-bar winnowed carbonate sands i.e sediments of the sixth Wilson'S (1975) standard facies belt. They originated by the transport of ooid sand and fossil detritus by tidal streams and waves and the deposition on tidal sand bars.
- With regard to determined fossil fauna and flora and on the basis of correlation of "pisolitic" horizon at Predole with "pisolitic" horizons elsewhere in Slovenia (Buser, 1978), the 50 meters thick sequence of "pisolitic" limestones at Predole is ranged into the lowermost part of Upper Jurassic.

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