

Younger Paleozoic, Mesozoic and Tertiary oolitic and oncolitic beds in Slovenia – An Overview

Mlajše paleozojske, mezozojske in terciarne oolitne in onkolitne plasti v Sloveniji – Pregled

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Abstract

Oolitic and oncoidal rocks, microfacies, depositional environments and their stratigraphic ranges in Slovenia are subjects of this article. Various types of calcareous ooids are present in the Upper Carboniferous, Permian and Tertiary (Paleocene and Miocene) beds and specially at many levels in an up to 6000 meters thick stratigraphic succession of the Mesozoic age. Sedimentological investigations have been carried out specially in the Triassic and Jurassic beds. The ooids occurring in the shallow-water and intertidal carbonate environment have been grouped into seven types and oncolites into four types. Oncolites are rather more abundant in Carnian and Norian/Rhaetian age. Late dolomitization of some oolitic beds is next to cementation the main diagenetic feature.

Izvleček

Predmet preglednega članka so oolitne in onkoidne plasti, mikrofacies, okolje nastanka ter njihova stratigrafska razširjenost v Sloveniji. Različne vrste apnenčevih ooidov najdemo v plasteh zgornjekarbonske, permske in terciarne (paleocen in miocen) starosti, posebej pestro pa so zastopane v več stratigrafskih nivojih mezozojskega obdobja, ki lahko doseže debelino tudi do 6000 metrov. Sedimentološko so bile v ta namen raziskane predvsem triasne in jurske plasti. Ooide, ki so nastajali v različnih okoljih plitvomorskega in medplimskega karbonatnega okolja, lahko razvrstimo v sedem skupin, onkoide pa v štiri skupine. Onkoidi so nekoliko pogostejši v karnijskem in norijsko/retijskem obdobju. Ponekod je tako oolitne kot onkoidne plasti zajela poznodiagenetska dolomitizacija.

Introduction

During regional and detailed geological mapping for the Basic Geological Map of SFR Yugoslavia on the scale of 1 : 100,000 (1964–1988) as well as stratimetric profilings through the Uppermost Permian and Mesozoic carbonate beds in Slovenia numerous oolitic horizons at various stratigraphic levels in different geotectonic units have been ascertained and described. Some oolitic beds were observed also in the Upper Carboniferous and Lower Permian succession in Karavanke Mts., in the Paleocene limestone of the Karst region and in Upper Miocene (Badenian) biocalcarenes in the northeastern Slovenia.

The purpose of this paper is to describe and classify ooids, oncolites, pisoids and their horizons as well as to show their spatial distribution in Slovenia. Oolitic rocks are even predominant facies in the Jurassic stratigraphic sequence and,

consequently, they play an important role in the building of the study area. Therefore, we discuss their depositional, paleogeographic and stratigraphic position. These rocks contain somewhere abundant fauna and flora.

Previous investigations

Important geological data for this work have been obtained during systematic regional geological mapping for the Geological Map of SFR Yugoslavia on the scale of 1 : 100,000 and the Geological Map of Slovenia on the scale of 1 : 50,000 (Map Sheet Grosuplje; DOZET – in print). Besides, stratimetric measuring and profiling as well as precise sedimentological and facies studies of the treated strata have been performed. Very good and valuable data were obtained in the frame of some other projects, such as *Mesozoic in Slovenia, Petrography and Sedimentology of Carbona-*

te Rocks of Slovenia and New Generation of Geological Maps in Slovenia.

More in detail are described Jurassic oolitic beds of the Mala gora section in the Suha krajina area (STROHMENGER et al., 1987a,b; STROHMENGER, 1988; STROHMENGER & DOZET, 1990) in the Javorški vrh-Kališe section on Trnovski gozd (OREHEK & OGORELEC, 1979) and at Verd near Vrhnika (DOZET, 2000c). The general summary of oolitic limestone and dolomite of the Mesozoic age in Slovenia is represented in the preliminary article of both authors (OGORELEC & DOZET, 2000). This publication is also the basis of present study.

Within the Mesozoic period oolitic beds are best represented and expressive in the Lower Triassic (GRAD & OGORELEC, 1980; DOLENEC T. et al., 1981; DOZET, 2000a; KOLAR-JURKOVŠEK et al., 2011b; and other sources), less in Carnian in the Mežica (PUNGARTNIK et al., 1982) and Zaplaza area (DOZET, 2004b), as well as in the Dachstein Limestone and Main Dolomite of the Norian-Rhaetian age (OGORELEC, 1988; DOZET, 1991a; OGORELEC & ROTHE, 1992). The Upper Carboniferous and Lower Permian oolites and oncolites have been studied by NOVAK (2007a, b) at Tržič, and by OGORELEC et al. (1999a) during the Karavanke road tunnel reaserches. The Miocene oolites are established in the Kozje area (ANIČIĆ et al., 2002), and oncolites in the Dolenjska area (MIKUŽ, 2004) and at Moravče (MIKUŽ, 2007). A lot of data on oolites and oncolites can be found also in the monography *The Geology of Slovenia* (PLENIČAR et al. – eds., 2009), particularly in the chapters on the *Middle and Upper Permian* (SKABERNE et al., 2009), *Triassic* (DOZET & BUSER, 2009) and *Jurassic* (BUSER & DOZET, 2009). Photographs and descriptions of oolitic varieties of the Mesozoic carbonate rocks from the Slovenian territory are also in the monography *Microfacies of Mesozoic Carbonate Rocks of Slovenia* (OGORELEC, 2011).

Geological setting

From the geotectonic point of view the studied area belongs to Dinarides and predominantly to the External Dinarides comprising the Julian and Dinaric Carbonate Platforms with intermediate Slovenian Basin (BUSER, 1989), where in a shallow-marine environment up to 6500 meters thick stratigraphic sequence has been deposited. The External Dinarides consist predominantly of Triassic, Jurassic and Cretaceous carbonate rocks – limestone, dolomitic limestone, dolomite and carbonate breccias (Fig. 1), and lesser of Uppermost Permian and Paleogene limestone.

The oolites are characteristic facies particularly in certain Mesozoic formations, especially in up to some hundred meters thick horizons in different parts of shallow-marine Jurassic rocks of the Dinaric Carbonate Platform. In thinner horizons they occurred also in the Upper Carboniferous and Lower Permian successions, in the Permian/Triassic (P/T) boundary interval, in Lower Triassic limestone and dolomite as well as in Carnian

and Rhaetian beds and in some parts of Lower and Upper Cretaceous and Paleogene limestone.

The oncolites appear in some carbonate horizons of Lower Permian, Carnian, Norian and Rhaetian in the form of thinner intercalations. Thicker oncolitic beds appear in some Jurassic intervals and in the Upper Cretaceous horizon of the Dinaric Carbonate Platform.

UPPER CARBONIFEROUS

The oldest up to now known oolitic rocks in the Slovenian territory were detected in the Karavanke Mts. Ooids are found in some beds of the bioosparitic limestone on Suhi vrh above the Karavanke road tunnel (OGORELEC et al., 1999a). They have a micritic and radial structure and are mixed with echinoderm plates and rare schwagerinas (Pl. 1, Fig. 8). The oolitic beds are described more in detail from the uppermost Carboniferous (Gzhelian) Schulterkofel Formation, previously known as the Lower Pseudoschwagerina Limestone, from Vratni vrh above the Tržiška Bistrica valley north of Tržič (NOVAK, 2007a,b).

Oolitic beds within the carbonate-clastic sequence are scarce. Limestone of grainstone type (Pl. 1, Figs. 7 and 8) contains beside ooids some fusulinids of genera *Staffella* and *Schwageriniformis*, as well as algal and molluscan fragments, echinoid plates and some percent of detrital quartz grains (NOVAK, 2007a).

PERMIAN

Lower Permian

The Lower Permian beds in Karavanke Mts. are most completely developed in Dovžanova soteska north of Tržič. They are composed of the Dovžanova soteska Formation, the Born Formation and Rigelj Beds (NOVAK, 2007a,b). In spite of some intermediate discordances the total thickness of the Lower Permian sequence reaches there up to 600 meters. Beds with ooids have been deposited in the continental-littoral belt of the shallow shelf; the oncoid horizon in the middle part of Rigelj Beds, however, in an open-sea lagoon.

Oolites are rarely occurring as thin lens-shaped beds of a bioosparitic limestone of grainstone type close above the basal bed of siltstone with quartz pebbles of the Born Formation, and in an individual bed in the lower part of Rigelj Beds. Ooids are small. They are up to 3 mm thick having often fusulinid foraminifers, crinoids, gastropods or detritic quartz grains in their cores (NOVAK, 2007a). Substantial number of cores were dissolved during diagenesis and filled with sparry calcite (Pl. 1, Fig. 6) during short-lasting subaerial exposure-phases.

In the upper part of Rigelj Beds, just below the Tarvis Breccia appear in Dovžanova soteska at Tržič beds of the black oncobiosparitic limestone of grainstone and packstone types (No-

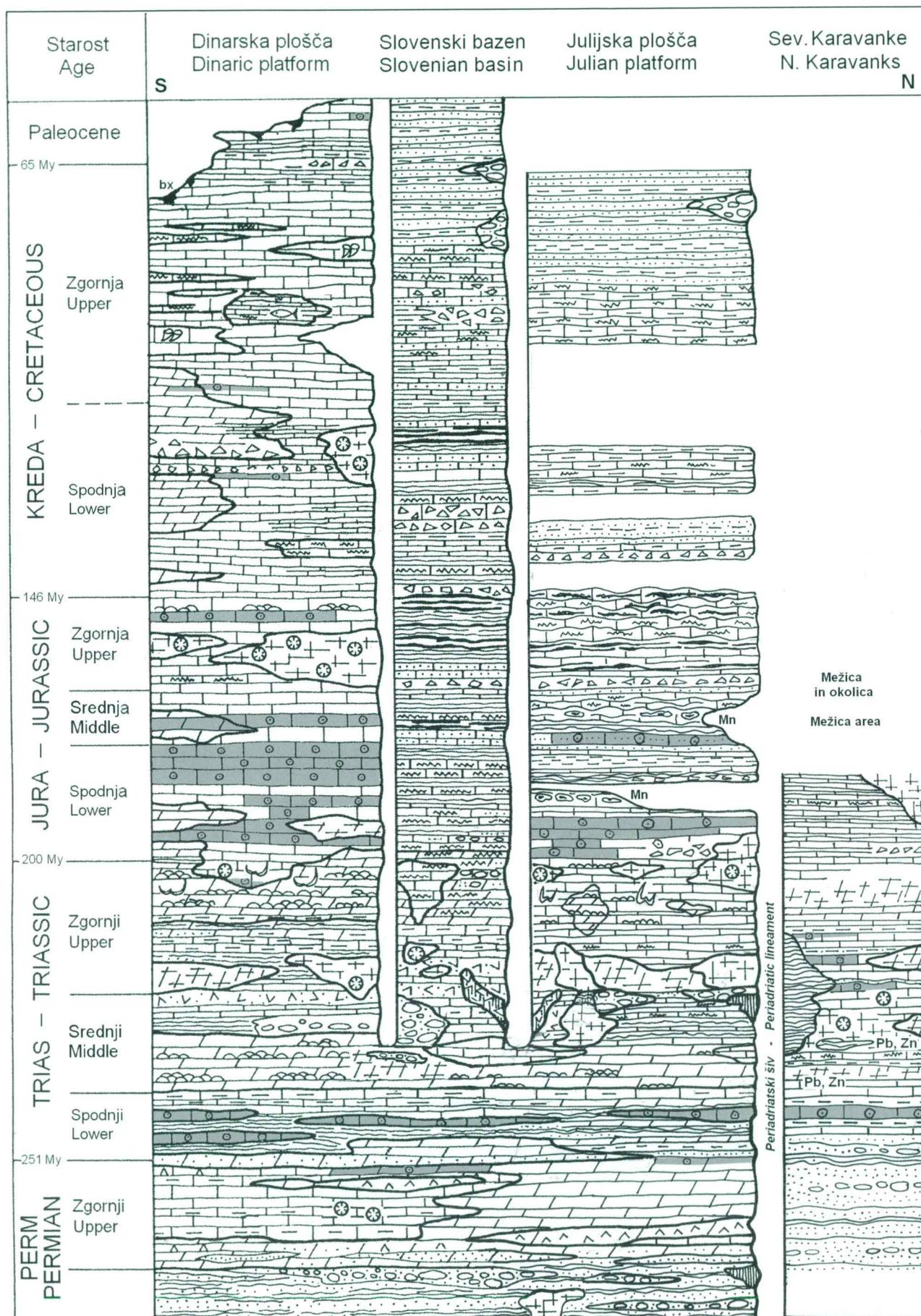


Fig. 1. Schematic depiction of oolitic rocks in Mesozoic beds development in various paleogeographic units of Slovenia (adapted after OGORELEC, 2011)

VAK, 2007a,b). Oncoids of the *Osagia* type differ in shapes having up to 15 mm in size and adapting their forms to the fossil shapes in their cores. They are represented by fusulinid foraminifers, algae and echinoderms (Pl. 1, Fig. 5). The 20 cm thick topmost part of the oncoid horizon is partly recrystallized.

Upper Permian

The Upper Permian beds below the P/T interval are built of carbonate rocks: dolomite, limestone, dolomitic limestone and dolomitic marlstone. They are characterized by dark to black colour and clear stratification. According to texture the limestone can be micritic, biomicritic and biointramicritic having up to 10 % of noncarbonate admixture. The dark colour of the limestone is a consequence of organic admixture and pyrite pigment.

The Upper Permian carbonate succession, that in the western Slovenia reaches up to 400 meters and in the eastern part of Sava Folds several meters to several tens meters of thickness, occurs in two developments. In the western and central Slovenia they are developed as the Žazar Formation (RAMOVŠ, 1858; BUSER et al., 1989) with rare interbeds of dolomite, plates of marlstone and lenses of evaporitic minerals, mainly gypsum. In Karavanke Mts. occurs the Karavanke Formation (BUSER et al., 1989) which is developed as a bedded dolomite with intermediate packets of cellular dolomite of the *rauhwacke* type. Limestone beds occur exceptionally. This development is an equivalent of the Bellerophon Formation in the Southern Alps (BUGGISCH, 1974; NOÉ, 1987). The fossils in the Žazar Limestone succession are quite common, in contrast to their rare occurrences in the dolomite of the Karavanke Formation. Most common and important fossils are algae *Gymnocodium bellerophontis*, *Vermiporella nipponica* and *Permocalculus fragilis*, the coral *Waagenophyllum indicum*, ostracods, gastropods (*Bellerophon* sp.) and echinoderm plates. In some places skeletal algae are so numerous that they are rock-building. Small foraminifers belong to the genera *Ammodiscus*, *Hemigordius* and *Nodosaria* (BUSER et al., 1989).

Upper Permian sediments were deposited in the restricted shallow shelf, lagoons respectively. Energy index of examined rocks is low. Ooids were formed in lagoons with higher energy. The sedimentation on the carbonate platform was frequently interrupted by inflows of terrigenous material. In the eastern Sava Folds (Sevnica, Trebelno, Bohor) oolitic dolomite beds were locally mineralized with Pb-Zn sulphides (DROVENIK et al., 1980).

In the Upper Permian sequence on the Slovenian Carbonate Platform oolites are very rare. The ooids are found only in the bed of dolomitized limestone in the topmost part of the Karavanke Formation in the Košutnik brook north of Tržič (OGORELEC, 2011, Pl. 3), where individual ooids are recognized only by their contours, and

in the coarse-grained dolomite close below the P/T boundary in the abandoned mine Ledina above Sevnica, where rare ooid envelopes grow over algal fragments.

In the southern Slovenia ooids are recognized in dark carbonate rocks lying conformly under the Scythian basal oolitic horizon in the Žlebič area and in the Upper Permian-Scythian section Skopačnik-Dobravica-Podgozd in the southeastern borderland of the Ljubljana Moor (BUSER, 1974; DOLENEC M. et al., 2006; DOZET & KOLAR-JURKOVŠEK, 2007). Ooids occur in dark oolitic dolomite and considerably dolomitized limestone. Mostly only contours of ooids can still be observed.

Permian/Triassic (P/T) boundary

On the Permian/Triassic boundary oolites are found, examined in detail and in several localities in the western, central and southern Slovenia.

In the Idrija area oolites were ascertained for the first time in the section of Idrijca river at Spodnja Idrija (DOLENEC M., 2000; DOLENEC & OGORELEC, 2001), and that in an only 20 cm thick bed close above and under this boundary. Afterwards, oolitic beds are found in the Masore section at Spodnja Idrija (DOLENEC T. et al., 1999a,c, 2004) as well as in the Žiri area (KOLAR-JURKOVŠEK et al., 2011a,b).

The carbonate beds with ooids are well documented with fossils in transitional beds on the P/T boundary in the section Lukač at Žiri (KOLAR-JURKOVŠEK et al., 2011b). In four meters thick detailed-sampled section, that lie above the evaporitic dolomite member of the Bellerophon Formation alternate dolomite beds with ooids and beds of laminated biomicritic limestone. Transitional beds represent the basal part of the Lukač Formation, as the lowermost formation of the Lower Triassic succession in western Slovenia. Ooids occur in the dolomite one meter under the P/T boundary. They are more abundant in the dolomite just above the P/T boundary, defined by the first appearance of the conodont species *Hindeodus parvus*.

All known beds with ooids at P/T boundary, examined in the Idrija-Žiri area, in the Sava Folds and Karavanke Mts. were dolomitized. For that reason, ooids are habitually recognizable only by contours and after coloration with alizarin red. In several cases ooids exhibit also traces of dedolomitization, a calcitization respectively, and the calcitic sparry cement. The calcitization occurred very probably during diagenesis when calcite and epsomite have been formed. The epsomite in determined samples has not been observed from the surface, but it has been formed and preserved in the pits of Idrija Hg mine (ČADEŽ, 1977; OGORELEC, 1977). The oolitic horizon on the P/T boundary is known as Tesero Horizon in the Alps (ASSERETO et al., 1972; BROGLIO-LORIGA et al., 1986) and in Hungary (HAAS et al., 2004, 2006). This horizon is also well-documented in the borehole Gartnerkofel-1 in the Carnic Alps (HOLSER & SCHÖNLAUB – eds.,

1991), where it is 20 meters thick belonging mostly already to the basal part of the Lower Triassic beds. At Višnja gora the Tesero Horizon is equivalently developed in the form of 2 to 3 meters thick horizon of a greyish yellow more or less fine-oolitic sandy dolomite. It has been denominated the Babčnik Horizon representing the basal part of the Višnja gora Formation (DOZET, 2000a).

In the southern Slovenia Upper Permian and Scythian beds as well as their contact are well exposed and defined in two places, namely: Skopačnik at Želimplje and Gorenji Lazi at Žlebič. The P/T boundary is there defined in detail by biostratigraphic and isotopic data (DOLENEC M. et al., 2006; DOZET & KOLAR-JURKOVŠEK, 2007).

TRIASSIC

Lower Triassic

Oolitic beds are one of the most expressive characteristics of the Lower Triassic beds in the whole Slovenian territory. They first occur in the lower and middle part of the Lower Triassic carbonate successions. They were found in the entire Slovenia area, which was in that time still a part of the Slovenian Carbonate Platform (BUSER, 1989).

The Lower Triassic stratigraphic sequence is built of clastic as well as carbonate rocks, among which limestone predominate over dolomite. The whole Lower Triassic stratigraphic sequence can reach the thickness of 500 meters (BUSER, 1979a; DOZET & BUSER, 2009). The Lower Triassic clastic rocks are absent only in the topmost part of the considered sequence, where marlstone and limestone thoroughly predominate.

Oolitic horizons mostly occur in up to 0.5 meters thick beds and in up to several meters thick packets, in minor lenses respectively, that in the distance of some tens or hundreds meters wedge out. The thinning out of oolitic horizons can be easily observed in the Idrija mine (ČAR et al., 1980) or in larger road cuts. In some places ooids are less numerous, appearing only as individual ooids among other allochems, mainly microgastropods *Holopella gracilior* and *Natiria costata*.

The oolitic horizons are researched in several localities in Karavanke Mts. at Tržič (DOLENEC T. et al., 1981), in the Karavanke road tunnel (OGORELEC et al., 1999a) in Savinja Alps (CELARC, 2004), further on, in the Idrija and Cerklje area (MLAKAR, 1969; ČAR et al., 1980; MLAKAR & ČAR, 2009; ČAR, 2010; KOLAR-JURKOVŠEK et al., 2011a,b), in the Škofja Loka area (DEMŠAR & DOZET, 2002), in Polhov Gradec area (GRAD & OGORELEC, 1980; JURKOVŠEK et al., 1998; NOVAK, 2001; DOZET & NOVAK, 2002), at Pleše in eastern Sava Folds (DOZET, 1985, 2000b), at Višnja gora (DOZET, 2000a), at Želimplje (MUŠIČ, 1992; DOZET & KOLAR-JURKOVŠEK, 2007), in the Bloke area (DOZET, 1978), on Bohor Mt. (OGORELEC, 1979), on Orlica Mt. (ANIČIĆ et al., 2001), in the Mišnica valley at Laško (RAMOVŠ & ANIČIĆ, 1995; RAMOVŠ et al., 2001) in the Kočevje

and Gorski kotar area (DOZET & SILVESTER, 1979) and in some other localities. Most important for the oolites is the Middle Scythian lithological sequence with the gastropod *Holopella gracilior*, which could be up to 100 meters thick (BUSER, 1974; MUŠIČ, 1992; DOZET & KOLAR-JURKOVŠEK, 2007).

Oolitic beds of the Višnja gora Formation are within the Lower Triassic (Scythian) stratigraphic sequence most expressive and important in their lowermost part (Babčnik = Tesero Horizon) and in the middle part (Sv. Tilen = Gastropod Oolite Member) and less in the upper part of this sedimentary succession (Kosca Member and Brinje Horizon – DOZET, 2000a). Oolites in the above-mentioned sections have various sizes and different textures. Individual ooids are up to 1 mm long in diameter and exhibit distinct concentric micritic envelopes, which alternate repeatedly with the sparry calcite. Many ooids have in their cores grains of muscovite or quartz, often also gastropod fragments and small foraminifers. Characteristical for these ooids is an intensive red and locally yellow colour, which is a consequence of hematite pigment. Chemical analyses of several samples show that samples of oolitic limestone or dolomite may have up to 1 % of iron, greater part, however, 0.2 to 0.5 % of iron. The enrichment of ooids with hematite is related to weathering of clastic rocks that accompanied carbonate interbeds in local subaerial exposure phases. On episodic vadose conditions of diagenesis can be concluded also by sparry cement, which can be observed in the cores of ooids in some horizons. In these cases are oolitic samples enriched with light $\delta^{13}\text{C}$ isotope (DOLENEC T. et al., 1981; OGORELEC et al., 1999b). The cement among the grains belongs to two generations: rim cement of the generation A and sparry cement of the generation B.

The origin of oolitic beds and lenses is connected with a very shallow environment inside the clastic-carbonate succession in semi-arid climate, repeatedly in intertidal deltas, where the energy of the environment was high enough for their generation.

In the Pleše area the Lower Triassic beds begin with dolomite and baryte (DOZET, 1985, 2000b). Variably red sandy oolitic dolomite occurs in the middle part of the Scythian sequence. Dolomitic grains are quite common occurring as well in ooids as in cement. The ooid-grains are smaller than 0.1 mm, reaching at Repče exceptionally the size of 15 to 2 mm. Allochems are generally impregnated with hematite.

In the southeastern Ljubljana Moor Borderland the Lower Triassic beds are exposed at Skopačnik in the Želimplje valley (BUSER, 1974; MUŠIČ, 1992; DOLENEC M. et al., 2006; DOZET & KOLAR-JURKOVŠEK, 2007), where the Lower Triassic sequence begins with several meters thick dark oolitic considerably dolomitized oolitic limestone (Tesero Horizon). Main intervals of oolitic (oospiritic) limestone can be found in the middle part of the Scythian lithologic sequence. The Lower Triassic oolitic limestone has been developed in

different sedimentary environments in the littoral. Thick-layered oolitic limestone originated in tidal deltas with relatively high energy.

In the Orlica Anticline area (ANIČIĆ, 1991; ANIČIĆ & DOZET, 2000; ANIČIĆ et al., 2001) and its surroundings (cross-section Mišnica valley-RAMOVŠ & ANIČIĆ, 1995; RAMOVŠ et al., 2001) the Lower Triassic sedimentary succession (Werfen Formation) is composed of siltstone, sandstone, claystone, sandy dolomite, oolitic, sparitic, and micritic limestone as well as calcareous breccias. The Tesero Horizon is not preserved there. Very expressive is the oolitic calcareous development with gastropods consisting of 65 meters thick sedimentary succession.

In the Toško Čelo area near Ljubljana (NOVAK, 2001; DOZET & NOVAK, 2002) the Scythian sedimentary succession lithostratigraphically consists of eight units. The lowermost lithostratigraphic unit is represented by 1 to 3 m thick horizon of bio-sparitic limestone very rich in mollusc bioclasts. Oolites occur more in the Gastropod Oolite Member containing interbeds of dolomite. Ooids are commonly rather small. The thicker horizon of the oolitic dolomite, containing up to 3 mm large ooids, pisoids respectively originated by latediagenesis. The thickness of the Gastropod Oolite is about 45 meters.

The Lower Triassic stratigraphic sequence on Križna Mt. (DEMŠAR & DOZET, 2002) is composed of limestone, dolomite, marl, sandstone, siltstone and subordinately of claystone and shaly claystone beds. The main characteristics of the Scythian sedimentary succession are rare fossils and poorly developed Gastropod Oolite Member.

Carnian

Rare oolitic beds are known in Slovenia from the Carnian epoch. Still most common and mentioned are those from the Mežica area and from Dolenjska. In fact, in the Carnian stage oncolites are more extended and important than oolites.

Cordevolian and Julian

The lower part of the Carnian succession is composed of several hundred meters thick sequence of massive and thick-bedded coarser-grained limestone and dolomite, which are placed in the lower part of the Carnian age. Due to intensive dolomitization its primary structure, an algal biosparite with numerous *Diplopora* algae and rarely with coral and sponges, is hardly recognizable (RAMOVŠ & TURNŠEK, 1984; TURNŠEK, 1997; ČAR, 2010).

In the Idrija area oolites and oncolites from the Cordevolian carbonate sequence are rare and poorly preserved. The ooid remains are discussed briefly by VLAJ (1969), who mentioned that in the Cordevolian beds the carbonate oolite passes into the limestone pseudoolite. Next to regular ooids with concentric structure and various fragments there are a lot of quartz and plagioclase grains in it. The oolitic limestone contains foraminifers,

crinoids, echinoid spines, gastropods and pelecypod fragments as well.

ČAR and co-workers (1980) studied in the Idrija area sedimentological characteristics of Upper Triassic circular coral bioherms. The carbonate rocks there have been deposited in relatively quiet water. A higher water energy value has been suggested for this limestone that contains oncoids. Some oncoids attain a diameter of four centimeters.

ŠTRUCL (1971, 1984) described the Wetterstein sequence in the N. Karavanke Mts. area of the Mežica Pb-Zn mine belonging to the Ladinian and Carnian stages. It has been developed in the back reef, reef and fore reef facies. The 1000 to 2000 m thick succession of the Wetterstein Beds consists almost entirely of carbonate rocks. The lower part is predominantly dolomitic, while the upper one is calcareous. Lithologically, they are of very heterogeneous composition. Pure oolitic interbeds can be observed in the uppermost 60 meters of the Wetterstein Limestone. The oncolites and oolites are very poor in fossils. Here and there oncolites contain skeletal algae and foraminifers. Sedimentological features (e.g. shrinkage pores, stromatolites and dessication cracks) indicate that this limestone was deposited in a shallow subtidal environment and partly in an intertidal zone.

RAMOVŠ (1990) reported that in Northern Julian Alps, in the Cordevolian bedded limestone and dolomite next to stromatolites occur in some places irregular, globular and ovoid coated grains, oncoids respectively. They are up to 0.5 cm in diameter.

Julian and Tuvallian

The middle and upper parts of the Carnian succession, which are of the Julian and Tuvallian age, are represented by the bedded dark biomicritic limestone and rarely by the dolomite with marlstone interbeds. In some places the deposition of carbonate beds inside a shallow restricted shelf is accompanied by volcanic activity in the form of tuff interbeds and clastic sediments (MLAKAR, 1969; BUSER, 1979a; DOZET, 2009; KRALJ & DOZET, 2009; ČAR, 2010).

As already mentioned, oolitic beds are significant sediments within the Julian and Tuvallian succession in the Mežica area, that lies north of the Periadriatic fault and can be, therefore, hardly compared with Carnian beds in Dinarides. With mining works in the Pb-Zn mine and with field researches these beds were sedimentologically examined (ZORC, 1955; ŠTRUCL, 1971, 1984; OGORELEC & KUŠEJ, 1979; PUNGARTNIK et al., 1982). In total, about 300 meters thick carbonate succession, in which limestone prevail over dolomite, is interrupted by three clastic horizons. Oolitic beds occur only in the footwalls of all three horizons, and especially of the second horizon in the Helena valley. Locally, they are pure oosparites (Pl. 2, Fig. 4). The bio-component is composed of mollusc fragments that often form ooid-cores, as well as plates and spines of echi-

noderns (JURKOVŠEK, 1978; JURKOVŠEK & KOLAR-JURKOVŠEK, 1997; JURKOVŠEK et al., 2002; KOLAR-JURKOVŠEK & JURKOVŠEK, 2010). Oncoids are rather small having in greater part less than one centimeter in diameter. Owing to authigenic grains of pyrite, that impregnated the oolites during the diagenesis, they are more or less dark coloured, in fresh cuts also black; on the surface after limonitization, however, they are brownish or yellowish.

On the Zaplaz near Trebnje sediments of the Julian and Tuvallian age are composed of mudstone and carbonate rocks. An alternation of variegated marlstone and claystone interrupted by several oolite, oncolite and dolomite horizons can be seen there. Due to their special development these beds are denominated the Zaplaz Formation (DOZET, 2004b). The oolitic-oncolitic rock, packstone and grainstone by texture, contains also crinoids, echinoid spines, molluscs and rare quartz grains. Oncoids are up to 3 cm thick.

From the lithological point of view the lowermost Upper Triassic (Carnian) beds in the Kočevje region are very much alike. The treated variegated sedimentary succession at Kočevska Reka (DOZET, 1990a; DOZET & SILVESTER, 1979) is characterized by an alternation of clastic and carbonate rocks. In the Julian-Tuvallian sequence predominates red dolomitic marlstone, intercalated with rare oncolite beds. Oncoids give to the considered rock a knobby appearance.

Otherwise, in southern and central Slovenia the Julian-Tuvallian lithologic column begins commonly with 5 to 40 meters thick bauxite horizon composed prevalently of oolitic bauxite rich in iron. It is well-exposed on the Kopitov Grič at Borovnica (RAMOVŠ, 1953; DOZET, 1979, 2004a; BUSER, 1980). The iron-bauxite of this deposit belongs to the karstic type of bauxite and it is of diagenetic origin, formed "in situ" in colloidal clay-iron rich sediments by dissolution and precipitation (BHATTACHARYYA & KAKIMOTO, 1982). In the Kopitov Grič ore deposit the iron oolitic bauxite, containing some bauxite pisoids as well, is prevalent. The electron-microanalysis examination showed that ooids are of iron, alumina and mixed chemical composition, and the groundmass is richer in iron than ooids, therefore it is generally darker than ooids. Similarly, pisoids are richer in iron and darker than ooids.

In several places in Rute (Zgonče, Kobilji curek, Selo) and Bloke (Perovo, Črni potok) several millimeters to one centimeter thick dark green ooids, pisoids respectively, can be observed in yellowish to greenish Carnian tuffs (DOZET, 1989; KRALJ & DOZET, 2009). They are composed of less chloritized cores and stronger chloritized envelopes. In the very central part of ooids and pisoids there is a microcrystalline substance having plagioclase characteristics.

Norian and Rhaetian

Norian and Rhaetian stages are characterized in Slovenia by the 1500 m thick carbonate

sequence of the Main Dolomite and Dachstein Limestone formations that exhibit all characteristics of the typical Lofer development, as it is known from their classical localities in the Northern Limestone Alps (FISCHER, 1964). In southern Slovenia the Main Dolomite prevails strongly over the Dachstein Limestone (BUSER, 1979a; OGORELEC, 1988; DOZET & OGORELEC, 1990; OGORELEC & ROTHE, 1992; NOVAK, 2003; DOZET & BUSER, 2009), in Julian Alps and Karavanke Mts., however, it is a reverse situation. In several places there occur also minor or larger reef patches and complexes, composed prevalently of corals (BUSER et al., 1982; TURNŠEK, 1997).

In the Main Dolomite and Dachstein Limestone oncolites are rare. They are developed only locally on the Trnovski gozd (OGORELEC & ROTHE, 1992) and in the Gorjanci area (BUKOVAC et al., 1984; BUKOVAC & SOKAČ, 1989). They occur as individual allochems together with mollusc fragments, being flooded in the micritic mud. Their origin is related, as we supposed, to local tidal channels inside littoral planes. These beds with ooids occur in the topmost part of the Dachstein Limestone, close to the boundary with Jurassic beds. Ooids are small, up to 0.5 mm in size, showing the radial structure of envelopes.

In the Main Dolomite and the Dachstein Limestone more frequent than ooids are oncolites. They are mentioned for the first time from the neighbourhood of Sodražica (BUSER, 1966) and that as algal species *Sphaerocodium bornemanni*. The forms of "Sphaerocodium" type have been investigated in the Carnian beds at Čatež at the northern foot of Gorjanci by BABIĆ (1970). Actually, he studied all up to then known findings with the algal species *Sphaerocodium bornemanni* from Slovenian and Croatian Dinarides. Since no algal filaments and proper algal structures were recognized in collected rock samples, he interpreted these structures as oncolites. Later, oncolite beds have been found at some other localities: in the central Slovenia (OGORELEC & PREMUR, 1975; DOZET, 1985,) in the Kočevje area (DOZET, 1990a, 1991b), on the Banjška planota (OGORELEC & ROTHE, 1992), on Krn Mt. (OGORELEC & BUSER, 1997), on Kanin Mt. (OGORELEC, 1984), in the Trenta valley (JURKOVŠEK, 1986) and in some other places.

Oncoids are different in size. A greater part of them have a thickness under 1 cm, larger, however, reach the thickness of up to 3 cm and more. According to texture they are mostly concentric with numerous envelopes (group SS-C – spheroidal structures, concentric form) after LOGAN et al. (1964), less commonly they belong to groups SS-R (randomly stacked form) or SS-I (inverted form, Pl. 3, Fig. 8). In these cases they are vadose pisoids or vadoids (FLÜGEL, 2004, 158). They originated in a vadose fresh-water or mixed marine-fresh water environment in intervals of short-lasting subaerial exposure phases of the littoral intertidal environment. As vadose pisolites or caliche they are described from the Main Dolomite in the Dolomites (BOSELLINI & ROSSI, 1974; AS-

SERETO & KENDALL, 1977) and Jurassic beds in the central Apennines (BERNOULLI & WAGNER, 1971). Recent cases of their origin are known from the Persian Gulf (EVAMY, 1973; SCHOLLE & KINSMAN, 1974; CHAFETZ & BUTLER, 1980). Classical examples of older vadose pisoids are from Permian beds in Texas (DUNHAM, 1969; PRAY & ESTEBAN, 1977).

In some cases (FLÜGEL, 2004, 158) pisoids can be of combined origin; at the beginning as vadose pisoids, later, however, these pisoids were impregnated with cyanobacteria envelopes like oncoids. Such a case exhibits for example the sample of the Main Dolomite from Koprivnik near Kočevje (OGORELEC, 2011, pl. 21/1).

JURASSIC

Dinaric Carbonate Platform

The Jurassic is the geologic period, which was for oolitic rocks far most important, as in the world as in Slovenia. In the Slovenian territory there are more than 4/5 of all oolitic beds as by extent as by the thickness of their horizons of the Jurassic age. On the Dinaric Carbonate Platform this span of time, when ruled several millions years long periods with warm climate and constant sedimentological conditions of a very shallow open shelf with high energy, was favourable for growth of ooids. Equal paleogeographic and sedimentological conditions existed on the Julian Carbonate Platform in the Liassic epoch as well. At the end of Liassic and in Dogger it came to its faulting and slow sinking, and from that time on it was fused together with the Slovenian Basin (Fig. 1), in which ruled deeper-water sedimentary conditions (BUSER, 1889; JURKOVŠEK et al., 1990; ŠMUC, 2005).

A general and complete review of developments of Jurassic rocks in the Slovenian territory is captured in works of BUSER (1968, 1979b) as well as BUSER and DOZET (2009); in the area of the Dinaric Carbonate Platform, relating data can be found in works of BUSER (1978), DOZET (1980, 1990b, 1992b, 1996), DOZET & ŠRIBAR (1981, 1998b), BUSER & DEBELJAK (1996), OREHEK & OGORELEC (1981), in reef developments, however, in works of TURNŠEK (1966, 1969, 1997) and TURNŠEK et al. (1981). The microfacies of limestone and dolomite has been researched by R. Radoičić already in the seventies of the last century on the entire Dinaric Carbonate Platform, which comprised then the area from Trnovski gozd, across the entire Dalmatia and Primorje to as far as Monte-Negro (RADOIČIĆ, 1966). In her study several localities and rocks from the Slovenian territory are also described. Later, the microfacies of Jurassic beds in the southern Slovenia have been researched by OREHEK & OGORELEC (1979, 1981), STROHMENGER (1988), DOZET (1989), DOZET & STROHMENGER (1996, 2000), STROHMENGER & DOZET (1990), STROHMENGER et al., 1987a,b), OGORELEC (2009, 2011) and others.

Liassic

The oolites of the Liassic age have been researched in detail in the Podbukovje-Korinj section in Suha krajina, south of the village Krka, where they build the 570 meters thick Podbukovje Formation (DOZET & STROHMENGER, 2000; DOZET, 2009), on Mala gora Mt. at Kopolje (STROHMENGER, 1988; STROHMENGER & DOZET, 1990) and in the central part of Trnovski gozd (OREHEK & OGORELEC, 1979).

Transitional beds between Upper Triassic and Liassic are in some places in the Notranjska region partially or totally dolomitized. Such case is stated in Preserje at Borovnica (OGORELEC, 2009) as well as in Bistra at Vrhnika (OGORELEC, 1988; OGORELEC & ROTHE, 1992). The dolomitization has there an early- and latediagenetic character.

The Podbukovje Formation is composed of five members. In the Krka Limestone, which represents the lower part of the formation, are very common intraclastic limestone, composed of small and bigger intraclasts and lithoclasts originated from erosion, further on, pellets, fenestral oncoids and/or vadose pisoids, the material originated at stormy weather by accumulation of eroded material in the intertidal and supratidal zones. These sediments are characterized by vadose features such as algal crusts, geopetal fillings, solution cavities, microstalactites and stromatolitic crusts. This lithofacies is characterized by typical Lofer rhythmic sedimentation. Developed are all three members of FISCHER'S (1964) cyclothems (DOZET, 1993). In these limestone biostratigraphically most important fossil is the alga *Palaeodasycladus mediterraneus*; while small megalodontids and gastropods occur as well.

The Krka Limestone Member (DOZET & STROHMENGER, 2000) is followed upwards by beds with orbitopsellas and an up to 40 meters thick horizon of dark lithotid limestone. The latter are above all interesting as beautiful ornamental stone, extracted in the Podpeč quarry in the vicinity of Ljubljana. The topmost part of the Podbukovje Formation is composed of grey oolitic limestone of the grainstone type with well-washed ooids and parallel cross-stratification, followed by the dark grey Spotted Limestone, the youngest unit of the Liassic carbonate sequence. It is composed of variously grey and greyish black, platy and bedded prevalently micritic (mudstone) and pelmicritic strongly bioturbated limestone, wackestone to packstone by texture, that due to activity of numerous bioturbating organisms, and late diagenesis became spotty. According to the dark colour, abundant bituminous content, structures and textures, and regarding micro- and macrofossils the Spotted Limestone was deposited in restricted parts of the shelf, where conditions were not favourable for greater diversity of organisms. In the micritic carbonate mud of the restricted lagoon were episodically brought by waves and currents rather numerous ooids, pseudoooids, microoncoids and intraclasts. Among structures only fine-lamination can be observed. In a calm

environment and shallow lagoons with marsh and paralic-limnic conditions in Kočevski Rog some coal lenses and thin beds were deposited during the Middle Liassic (DOZET, 1998).

A particularity exists, that the Podbukovje Formation is ended by an up to 3 meters thick packet of thin-bedded dark micritic limestone with orange red and red Fe-ooids (iron-oid wackestone) with fossil association of benthic foraminifers, ostracods, and crinoid fragments with micritic envelopes (DOZET & STROHMENGER, 2000). These iron ooids can be found, above all, in the Suha krajina, Krka (DOZET & STROHMENGER, 2000), Mala gora (STROHMENGER & DOZET, 1990) and Predole (DOZET, 2009) area. Ferruginous ooid grains have regular concentric laminations and are up to 2 mm thick in diameter. Some ooids have nuclei of bioclastic fragments. The iron laminae are formed of magnetite, limonite and goethite. As for genesis of ferruginous ooids in Spotted Limestones, the ooids in question were priorly formed under the dynamic conditions of agitated water in an oxidized stage, whereas the iron minerals, present in them, were produced under calm environmental conditions replacing the carbonate of ooids during the diagenesis. SIEHL and THON (1978) believed that ferruginous ooids are derived from continental latasol, when the cap-rock is eroded and the ooids are transported from the dry-land into a marine environment. WILSON (1966) attributed the Fe-enrichment in ooids to continental weathering processes.

At Predole near Zagradec alternate variously grey and more rarely white bedded limestone of mudstone, wackestone and ooid-grainstone types (DOZET, 2009). The ooids have a tangential and radial structure. The cores of ooids consist of more or less rounded bioclasts (foraminifers, algae, mollusc fragments) and intraclasts. Occasionally, rare up to several meters thick beds of oncolitic limestone occur as well.

On the Trnovski gozd the lithiotid horizon is not developed everywhere and, in some places, it is replaced by the horizon of small brachiopods (BUSER, 1978; OREHEK & OGORELEC, 1979). Oolite interbeds with large oncooids, individual corals-parastromatoporids and the foraminifer *Orbitopsella praecursor* have been recognized in the coral patch reef above the lithiotid limestone (TURNŠEK et al., 2003). Concordantly on the white reef limestone rest alternating white micritic and bedded oolitic limestone of the grainstone and packstone type. Oolites have different texture; predominant are those with radial texture (Pl. 3, Figs. 3, 4; OGORELEC, 2011 – Pls. 24 and 25). Rarities in the Trnovski gozd are “half-moon ooids” (Pl. 4, Fig. 8), whose cores are in a part dissolved and dropped to the bottom of the outer layer, forming geopetal fabric. The origin of such ooids is related to early diagenetic processes in a vadose environment.

Numerous up to four centimeters large oncooids together with foraminifers of the species *Orbitopsella praecursor* occur within the oncolitic beds forming up to 20 meters thick oncooid horizon. The oncooids are of two different types: 1 – the thicker

have irregular shapes and they are mixed between fossils, 2 – somewhat minor (1–2 cm in size) oncooids, i.e. spheroidal spongiostromate-parastromate oncooids with well-expressed micritic texture of envelopes. These oncooid beds are an important marking horizon that is especially significant for areas of Notranjska and Trnovski gozd (OREHEK & OGORELEC, 1981), being followed also on the Vahta passage on Gorjanci Mts. Oncooidal beds are often dolomitized (Pl. 3, Fig. 5), and in some places partly dedolomitized as well. Dedolomitized is for the most part the sparry cement. These oncooid beds are mentioned as particularity also by FLÜGEL (2004, 129) in his text-book on microfacies of the carbonate rocks.

In the upper part of the oolitic limestone small corals, bryozoans and stromatoporoids can be observed on the Trnovski gozd plateau. Upwards follows an up to 10 m thick horizon of the white bedded micritic limestone with rock-forming lithiotid bivalves of the species *Lithioperna scutata* (BUSER & DEBELJAK, 1996; DEBELJAK & BUSER, 1998).

Lower Dogger

The Late Liassic and Dogger epochs were on the Dinaric Carbonate Platform most productive time intervals with oolitic beds.

In the Mala gora sections Lower Dogger beds are exclusively developed as ooid grainstone, which can be laterally also somewhat dolomitized (STROHMENGER, 1988; STROHMENGER & DOZET, 1990). The uppermost beds of the ooid grainstone are rich in the foraminifer *Dictyoconus cayeuxi* together with *Mesoendothyra croatica* that are well-known index-fossils of Lower Dogger in the entire Dinarides (VELIĆ, 2007).

The studied Jurassic carbonate sequence clearly indicates a short-lasting stratigraphic gap during Dogger in the Suha Krajina area (DOZET & STROHMENGER, 2000). The index-fossils, which could be identified, point at an age older than Callovian. The break in sedimentation coincides with the supposed fall of the sea level during the Callovian or at the end of Bathonian (HALLAM, 1978, 1988; BOSELLINI et al., 1981).

In the Dogger carbonate sequence of Dolenjska (southern Slovenia) nine oolitic interbeds are developed. The ooids range in diameter from 0.5 to 0.7 mm. STROHMENGER, DOZET and KOCH (1987b) distinguished radial concentric (T1), micritic (T2) and composed (T3) ooids there. Pitted-ooids are also very common.

The oolitic limestone from the large quarry of Verd above Vrhnika is composed of several oolitic horizons with different thicknesses; the thickness of the larger one attains up to 60 meters. Also several types of ooids can be distinguished there; the most numerous are limestones of grainstone type in which ooids show a radial structure of calcitic envelopes (DOZET, 2000c).

In the Suha krajina area (DOZET, 2000d) oolitic limestone (Hočevje Oolitic Group) is the most extended rock exposed at the surface. Lithologi-

cally and according to fauna we can distinguish two units: 1 – Laze Formation (Dogger) and 2 – Šentrumar Formation (Malm). The Laze Formation is exclusively developed as ooid-grainstone, which laterally can be more or less dolomitized and can involve several meters thick interbeds of micritic limestone. The carbonate sequence in question contains index fossils *Mesoendothyra croatica* and *Dictyoconus cayeuxi*. The appearance of oomicritic limestone of packstone type indicates that these ooids were formed in a more or less restricted environment with minor water energy.

In the Trnovski gozd area among thick-stratified oolitic beds of the grainstone type limestone also occur with characteristics of littoral and intertidal sedimentation: loferites, laminites and intraformational breccias. These limestone exhibit also signs of paleokarstification – larger and minor corrosion vugs. Episodic short-lasting emersion-phases are evident also by gravitational cement among ooids and bioclasts and with reference to diagenetic characteristics for the meteoric environment (OREHEK & OGORELEC, 1979). Individual beds were subjected to late-diagenetic dolomitization.

Between Predole and Mlačevo at Zagradec in Suha krajina the 85 meters thick Middle Jurassic (Dogger) lithologic sequence (Predole Beds) is composed of the dark oolitic limestone of grainstone type (DOZET, 2009). In the investigated carbonate rocks predominate from 0.3 mm to 0.8 mm thick ooids together with intraclasts, bioclasts and pellets. Microfossils *Holosporella sianensis*, *Spiraloconulus giganteus* and *Gutnicella (Dictyoconus) cayeuxi* are biostratigraphically important for these rocks. Interbeds of micritic and sparitic limestone in the considered oolitic complex speak for a subtidal to intertidal sedimentary environment in close vicinity of tidal channels.

Upper Dogger

Upper Dogger oolites consist chiefly of radial and tangential form of envelopes. In many places, in Suha krajina (STROHMENGER & DOZET, 1990), in the Kočevje area (DOZET, 1980, 1990b, 1992a) and Trnovski gozd (OREHEK & OGORELEC, 1979) their primary structure is demolished because of secondary dolomitization.

Lower Malm

In the Early Malm epoch several ten kilometers long and up to 500 meters thick coral-stromatopod reef of barrier type existed on Trnovski gozd (TURNŠEK, 1966, 1969; TURNŠEK et al., 1981) passing with an interruption towards Suha krajina (DOZET & ŠRIBAR, 1998a), crossing the Gorjanci Mts. (OREHEK & OGORELEC, 1981) and stretching forwards to Lika in Croatia (TIŠLJAR et al., 2002; VELIĆ et al., 2002). For the intra- and back reef environments biomicritic limestone of wackestone and packstone type with hydrozoan *Cladocoropsis mirabilis* is significant. Oolitic and

oncolitic beds are in the Lower Malm rather rare what is the case particularly in the Suha krajina and Kočevje area (DOZET, 1989; STROHMENGER & DOZET, 1990).

At Predole in the Grosuplje area the Malm stratigraphic sequence begins with 50 m thick lithological interval, represented by the medium-dark grey platy and bedded Pisolitic Limestone, composed of 1 cm to 2.5 cm thick pisoids, cemented with sparitic calcite which is partly dolomitized. Usually, the late-diagenesis do not embrace pisoids. A similar pisolitic horizon is also found along the railway in Čušperk at Grosuplje and near Col on Trnovski gozd (BUSER, 1978). The Pisolitic Limestone at Predole contains the following fauna and flora: *Trocholina alpina*, *Cladocoropsis mirabilis*, *Aeolisaccus dunningtoni* and *Cayeuxia* sp. On the basis of determined fauna and flora the pisolitic limestone at Predole represents the basal Malm interval.

In the Krka area (DOZET, 2009) rests discordantly upon the Laze Formation (Dogger) the carbonate sequence of Šentrumar Formation (Malm) composed of massive oolitic limestone and coarse-grained brownish dolomite. Limestone beds often show cross-bedded stratification. The considered oolitic formation contains radial, micritic and tangential ooids, fossil remains and detritus. Lithologically, this limestone belongs to biolithite, biointrasparite, and prevalently to various oosparite types. The oolitic prevalently massive carbonates are typical tidal-bar winowed carbonate sands (WILSON, 1975) belonging to the standard facies belt 6. The Šentrumar Formation also includes the Nace Oncoid Member (DOZET, 1995) lying in the lower part of the Šentrumar Formation. The Nace Oncoid Member is about 3 m thick carbonate sequence, composed of grey thick-bedded micritic limestone with oncoids. The primary component of the algally coated-grains (oncoids) is the cyanobacteria of the genus *Girvanella*.

Of the Lower Malm age are also dark grey bedded oosparitic and intraoosparitic (grainstone) limestone with radial growth of crystals on Stružnica SW from Banja Loka in the Kočevje area (DOZET, 1989), dark grey and greyish black bedded biointraoosparitic limestone with partly or totally micritized ooids at Prežula near Kočevska Reka as well as the dark grey biopelmicritic limestone with the foraminifer *Trocholina elongata*. The first two oolites from the Kočevje area originated in a shallow open shelf, whereas the last one was deposited in a restricted shelf sea.

Upper Malm

Oolitic beds are again more numerous in the Upper Malm series occurring in thinner horizons between biomicritic limestone, laminites and dolomitized limestone with characteristics of intertidal environment as well as paleokarstification. Their Kimmeridgian and Portlandian age is defined particularly with algae *Clypeina jurassica* and *Salpinogoporella annulata* (BUSER, 1979B). In

the Trnovski gozd area these beds are exposed at Krnica (OREHEK & OGORELEC, 1979), in Suha krajina (DOZET & ŠRIBAR, 1998b) and at Krka in the Dolenjska area (STROHMENGER & DOZET, 1990), at Vrhnika (OREHEK & OGORELEC, 1981) and in some other places. The oolites chiefly consist of radial, tangential and mixed radial-micritic types. In ooid cores fragments of algae *Clypeina jurassica* have been recognized.

The ooids and *Gyrvanella* type oncoids occur also in the Upper Malm stratigraphic sequence (DOZET & ŠRIBAR, 1998b), but they are not so extended there as in the Lower Malm. Oncoids originated at a very low rate of sedimentation in lagoons, restricted shoals and on bars. The oncoids are mostly irregularly shaped and poorly sorted. The SS-C oncoid type is subordinate. At Zavrh above the river Kolpa in the Kočevje area the strongly dolomitized oosparitic limestone with algae *Clypeina jurassica* has been found (DOZET, 1989).

Julian Carbonate Platform and Slovenian Basin

Shallow water Jurassic limestone can be found on the Julian Carbonate Platform in the area of Upper Posočje, mainly on the southern slope of Kanin Mt., on the Kobariški Stol Mt. and on Polovnik Mt. In several places in the Trenta valley and on Mangart Mt. (KUŠČER et al., 1974; JURKOVŠEK, 1986; JURKOVŠEK et al., 1990; ŠMUC, 2005). They were deposited during the Early Jurassic period on the shallow shelf, on which lagoonal environments alternated with intertidal flats; repeatedly, the shelf was open having favourable conditions for origin of ooids. The oolitic limestone is a grainstone and partly packstone by origin. Ooids are relatively large and mostly of mixed type – with micritic and radial laminae. Ooids are often mixed blended with echinoderm plates and foraminifers, rarely occur oncoids as well.

In Dogger the Julian Carbonate Platform was submerged so that shallow-water limestone were replaced by deeper-water ones with chert nodules and pelagic microfauna. From this epoch the beds with Mn-nodules, which some scientists consider ocean-oncoids, are especially important since they are much alike to them by shape as well as by size.

The size of Mn-nodules ranges from one mm up to 12 cm in diameter showing clear zonal lamination of crusts. Rocks, in which they occur, are reddish biomicritic limestone of wackestone and packstone types, with numerous echinoderm plates, pelagic foraminifers and small ammonites (OGORELEC et al., 2006). Beds with nodules are equally such as oolitic limestone most developed at Bovec under Rombon Mt., in Slatnek gorge under Polovnik Mt., on Čisti vrh in Trenta valley and under Mangart Mt. (JURKOVŠEK et al., 1990; ŠMUC, 2005).

Worth mentioning is also the deeper water alodapic limestone of the Early Jurassic age on the

northern margin of the Slovenian Trough, especially on Kobla and Slatnik Mts. (ROŽIČ & POPIT, 2006; ROŽIČ & KOLAR-JURKOVŠEK, 2007; BUSER & OGORELEC, 2008; ROŽIČ, 2008; ROŽIČ et al., 2009). Within considered beds numerous ooids can be found among carbonate allochems as well, so that these sediments have at first sight an appearance of oolitic rocks. Ooids have been washed into these calcarenites and calcirudites with a micritic groundmass, respectively, they slid down into the basin along the shelf slope; their source place was, however, the edge of the Julian Carbonate Platform.

CRETACEOUS

The Cretaceous beds of the Dinaric Carbonate Platform are developed in whole carbonatic, in greater part as shallow-water limestone attaining thickness of up to 2000 meters. In spite of monotonous composition they exhibit a variegated facies, in which biomicritic variety prevails (PLENIČAR & PREMUR, 1975; PLENIČAR, 1979, 2009; DOZET, 1989; OGORELEC, 2011).

Lower Cretaceous

In the Lower Cretaceous limestone sequence oncolites and locally oolites of the Berriasian age are recognized. In the Trnovo area two different textural oncolitic types have been found (KOCH et al., 1989) – a poorly dolomitized oncosparite and poorly dolomitized oncobiopelmicrite (packstone). Among foraminifers trocholinids can be observed.

Rare oolites and individual pisolites are registered in the profile between Vrhnika and Logatec (OREHEK & OGORELEC, 1981), along the motorway Vrhnika – Logatec (DOZET & MIŠIČ, 1993) and in the Podpoljane section (DOZET & ŠRIBAR, 1998a). They occur in combination with foraminifers and pellets in limestone of wackestone type indicating only episodic higher energy conditions within a shallow restricted shelf.

Oncolites appear also in the Valanginian-Hauterivian stratigraphic sequence, but they are less common there. The oncolitic limestone contains algae *Clypeina solkani*, *Salpingoporella annulata*, *S. melitae*, foraminifers (Miliolidae), ostracods and molluscs. Oncoids of SS-C type are small and don't reach 0.5 cm in diameter (KOCH, 1988; KOCH & OGORELEC, 1990). Of such kind are oncoids in the section Dvor in the Suha krajina area (pl. 5, fig. 8). Oncoids and ooids occur very rarely also within the Aptian sedimentary succession. Thus, thin oncoids are to be found within the Aptian lithologic column. Thin oncoids together with foraminifers and corals have been found south of Slovenski vrh at Kočevje (DOZET, 1989), in the basal unit of the patch-reef on the Sabotin Mt. (KOCH et al., 2002, JEŽ, 2011) and in the limestone of Albian age in the section Nadrt on the Hrušica Mt. (JEŽ, 2011).

Upper Cretaceous

In the Upper Cretaceous limestone, above all, in the Turonian and Santonian stages, oncoids are more frequent, in spite of the fact, they occur only locally and in thinner horizons.

In the Kras area an oncolite horizon is known, composed of several beds with up to 3 cm thick oncoids, within the basal part of the Sežana Formation (JURKOVŠEK et al., 1996; JURKOVŠEK, 2008, 2010). This is a significant marking horizon in wider area of the External Dinarides. On the island Brač in Croatia it is known as the Gračišće Horizon (GUŠIĆ & JELASKA, 1990). With reference to accompanying beds of the limestone with desiccation pores can be concluded that oncoids originated in a very shallow near-shore and intertidal parts of the shelf.

In Matarsko Podolje near Materija (section Hrušica) a packet of oncolite limestone occurs in the biostratigraphic Unit E, and that between peloid- foraminiferal limestone of the mudstone-wackestone type and fenestral mudstone (JEŽ, 2011; JEŽ et al., 2011). Rare beds with oncoids occur also within bedded micritic, biomicritic and rudistic limestone in the Kočevje area (DOZET, 1989).

TERTIARY

In Tertiary beds on the Slovenian territory oolitic beds are rather rare; somewhat more common are oncoids.

Paleogene

Early Paleogene rock succession in the southwestern Slovenia is developed in its lower part (Paleocene and a part of Eocene) calcareously with shallow-water limestone, in the upper part, however, as flysch (DROBNE, 1979; DROBNE et al., 2009). In the above mentioned rocks, ooids can be recognized only as individual allochems, for example in the limestone of Danian age in Čebulovica on Kras (OGORELEC et al., 2001). Ooids, washed into the micritic matrix (Pl. 5, Fig. 3), are thin and only up to 0.5 mm big. The cores composed of micrite are overgrown by individual envelopes of radial sparry calcite. With reference to the fact, that the limestone of the Danian part of the Liburnian Formation (JURKOVŠEK et al., 1996) has been deposited in a very shallow and low-energy environment within the intertidal part of the shelf and in lagoons, we interpret the origin of ooids with higher energy mostly within tidal channels in coastal lagoons.

Neogene

The Neogene rocks crop out in central and eastern part of Slovenia. They have been deposited in the area of then-existing Central Paratethys, precisely on the edge of the Pannonian Basin. They are composed of prevalently clastic rocks, such as

various sandstone, conglomerate and marl; carbonate rocks are greatly subordinated. They are mostly extended in the Upper Miocene, Badenian respectively, as the *Lithothamnion* Limestone. In these different beds the oolitic interbeds occur as well.

Pure oolitic limestone is very rare. Such oolitic grainstone appears in the abandoned quarry Osek within the Badenian sedimentary succession at Lenart in Slovenske gorice area (Pl. 5, Fig. 2). The ooids are relatively thick, with radially arranged calcite crystals; the rock, however, is very porous, since it reaches the share of intergranular porosity up to 8 %.

Ooids are present in biocalcarenite beds. They are mixed together with bioclasts and detritic quartz grains. Their content in the rock attains up to 40 %. Such biocalcarenites could be observed in Kozjansko, in the Šmarje pri Jelšah area and above all at Laško (ANIČIĆ et al., 2002).

However, very interesting in the Miocene beds are oncolite horizons. They are described in detail by MIKUŽ (2004, 2007). In the sand pit Drtija at Moravče two horizons, 3.5 m and 2.5 m thick, overly the quartz sand. They are of the Early Miocene age (Eggerian-Eggenburgian) attaining diameter of up to 12 cm; in greater part however, they have several centimeters in diameter. Roundish and discoidal shapes of oncoids with clear laminae predominate. Their cores are very often represented by gastropod or mollusc fragments (MIKUŽ, 2007).

Likewise interesting are also oncoids within the Upper Badenian and Lower Sarmatian rock sequence at the rim of the Krško Basin. Numerous, several centimeters thick oncoids can be found in the basal beds of 25 m thick carbonate-clastic sedimentary succession at Bela Cerkev and Šmarjeta. In detail they are described from Orešje at Kostanjevica by MIKUŽ (2004). There too, the type of roundish oncoids prevails with clearly visible concentric envelopes overgrowing molluscs and especially gastropods. Oncoids from the Bela Cerkev locality have several centimeters big gastropods in their cores and very thin cyanobacterial laminae (Pl. 5, Fig. 1).

Conclusions

Detailed study of sedimentary sequences on both carbonate platforms, the Dinaric and Julian Carbonate Platform exhibit great facies variability indicating shallow-marine, rimmed shelf, lagoonal and tidal and intertidal flat paleoenvironments. The most extended among carbonate rocks of our interest are oolitic rocks occurring in the Upper Paleozoic, Triassic, Jurassic, Cretaceous and Tertiary stratigraphic sequences. Ooids and oncoids were most common and rock-forming within the Jurassic system. The oncolitic rocks are commonly accompanied by the oolitic ones, but their thickness are much smaller. The pisolites, being the rarest of all, were found only in the Jurassic stratigraphic sequence.

However, Jurassic, Cretaceous and partly Triassic carbonate rocks are predominant in the geologic composition of the karst area, i.e. in the western and southern Slovenia. In formations, where oolites and oncoids occur, limestone strongly prevails over dolomite. The latter are more frequent only in the Upper Triassic series. With reference to deposition of the oolitic rocks, however, most extended are shallow-water environments with increased energy.

Our study of sedimentology and stratigraphy of the Uppermost Permian - Tertiary lithologic sequence enabled us to distinguish types of microfacies belonging to the paleoenvironments with sabkas, tidal flats, restricted lagoons, sand bars and open marine environments.

Oolitic rocks, respectively ooids, present in some beds of Late Carboniferous and Miocene age are connected to biocalcarenic type of rocks. They were formed in very shallow parts of littoral shelf, where erosion of the land was quite intensive. As a consequence, detrital grains of quartz and other noncarbonate minerals are mixed with ooids.

Evaporitic intertidal conditions, evident in the beds of the Upper Permian/Triassic boundary succession (Tesero horizon) were favourable for the formation of some oolitic beds, while ooids of the Early Triassic age were deposited in the intertidal channels and deltas. Ooids are mixed also with some detrital grains. Reddish color, connected to Fe-oxide and hydroxide mineral pigment is a characteristic feature of them.

In the Late Triassic (Norian and Rhaetian) age, oolitic beds are scarce, regarding quite a huge thickness of the Main Dolomite and Dachstein Limestone Formations (up to 1500 meters). Somewhat more abundant are oncoids in the Carnian succession of the Karavanke Mts. (Mežica area). Vadose pisoids, connected to local emersion phases and carstification of carbonate rocks are present in some beds of the Norian/Rhaetian age.

In the Jurassic period existed repeatedly open very shallow shelf, on which several tens or even up to 300 meters thick packets of oolitic beds were deposited in very short span of time. Such environments are known today on the Bahama shelf and in the Persian Gulf. Ooidal and oncoidal packstone and wackestone originated in restricted shoals and lagoons, mostly in tidal channels, whereas thick-bedded ooidal grainstone were deposited on open bars and in the back-reef environment.

Episodically, individual parts of the Dinaric Carbonate Platform became for shorter or longer time span a dry-land and exposed to karstification processes falling under the influence of vadose diagenesis. The results of such phases are emergence-breccias as well as bauxite horizons and pockets. Periods with bauxites are recognizable in the Carnian epoch in the central and southern Slovenia, and in Primorje in the time interval between the Late Cretaceous and Paleocene. The iron bauxites often exhibit an oolitic

texture, as a result of diagenetic processes “in situ” in deposits rich in iron and clay colloids.

Seven types of calcareous ooids and four types of calcareous oncoids, found in the Uppermost Permian-Tertiary stratigraphic sequence in the Slovenian territory, characterize specific depositional environments. Among ooids the following types can be recognized:

- Micritic (random) ooids with poorly developed concentric envelopes (Pl. 2, Fig. 7; Pl. 3, Figs. 3 and 4 partly)
- Radial fibrous concentric ooids with radially arranged crystals (Pl. 3, Fig. 2; Pl. 4, Figs. 1 and 4; Pl. 2, Fig. 5; Pl. 5., Fig. 2; SANDBERG, 1975)
- Mixed type of ooids (Pl. 3, Figs. 2 and 3; TUCKER, 1984)
- Ooids with rim cement (cemented in a phreatic environment); Pl. 3, Fig. 4; Pl. 2., Fig. 7)
- Ooids having cores substituted with blockcalcite cement (evidence for vadose diagenesis; Pl. 1, Fig. 6; Pl. 2, Fig. 6; Pl. 4, Fig. 2; CAROZZI, 1963)
- Partly dissolved ooids, corroding each other (Pl. 3, Fig. 1)
- Half moon ooids (their interior cores have dropped to the bottom, forming a geopetal fabric; Pl. 4, Fig. 8; CAROZZI, 1963; MAZZULO, 1977)

A greater part of above-mentioned ooids occur as well in calcitic as in dolomitic variety. Commonly, the considered ooids are only partly dolomitized (Pl. 1, Figs. 1-4; Pl. 2, Fig. 8; Pl. 4, Figs., 5-7). Which type of ooids occurs within the carbonate succession depends primarily on mineralogical, hydrodynamic and microbiological parameters, type and energy of depositional environment as well as diagenetic particularities, especially by processes of early diagenesis and late dolomitization (RICHTER, 1983). Depositional environment and the formation of some ooid types is presented in the explanatory text to figures on Plates 1 to 5.

Among oncoids less variation of types than with ooids can be found. Following types were recognized:

- Spheroidal spongiostromate oncoids, with indistinct micritic and meshy laminae (Pl. 2, Fig. 1; Pl. 4, Fig. 5)
- Spheroidal and discoidal oncoids with concentrically shaped layers (type SS-C, Pl. 2, Fig. 3)
- *Osagia* type oncoids, irregularly shaped with concentric layers (Pl. 1, Fig. 5; Pl. 5, Fig. 1)
- Irregular and lobate growth forms (type L; Pl. 3, Fig. 7).

Spongiostromate oncoids with micritic laminae and spheroidal oncoids are significant for agitated shallow-water environments with constant energy; they were in permanent motion, so that laminae could be formed concentrically; accordingly, they are commonly somewhat smaller (below 1 or at most 2 cm). In areas, where the energy episodically declined and ooids stopped to

move, they went under an interruption of their growth, partial destruction and renewed growth after transport. Such oncoids are commonly larger and can attain several centimeters in diameter (FLÜGEL, 2004).

Today, oolitic limestone and especially dolomite have practical economic importance in the world, above all in oil-geology as collector rocks owing to their potential porosity. Although some Jurassic oolitic limestone in the world attain porosity of up to 20 % (Saudi Arabian; WILSON, 1975), oolitic beds in the Slovenian territory are very compact, entirely cemented with sparry calcite and attaining porosity of much below 0.5 %. The only exception are some dolomitized oolitic horizons within the Scythian sedimentary succession, and locally rare beds of the Jurassic oolitic dolomite where their porosity attains up to 5 %.

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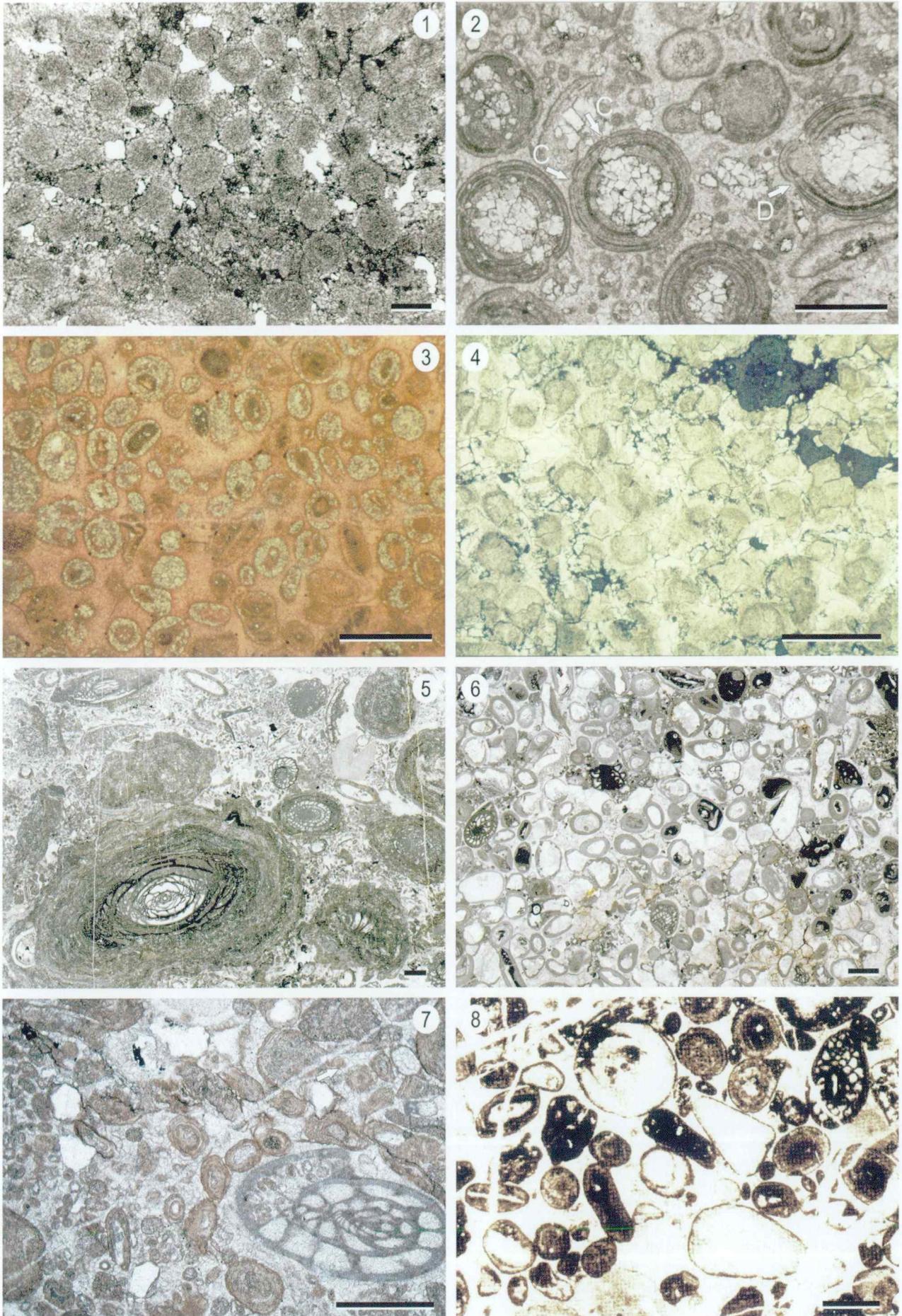
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PLATE 1

Scale on all figures is 1 mm

- 1 Oosparitic dolomite – grainstone. Primary oolitic structure is recognized by ooid contours. Intergranular porosity is affected by dolomitization. Upper Permian, Zajasovnik at Trojane
- 2 Oosparitic dolomite – packstone. Ooid nuclei show selective late-diagenetic dolomitization. Some ooids show slight cerebriform texture (arrow C) of outer laminae and their deformation (arrow D). Lower Triassic, Zakamnik above the Karavanke road tunnel
- 3 Oolitic grainstone, affected by late-diagenetic dolomitization. Tesero horizon at Permian/Triassic boundary. Idrija river bed at Spodnja Idrija. Alizarin red staining
- 4 Sparry dolomite with preserved primary oolitic structure and with sphalerite crystals. Permian/Triassic boundary, abandoned Pb-Zn mine Trebelno at Mokronog
- 5 Oncobiosparitic grainstone. Fusulinid foraminifers as nuclei in some oncoids of Osagia type. Rigelj beds, Lower Permian, Dovžanova soteska at Tržič (M. Novak collection)
- 6 Oolitic grainstone with some foraminifers. Nuclei of ooids were leached during diagenesis and later cemented in the vadose environment by sparry calcite. Base of Born Formation, Lower Permian, Dovžanova soteska at Tržič (M. Novak collection)
- 7 Bioosparitic grainstone with small ooids, bigger fusulinids and some detrital quartz grains. Upper Carboniferous (Gzhelian), Schulterkofel Formation, Dovžanova soteska at Tržič (M. Novak collection)
- 8 Bioosparitic grainstone with some ooids, fusulinids and echinoid plates. Upper Carboniferous, Suhi vrh above the Karavanke road tunnel

PLATE 1



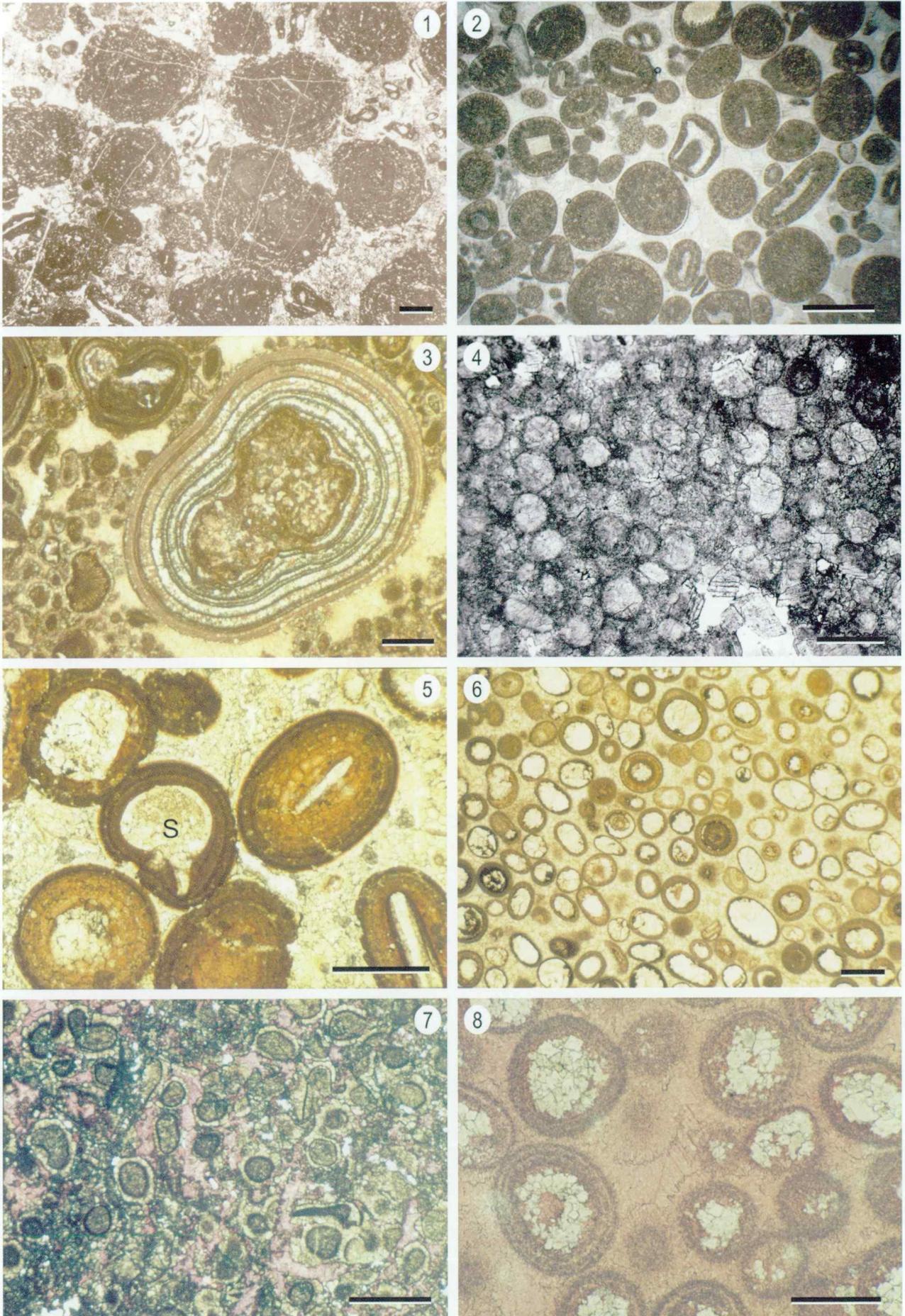
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PLATE 2

Scale on all figures is 1 mm

- 1 Spheroidal oncoidal packstone. Carnian, Gačnik on Vojsko plateau at Idrija
- 2 Oolitic grainstone. Nuclei of some ooids are echinoderm plates. Carnian, Pikov vrh above Helena creek at Mežica
- 3 A pisoid in oobiosparitic grainstone. The biomicritic nucleus is surrounded by selectively dolomitized laminae. Lower Carnian, Krma valley in Julian Alps
- 4 Oosparitic dolomite – grainstone. Primary oolitic structure is still evident by their contours. Intergranular pores were formed during the late dolomitization. Ladinian, Jazbina gorge at Mežica
- 5 Oosparitic grainstone. Ooids are reddish stained due to ferroan hydroxides. Central ooid (S) was deformed during compaction in vadose environment. Lower Triassic, Kisovec quarry at Zagorje
- 6 Oolitic grainstone with dissolved superficial ooids. Intergranular “moldic” pores are filled with granular and drusy meteoric sparite cement. Lower Triassic, Laško
- 7 Sparry dolomite with preserved structure of micritic oolites. Intergranular pores are cemented by late diagenetic sparry calcite. Some detritic quartz grains. Permian/Triassic boundary, footwall of Velenje coal mine. Alizarin red staining
- 8 Oosparitic grainstone. Ooid nuclei show selective dolomitization. Lower Triassic, Masore at Spodnja Idrija. Alizarin red staining

PLATE 2



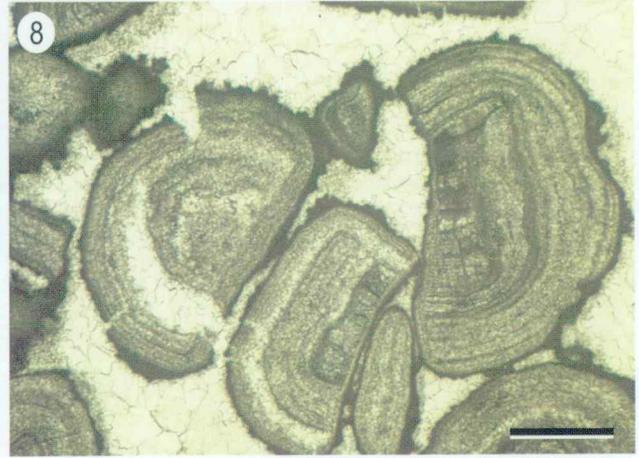
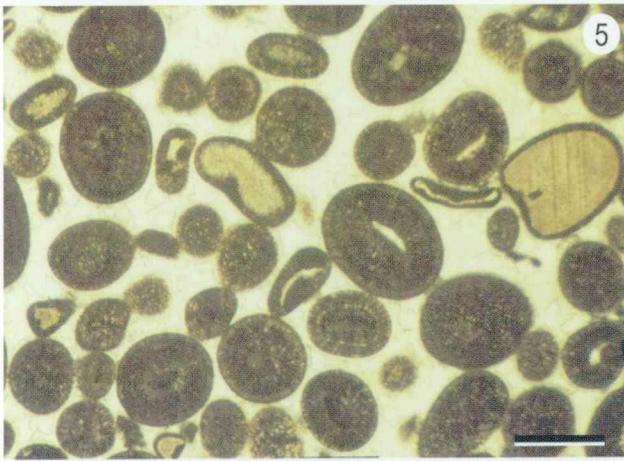
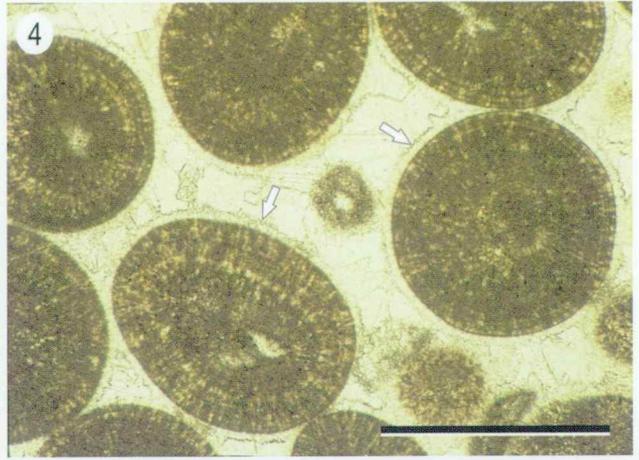
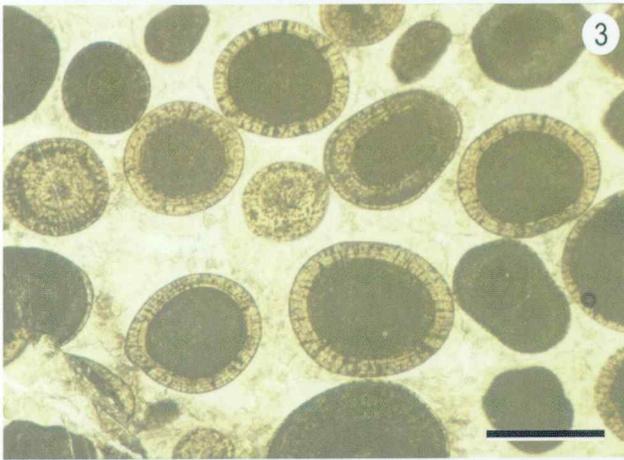
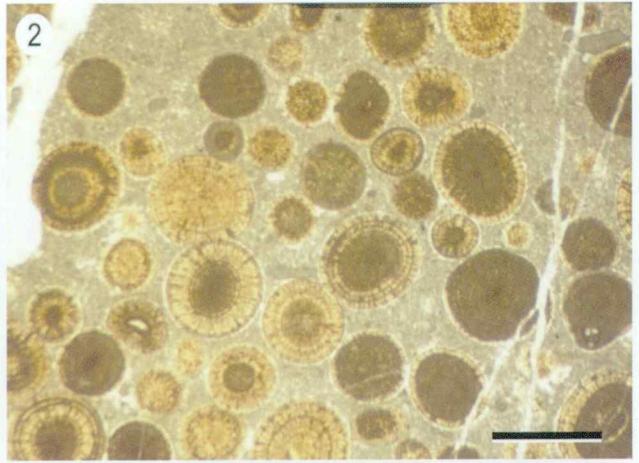
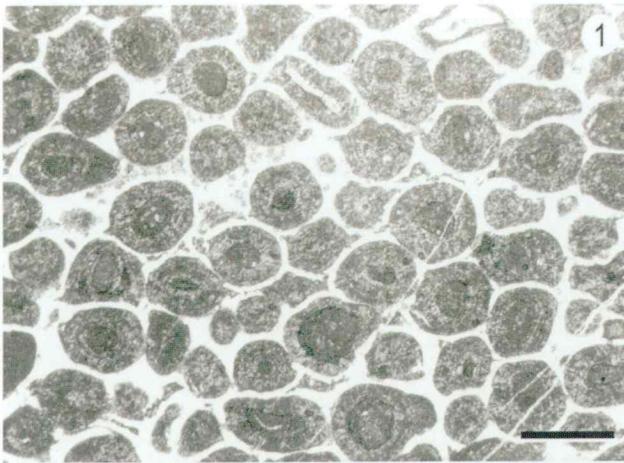
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PLATE 3

Scale on all figures is 1 mm

- 1 Oolitic grainstone. Ooids are slightly deformed and flattened, due to tectonics and dissolution. Rim cement is most evident. Lower Jurassic, Krka
- 2 Ooids in micritic matrix – packstone. Micritic texture of nuclei and radial-fibrous structure of outer laminae. Lower Jurassic, Grčarevec–Kalce
- 3 Oosparitic grainstone with typical mixed composition of ooids - micritic nuclei are overgrown with radial fibrous calcite laminae. Lower Jurassic, Verd at Vrhnika
- 4 Detail of oosparitic limestone. Two generations of cement – rim cement A (arrow) and sparry calcite in intergranular pores are evident. Radial-fibrous type of ooids. Lower Jurassic, Trnovski gozd
- 5 Oosparitic grainstone. Echinoid plates occur as nuclei in some ooids. Lower Jurassic, Trnovski gozd
- 6 Vadose pisoids in the intramicritic dolomite with shrinkage pores. Rhaetian, Trenta
- 7 Irregular lobate growth form oncoids in micritic dolomite with shrinkage pores. Norian/Rhaetian, Kanin Mts., Julian Alps
- 8 Vadose pisoids, encrusted by cyanobacteria. Sparry dolomite between the pisoids. Main dolomite, Norian, Koprivnik at Kočevje

PLATE 3



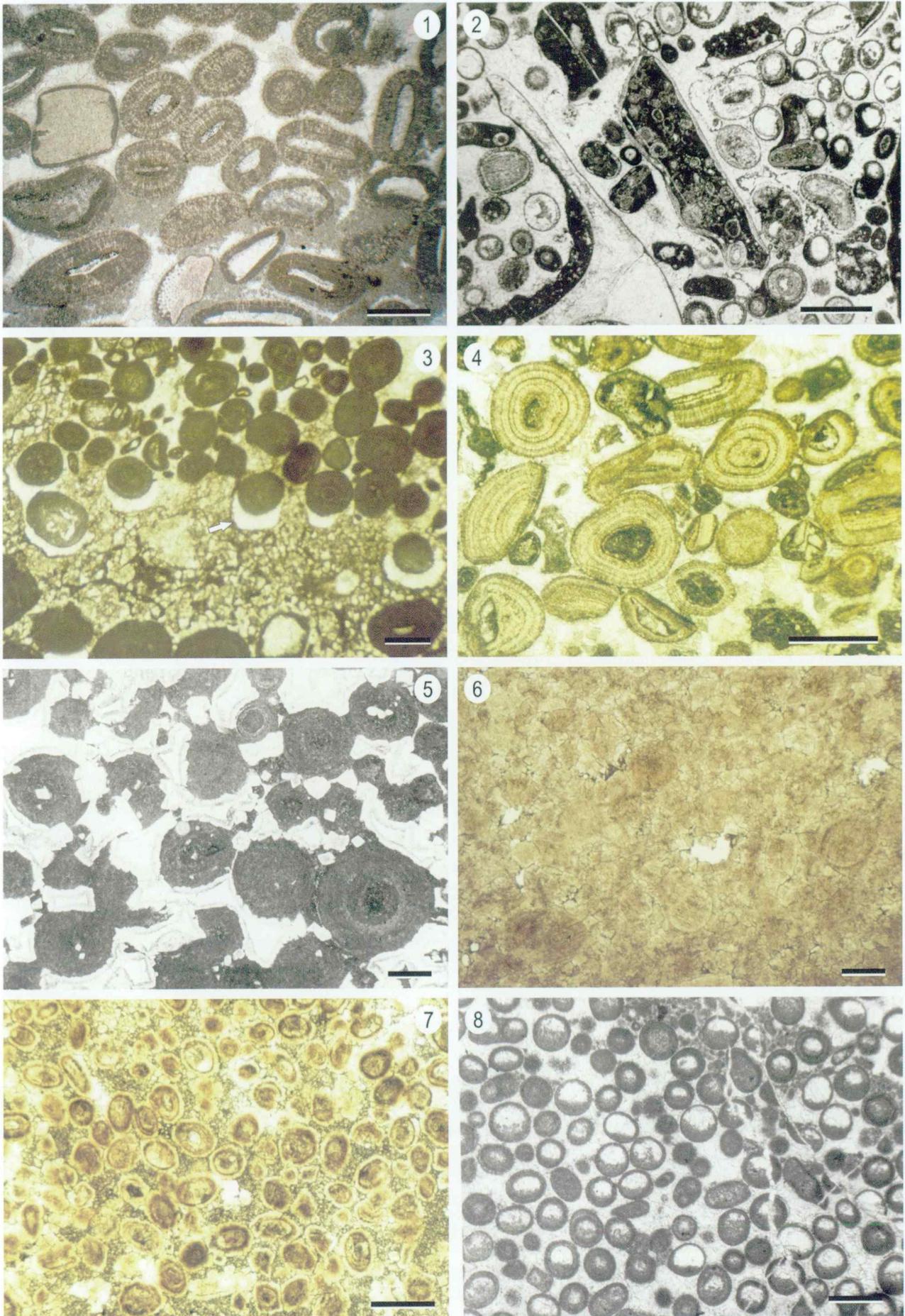
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PLATE 4

Scale on all figures is 1 mm

- 1 Oolitic grainstone with radial-fibrous ooids. Micritic matrix is still preserved somewhere. Echinoid plates occur as nuclei in some ooids. Middle Jurassic, Trnovski gozd
- 2 Intraoosparitic grainstone. Some intraclasts are coated with oolitic laminae. Upper Jurassic, Vrhnik - Logatec
- 3 Oosparitic grainstone. Stalactitic cement under ooids (arrow) indicates diagenesis in meteoric environment. Lower Jurassic, Grčarevec - Kalce
- 4 Oosparitic grainstone. Ooids have radial-fibrous envelopes. Some of them are broken and show “re-generation”. Lower Jurassic, Gozd at Col
- 5 Oosparitic grainstone, affected by selective late-diagenetic dolomitization, prograding from pores into ooid grains. Lower Jurassic, Vrhnik - Logatec
- 6 Sparry dolomite with open intergranular pores, formed during the late dolomitization. Primary oolitic structure is still evident. Lower Jurassic, Bistra at Vrhnik
- 7 Sparry dolomite with preserved primary oolitic structure. Lower Jurassic, Onek at Kočevje
- 8 “Half moon” ooids in oosparitic grainstone. Nuclei in most ooids have dropped to the bottom of the concentric outer layers, forming geopetal fabric. Such ooids are products of evaporate or aragonite solution process during meteoric diagenesis. Lower Jurassic, Javorški vrh on Trnovski gozd

PLATE 4



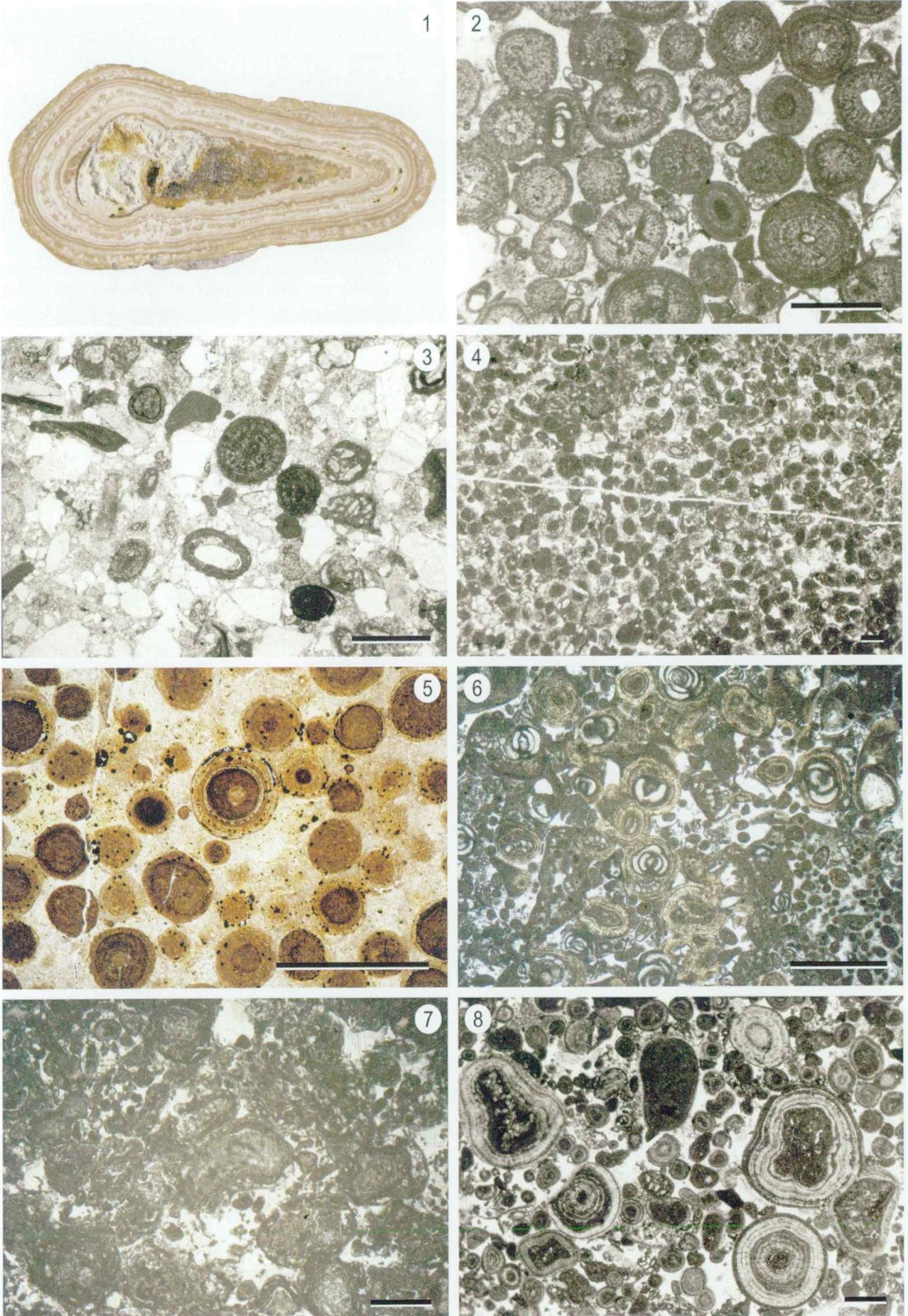
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PLATE 5

Scale on figures is 1 mm

- 1 Oncoidal overgrowth of gastropod shell. Lower Sarmatian, Orešje at Kostanjevica. Length of oncid is 5.5 cm. (V. Mikuč collection)
- 2 Oolitic grainstone with radial-fibrous concentric ooids. Upper Miocene (Badenian), Osek quarry at Lenart in Slovenske gorice
- 3 Calcareous sandstone – biocalcarenite with rare ooids. Upper Miocene (Badenian), Sedovec at Šmarje pri Jelšah
- 4 Pelmicritic limestone with some ooids. Lower Paleocene (Danian), Čebulovica at Divača
- 5 Oolitic bauxite. Santonian – turonian, Mt. Nanos – Podraška bajta (J. Jež collection)
- 6 Intraoosparitic packstone. Foraminifers as nuclei in some ooids. Lower Cretaceous (Albian), Nadrt at Hrušica, (J. Jež collection)
- 7 Small oncoids in pelmicritic, partly washed packstone. Lower Cretaceous (Hauterivian), (J. Jež collection)
- 8 Dark grey poorly sorted bedded oosparitic limestone with rare foraminifers. Urgonian facies – Lower Aptian

PLATE 5



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