Microfacies characteristics of the Lower Jurassic lithiotid limestone from northern Adriatic Carbonate Platform (central Slovenia)

Sedimentološke značilnosti spodnjejurskega litiotidnega apnenca s severnega roba Jadranske karbonatne platforme (osrednja Slovenija)

Luka GALE[1,2]

[1]University of Ljubljana, Faculty of Natural Sciences and Engineering, Department for Geology; Privoz 11, SI–1000 Ljubljana, Slovenia; e-mail: luka.gale@ntf.uni-lj.si
[2]Geological Survey of Slovenia, Dimičeva ul. 14, SI–1000 Ljubljana; e-mail: luka.gale@geo-zs.si

Abstract

The lithiotid limestone is characteristic for many Late Sinemurian – Pliensbachian tropical and subtropical carbonate platforms of the Neotethys and the Piemont-Liguria Oceans. On the northern edge of the ancient Adriatic Carbonate Platform (present NW External Dinarides) the lithiotid limestone forms a few hundred kilometres long belt. Sedimentological characteristics of the lithiotid limestone have been recorded in samples taken from three sections located in central Slovenia. Peloids, ooids, aggregate (lump) grains, benthic foraminifera, and micritised bivalve shells (cortoids) are the dominant grains. The microfacies association suggests restricted to open marine interior of a carbonate platform bordered by marginal sand shoals, or an inner ramp setting. Subtidal conditions were occasionally interrupted by emersions.

Izvleček

Litiotidni apnenec je značilna spodnjejurska litološka enota karbonatnega zaporedja številnih tropskih do subtropskih karbonatnih platform z obrobja Neotetide in Piemont-Ligurijskega oceana. Na severnem robu nekdanje Jadranske karbonatne platforme (današnji SZ Zunanji Dinaridi) se litiotidni apnenec razteza v smeri ZSZ-VJV v nekaj sto kilometrov dolgem pasu. Dosedanje poznavanje litiotidnega apnenca dopolnjujem s podrobnim sedimentološkim opisom vzorcev, nabranih v treh profilih na območju Krima v osrednji Sloveniji. Od klastov v apnencu prevladujejo peloidi, ooidi, agregatna zrna, bentoške foraminifere in delno mikritizirane lupine mehkužcev (kortoidi). Faciesna združba kaže na odlaganje v plitvem, nekaj metrov globokem morju razčlenjenem na zaprto laguno, odprto laguno, nakopičenja litiotidnih školjk in ooidne sipine. Podplimske pogoje so prekinjala kratkotrajna obdobja okopnitve vrha platforme, do katerih je pogosteje prišlo v spodnjem pliensbachiju.

Introduction

The Early Jurassic sea-level rise (HALLAM, 2001), a gradual recovery of biota after the alleged biocalcification crisis in the latest Triassic (HAUTMANN et al., 2008; GREENE et al., 2012), and, in many cases, extensional tectonics (RUIZ-ORTIZ et al., 2004; ŠMUC, 2005; VERWER et al., 2009) brought a gradual change from flat, uniformly shallow and skeletal-poor carbonate platforms of the earliest Jurassic (DOZET, 1993; BUCKOVIĆ et al., 2001; AZERÊDO et al., 2003; EREN et al., 2002; BARATTOLO & ROMANO, 2005; POMONI-PAPAIOANNOU & KOSTOPOULOU, 2008; WILMSEN & NEUWEILER, 2008; BOSENCE et al., 2009; OGORELEC, 2009) into the middle Early Jurassic platforms characterised by the abundance of biota and a variety of facies types (GALLI, 1993;

FUGAGNOLI & LORIGA BROGLIO, 1998; MASETTI et al., 1998; BLOMEIER & REIJMER, 1999; SCHEIBNER & REIJMER, 1999; COBIANCHI & PICOTTI, 2001; FRASER et al., 2004; WILMSEN & NEUWEILER, 2008). Among the more extensively researched carbonate platforms of the Early Jurassic is also the Adriatic Carbonate Platform (AdCP), a large carbonate platform with an approximate length of 600 km (DRAGIČEVIĆ & VELIĆ, 2002; TIŠLJAR et al., 2002; VLAHOVIĆ et al., 2002, 2005; ČADJENOVIĆ et al., 2008), positioned in the western part of the Neotethys Ocean (THIERRY, 2000; BOSENCE et al., 2009) (Fig. 1).

One of the most distinct facies types on the AdCP is the Late Sinemurian – Pliensbachian (according to SABATINO et al., 2013 also earliest Toarcian) lithiotid limestone (BUSER, 1965;
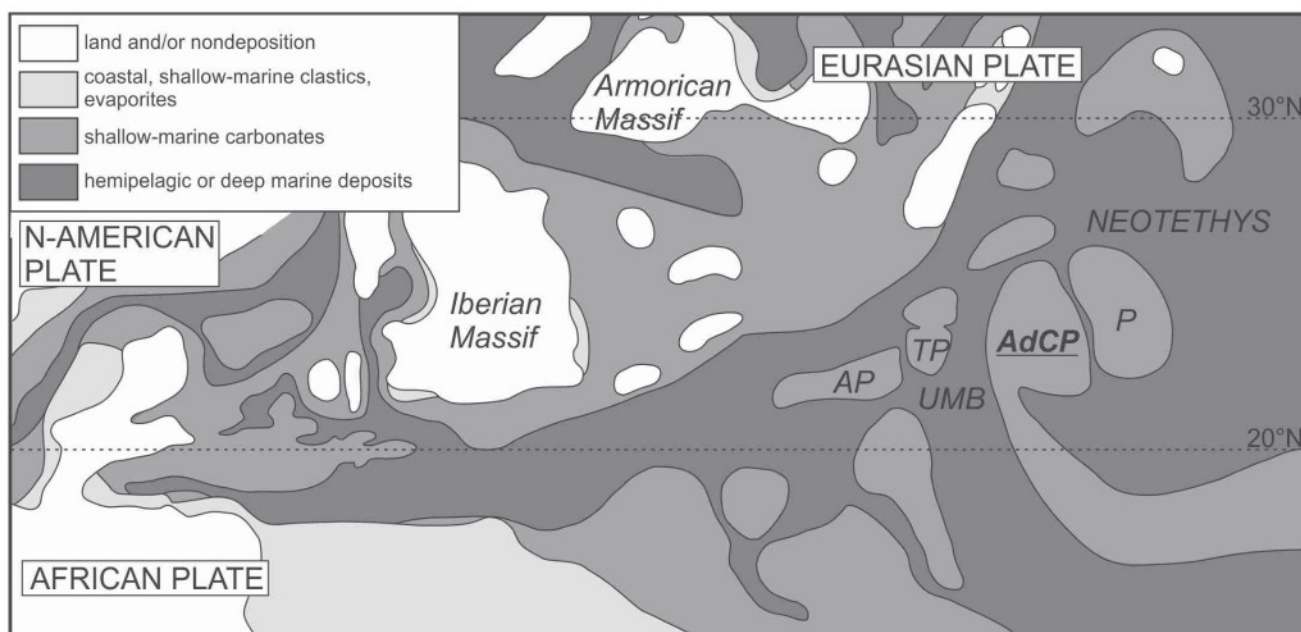
Figure 1. Palaeogeographic map of the western Neotethys for Late Sinemurian. AdCP – Adriatic carbonate platform; AP – Apennine Carbonate Platform; P: Pelagonia; UMB – Umbria Marche Basin; TP – Trento Platform. Modified after THIERRY (2000) and BOSENCE et al. (2009).

RADOIČIĆ, 1966; ŠRIBAR, 1966; STROHMENGER & DOZET, 1991; DOZET, 1992, 1996; BUSER & DEBELJAK, 1996; DEBELJAK & BUSER, 1997; TURNŠEK & KOŠIR, 2000; TIŠLJAR et al., 2002; TURNŠEK et al., 2003; ČADJENOVIĆ et al., 2008; ČRNE & GORIČAN, 2008; MARTINUŠ et al., 2012; GALE, 2014). At the northern part of the AdCP, structurally belonging to the north-western External Dinarides (PLACER, 1999), the lithiotid limestone extends in over 100 km long belt from Trnovski gozd in the west towards Kočevje and further to the east-southeast (BUSER & DEBELJAK, 1996). The lithiotid limestone was quarried south of Ljubljana and became known as the "Podpeč limestone" (RAMOVŠ, 2000; ŠTUKOVNIK et al., 2011; KRAMAR et al., 2015). Dozet named it the Lithiotid Limestone Member of the Podbukovje Formation (DOZET & STROHMENGER, 2000) or the Lithiotid Limestone Member of

the Predole beds (DOZET, 2009). On the basis of a detailed description of the lithiotid limestone from Trnovski gozd ČRNE and GORIČAN (2008) advocated a ramp model for the northern part of the AdCP, gradually passing into the deep-water Slovenian Basin to the north, while previous studies suggested a rimmed carbonate platform model (BUSER & DEBELJAK, 1996).

The aim of this paper is to extend the current knowledge on the lithiotid limestone at the northern edge of the AdCP by giving a detailed description of the lithiotid limestone from the Mt. Krim area (central Slovenia) (Fig. 2). The described sections are subsequently compared with the lithiotid limestone from Trnovski gozd, described in ČRNE and GORIČAN (2008). Finally, the question of the platform geometry is discussed.

Figure 2. Position of the studied area. Other localities, mentioned in the text (Kovk on Trnovski Gozd, Kočevje, R.p. – Radensko polje), are shown in other rectangles.

Geological setting

The northern part of the AdCP structurally belongs to the External Dinarides, which represent a deformed margin of the Adriatic tectonic microplate. The deformations in the External Dinarides are due to post-Cretaceous collision with the European plate, accompanied by folding and thrusting in SW direction during Late Cretaceous to Paleogene (PLACER, 1999; VRABEC & FODOR, 2006; PLACER, 2008; KASTELIC et al., 2008). The thrust units, from the uppermost to the lowermost, comprise: the Trnovo Nappe, the Hrušica Nappe, the Snežnik thrust block, and the Komen thrust block (Fig. 3). Thrust blocks consist of Late Paleozoic to Middle Triassic clastics and carbonates, followed by carbonates deposited on the AdCP. Towards north, the External Dinarides border the Tolmin thrust unit of the Southern Alps along the South-alpine reverse fault and the Marija Reka fault. The Tolmin thrust unit mostly comprises deep water sediments of the Slovenian Basin, originally extending along the northern margin of the AdCP (PLACER, 1999). Thrusts are further cut and displaced by dextral strike-slip faults active since the Pliocene (VRABEC & FODOR, 2006; KASTELIC et al., 2008; KASTELIC & CARAFA, 2012).

The Mt. Krim area structurally belongs to the Hrušica Nappe of the External Dinarides (PLACER, 1999). The geological structure of this territory was established by LIPOLD (1858), KRAMER (1905), VETTERS (1933), BUSER et al. (1967), BUSER (1968), and MILER and PAVŠIČ (2008). The Mt. Krim area mostly consists of Upper Triassic to Middle Jurassic shallow water carbonates (BUSER et al., 1967; BUSER, 1968, 1989; OGORELEC & ROTHE, 1993), which today form the southern hilly rim and the southern basement of the younger, post-Pliocene tectonic Ljubljana Moor Basin (JAMŠEK RUPNIK et al., 2015). Mesozoic
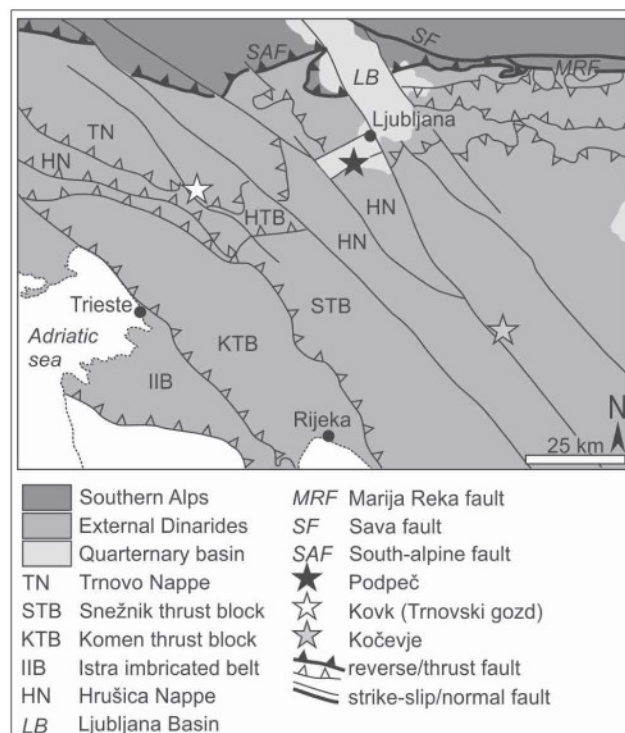

Figure 3. Structural map of the south-western Slovenia. Simplified after PLACER (1999).

carbonates are dissected by N-S and WNW-ESE to NW-SE running faults (BUSER et al., 1967; BUSER, 1968) (Fig. 4).

The Lower Jurassic succession in the Mt. Krim area conformably overlies the Norian-Rhaetian Main Dolomite (Fig. 5), which is characterised by medium to thick-bedded crystalline dolomite, laminated fenestral dolomite and intraclastic breccia, marking cyclically interchanging shallow subtidal, intertidal and supratidal conditions (OGORELEC & ROTHE, 1993; MILER et al., 2007; MILER & PAVŠIČ, 2008). The lowermost Jurassic
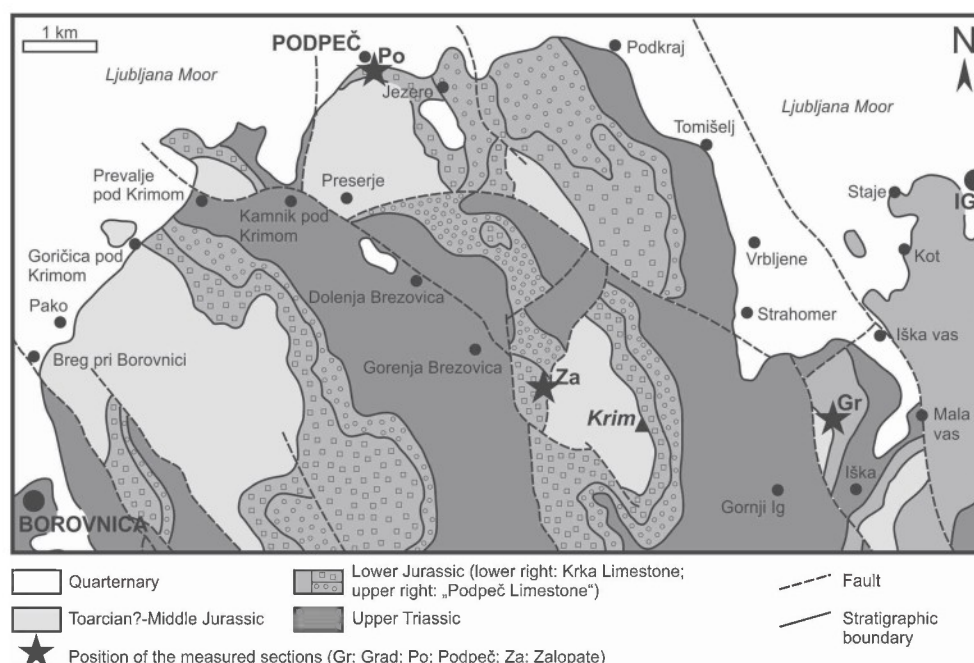

Figure 4. Geologic map of the Mt. Krim area. Modified after BUSER et al. (1967) and BUSER (1968).

Figure 5. Lower Jurassic lithological succession in the Mt. Krim area, and comparisson to the lithostratigraphic division proposed by DOZET and STROHMENGER (2000) for the Suha krajina and by DOZET (2009) for the Radensko polje. The positions of the measured sections are shown with gray rectangles.

(Hettangian-Sinemurian) succession consists of medium to thick-bedded coarsely crystalline dolomite, finely laminated dolomite, bedded micritic, rarely peloidal and oolitic limestone. Emersion surfaces are indicated by red-stained irregular upper bedding planes. This succession also deposited in peritidal and shallow subtidal setting (MILER & PAVŠIČ, 2008; OGORELEC, 2009). Discontinuous, up to several tens of meters thick bodies of mud-supported breccia are locally present (BUSER, 1965), as well as up to a meter wide dikes, filled with large angular blocks of dolomite in dolomitised matrix (visible along road cut south of Pijava Gorica). Upwards, oolitic and bioclastic limestone predominates, gradually passing into dark grey to black limestone with lithiotid bivalves, bioclastic packstone, floatstone, ooid packstone and grainstone (BUSER & DEBELJAK, 1996; MILER & PAVŠIČ, 2008). On the basis of lithiotid bivalves and foraminifera, a Late Sinemurian-Pliensbachian age has been determined for the lithiotid limestone (BUSER & DEBELJAK, 1996; GALE, 2014). Discontinuous, but much rarer bodies of black limestone breccia can be laterally found (BUSER, 1965), for example west of Jezero. The Lower Jurassic succession ends with the Toarcian thin-bedded, often nodular micritic limestone (A. Košir, pers. com.). The Middle Jurassic succession consists of mostly strongly dolomitised thick succession of oolitic limestone (BUSER, 1965, 1968; MILER & PAVŠIČ, 2008).

Material and methods

The facies analysis of the "Podpeč limestone" is based on three detailed sections, namely the Zalopate (45°56'09'' N, 14°27'21'' E), the Podpeč quarry (45°58'22'' N, 14°25'16'' E) and the Grad (45°55'46'' N, 14°30'14'' E) sections (Fig. 4). Bed thickness classification follows TUCKER (2001).

Altogether, 63 thin sections were investigated and described according to terminology of DUNHAM (1962), and EMBRY and KLOVAN (1971). The proportion of grain types was estimated with the use of comparison charts of BACELLE and BOSELLINI (1965). Sand-size, roughly spherical homogenous lime-mud particles are termed peloids sensu FRIEDMAN (2003). Microfacies (MF) types were compared to Standard Microfacies Types in FLÜGEL (2004).

Description of sections

The Zalopate section (Fig. 6) is 42.5 m thick and consists mostly of grey to black limestone of variable textures. Bed thickness ranges from 6 cm to 320 cm, but thicker beds predominate in the lower part of the section, whereas thin to medium thick beds are more common in the upper half of the section. The texture of the limestone varies from mudstone to floatstone with grainstone

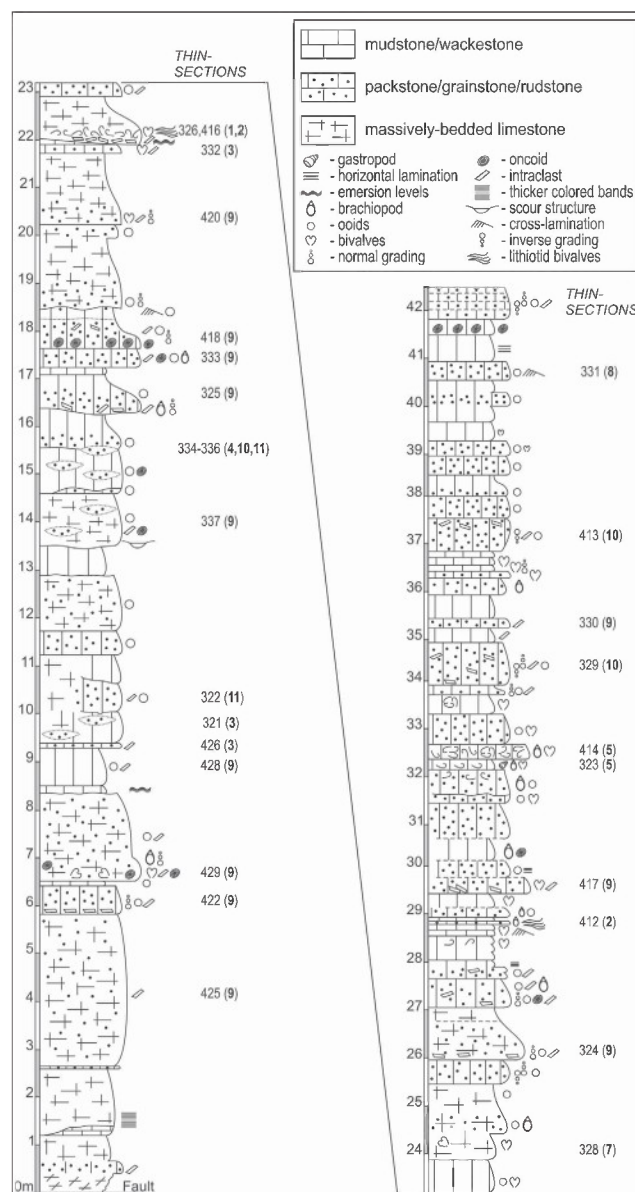Figure 6. The Zalopate section. This is the lower part of the "Podpeč limestone" s.l. (note the scarcity of lithiotid bivalves). Late Sinemurian – early Early Pliensbachian. Number in brackets denotes the microfacies type.
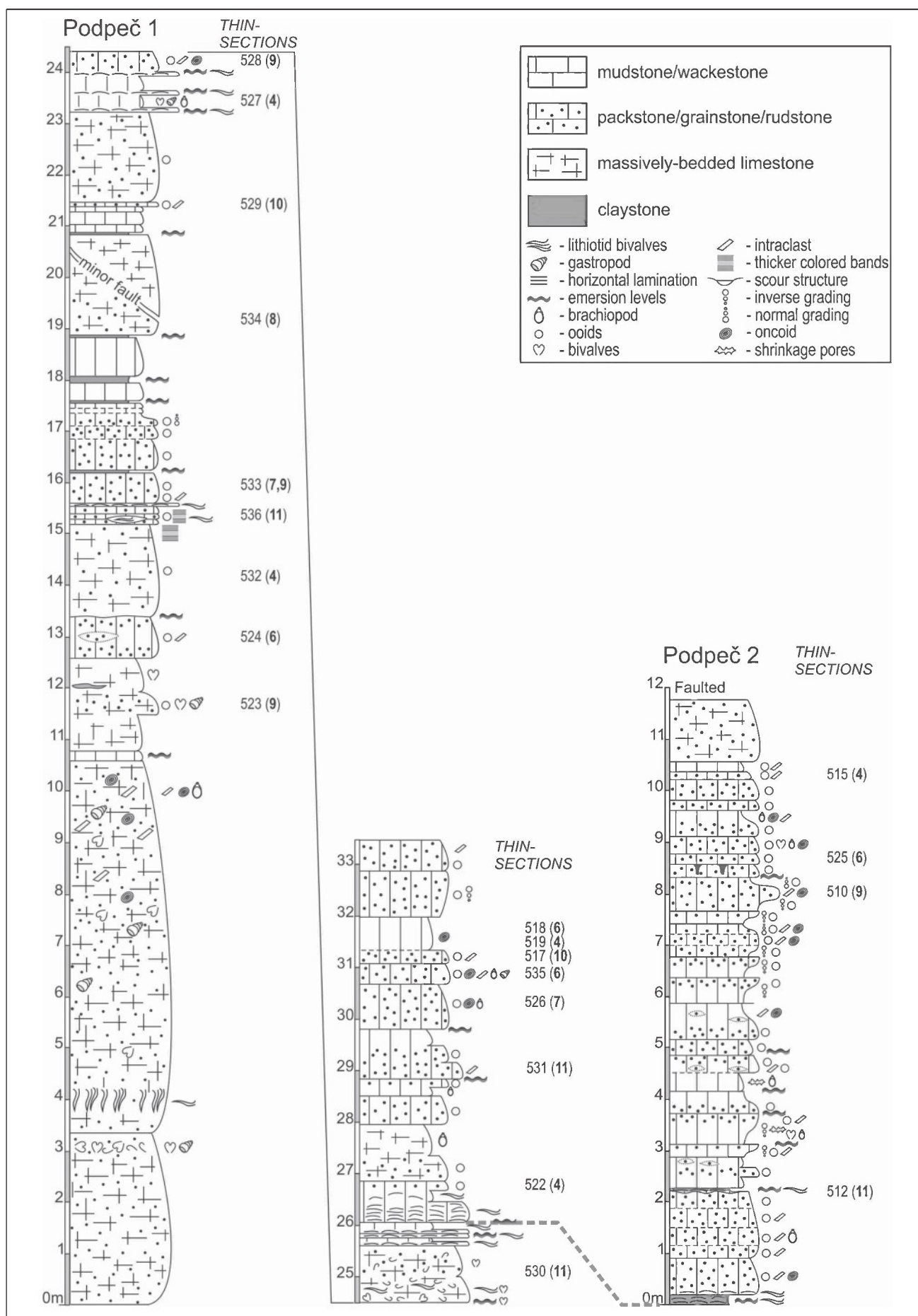
Figure 7. The lithiotid-rich "Podpeč limestone" from the type locality in the Podpeč quarry. Two overlapping sections were measured. Early Pliensbachian. Number in brackets refer to mikrofacies type.

support, often within the same bed, either through grading, or through irregular mixing (at least in part due to bioturbation) and lateral pinching out. Normal grading is the most common sedimentary structure. Some accumulations of fossils (mostly fragmented bivalve shells) can be found at the bottom of beds. Bivalve shells are more commonly dispersed in oolite. Several bedding planes show irregular morphology, reddish colouration, and thin intercalations of red or yellow claystone. Lithiotid bivalves are rare, and only up to 5 cm long, undetermined specimens were found, in one case accumulated above a score structure, cutting through mudstone with birdseyes-type porosity and red clayey surface. Cross-lamination is rarely found in oolitic limestone. The section is placed in the *Orbitopsella primaeva* partial-range zone of Late Sinemurian to early Early Pliensbachian age (VELIĆ, 2007; not into the early Late Sinemurian *Lituosepta recoraensis* zone as stated in GALE, 2014).

In the Podpeč quarry two sections were logged and correlated: Podpeč 1 (33 m thick) and Podpeč 2 (12 m thick) (Fig. 7). Limestone predominates, but up to several centimetres thick intercalations of red claystone are common. The measured section starts with 3 m thick packstone/grainstone with superficial ooids and recrystallised bivalve shells concentrated near the upper bedding plane in a 20 cm thick layer. Grainstone is followed by almost 7 m thick packstone/grainstone with lithiotid bivalves oriented perpendicular to the bedding plane, with commissures oriented upwards (i.e., preserved in toto). A 20 cm thick limestone bed with claystone intercalations follows. Throughout the rest of the section thick to very thick limestone beds predominate. Grey oolitic limestone is the most common lithological type. Dispersed bivalve shells may be present. Gradual transition from oolite into micritic limestone or vice versa is common. Oncoids are frequent in the upper part of the section. Mudstone and wackestone are also present. The latter may contain dispersed, randomly oriented terebratulid brachiopods or megalodontid bivalves. Limestone beds are often separated by red claystone layers, which may be several centimetres thick. Red claystone partings are common near the top of individual beds, and may be present also inside limestone beds. Irregular subvertical pockets filled with yellowish claystone were also found near the top of the measured section (8.5 m above the base of Podpeč 2 section in Fig. 7). Some limestone beds and claystone interlayers contain accumulated shells of lithiotid bivalves oriented parallel to the bedding plane, but often with both valves preserved together. Up to 15 cm large fragments of shells are commonly found eroded from the latter. According to BUSER and DEBELJAK (1996), *Lithioperna scutata* is present in the lower part of the Podpeč quarry succession, whereas *Cochlearites loppianus* appears higher. The section belongs to the Early Pliensbachian *Orbitopsella praecursor* taxon range zone (GALE, 2014).

The Grad section measures 8 m in thickness (Fig. 8). Medium to thick beds predominate, which are internally often heterogenous. Mudstone, wackestone, bioclastic and ooid packstone, floatstone and rudstone with brachiopods and bivalves were determined in the field. Few beds have wavy lower boundaries and chaotic shell accumulations at the bottom, gradually passing into ooid packstone and wackestone. Lithiotid bivalves are present, but shells are randomly distributed and fragmented. The section belongs to the Early Pliensbachian *Orbitopsella praecursor* taxon range zone (GALE, 2014).
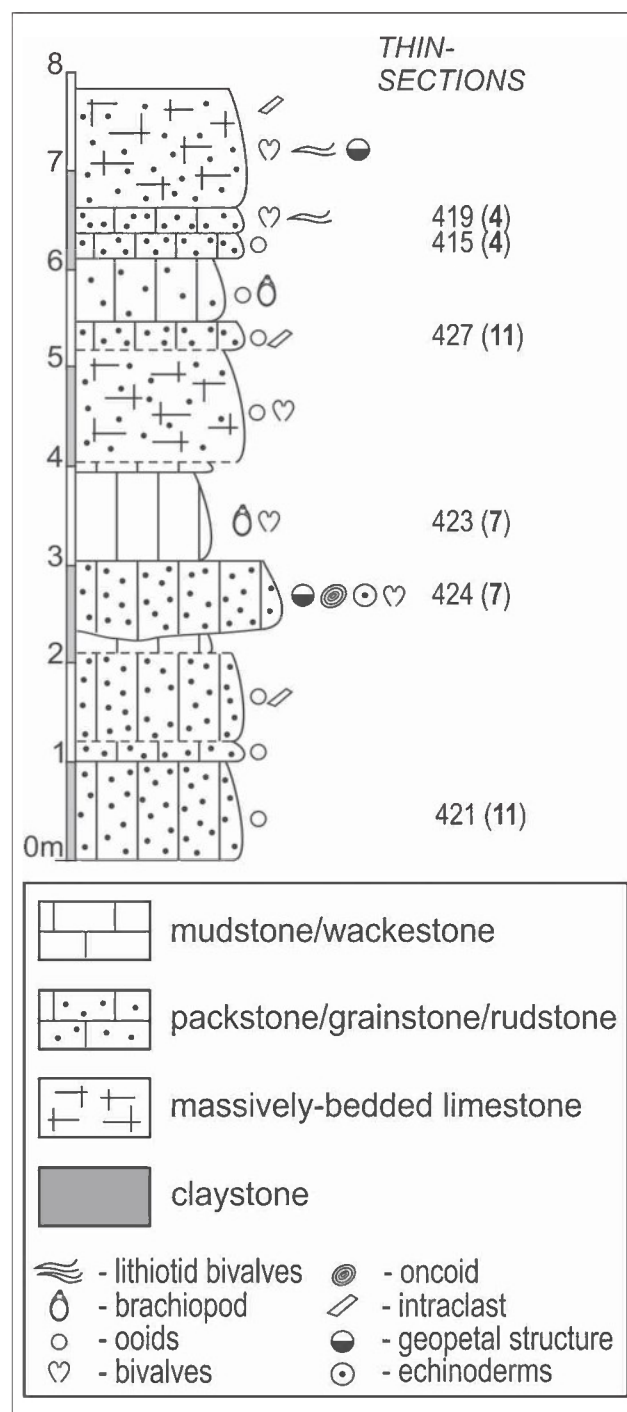

Figure 8. The Grad section of the lithiotid limestone ("Podpeč limestone" s.str.). Early Pliensbachian. Numbers in brackets denote the microfacies type.

Microfacies description

Eleven microfacies (MF) types were recognised, although subtle variations in some of them could lead to several subtypes. Comparison of described MF types with standard microfacies types (SMF) is given in Table 1.

MF 1 – Mudstone

A very common facies type is grey or black micritic limestone in thin to very thick beds. Micritic matrix is devoid of grains. Fenestrae (5 % of the thin section surface) show geopetal fabric formed by crystal silt in the lower and blocky spar in the upper part (Fig. 9.1).

MF 2 – Lithiotid floatstone to rudstone

Lithiotid bivalves are commonly accumulated in several horizons in Grad and Podpeč sections, whereas only up to several centimetres large specimens were recorded in the Zalopate section. Shells comprise up to 50 % of the thin section surface. They are partly neomorphically altered into blocky spar, and retain fibrous outer layer. They are embedded into peloidal wackestone or packstone with some fenestrae (Fig. 9.2-9.3). Small

fragments of shells are common and rare benthic foraminifera are present.

MF 3 – Peloidal wackestone-packstone with Thaumatoporella

This MF type was found in thin to medium-thick beds of the Zalopate section. The distinct feature of this microfacies is the abundance of the problematic algae *Thaumatoporella* and a low abundance of benthic foraminifera. The matrix is peloidal-bioclastic wackestone with some fenestrae, and with up to 45 % of grains. Peloids represent 80–90 % of grains. Subordinate are benthic foraminifera (*Meandrovoluta asiagoensis*, *Textularia* sp. and *Siphovalvulina* spp. predominate), mollusc fragments and *Thaumatoporella* thalli. Micritic matrix in places appears clotted (Fig. 9.5).

MF 4 – Peloidal wackestone to packstone

This MF type is similar to MF 3 by the high abundance of peloids, but contains more diverse biota. It was found in medium to very thick beds and is rather common in all sections. Accumulations of lithiotid shells are sometimes present in the lower part of the same beds.

Table 1. Comparison of the determined microfacies (MF) types with Standard Microfacies Types from FLÜGEL (2004).

Described microfacies Type	Standard Microfacies Type (Flügel, 2004)	Occurrence on flat-top platform	Occurrence on ramp
1: Mudstone	SMF 23	FZ 8 (tidal flat)	Inner ramp
2: Lithiotid floatstone to rudstone	SMF 12-Lithiotid	FZ 8 (restricted platform and tidal flat), FZ 7 (open platform)	Inner ramp
3: peloidal wackestone-packstone with *Thaumatoporella*	?SMF 18	FZ 8 (restricted platform; as bar sand channels, sand shoals heaped up by tidal currents in shallow lagoon and bays), FZ 7 (shelf lagoon with open circulation)	Inner ramp
4: Peloidal wackestone to packstone	SMF 16- Non-laminated to SMF 10	FZ 7 (open shelf lagoon) FZ 8 (restricted platform)	Inner ramp
5: Bivalve floatstone to rudstone	SMF 12-Bs	FZ 8 (restricted platform) FZ 7 (open platform)	Open inner ramp
6: Oncoidal-peloidal floatstone	SMF 22	FZ 8 (low-energy part of shallow lagoon and tidal zone)	Middle and outer ramp
7: Coated bioclastic floatstone with peloidal-bioclastic wackestone-packstone matrix	SMF 10	FZ 7 (open shelf lagoon)	Inner ramp
8: Peloidal grainstone	SMF 16-Non-laminated	FZ 8 (shallow platform interior)	Inner ramp
9: Cortoid floatstone to rudstone with peloidal-bioclastic grainstone matrix	(no single analogue; mostly SMF 14)	Shallow platform interior with moderate to high water energy	Inner ramp (shoal)
10: Bimodal poorly to medium sorted ooidal-peloidal grainstone	SMF 17	FZ 7 (shallow open shallow platform)	(very rare)
11: Well sorted ooidal grainstone	SMF 15	FZ 8 (restricted lagoon) FZ 7 (oolitic shoals, tidal bars, beaches)	Inner ramp

Grains represent 40–50 % of the thin section surface, and are well to very well sorted (Fig. 9.6). Peloid size is 0.1–0.15 or 0.2–0.35 mm.

Subangular to well-rounded peloids predominate (60–80 % of clasts; Fig. 9.7). Mollusc fragments (in some thin sections with micritic outlines) and micritic intraclasts represent 5 % of grains each. The rest of the clasts are represented by small benthic foraminifera (*Meandrovoluta* sp., Lagenina), pellets (*Parafavreina* sp.), microproblematica *Thaumatoporella* sp., green algae, echinoderms, and ostracods. Aggregate grains (mature lumps) are very rare. Subangular, sub-elongated mudstone intraclasts (mudchips) are rarely present.

Into microspar recrystallised matrix is bioturbated and contains some fenestrae. Vugs, filled with blocky spar, represent 2.5–5 % of the thin section surface.

MF 5 – Bivalve floatstone to rudstone

Present in medium thick beds, without apparent orientation of shells or with convex side turned downwards.

This MF is characterised by accumulation of up to several milimetres large bivalves and rare gastropods embedded in micritic matrix (Fig. 9.8). Both valves are present, mostly unbroken, without micritic outlines, and positioned oblique or parallel to bedding. The original shell material is replaced by blocky spar. Microcrystalline spar is present at the bottom of some valves, succeeded by blocky spar, suggesting dissolution of shells. Ostracods are very rare.

MF 6 – Oncoidal-peloidal floatstone

This type of microfacies was recorded in thick beds, overlying oolite with intraclasts and passing into ooid-intraclastic packstone to rudstone. It may also form a homogenous texture within individual beds.

This MF is characterised by 20–40 % of 4–12 mm large oncoids with micritic inner structure. Some peloids, small spar crystals, encrusting foraminifera, and microproblematica *Thaumatoporella* are found within the oncoids. A possible partly bored sponge was found in the center of one of the oncoids. Two subtypes may be distinguished on the basis of the matrix surrounding the oncoids.

In the first subtype, oncoids are embedded in packstone matrix (Fig. 10.1). Patches of peloidal grainstone with intergranular drusy mosaic spar are present along the packstone. Grains comprise 50 % of the area. They are poorly sorted, with an average size 0.15 mm. Peloids predominate (80 % of grains) over intraclasts (10 %), foraminifera (4 %), bivalve fragments (3 %), and microproblematica *Thaumatoporella* and *Tubiphytes* (2 %). Gastropods, echinoderms and green algae are very rare. Large lituolid foraminifera are rarely present. Echinoderm plates are overgrown by sintaxial calcite.

In the second subtype, oncoids are embedded in wackestone with patches of packstone (Fig. 10.2). Washed-out patches are rarer (2.5 % of surface), filled with drusy mosaic cement. Peloids are the dominant grain type. Superficial ooids, foraminifera, intraclasts, echinoderms, and serpulid fragments are subordinate.

MF 7 – Coated bioclastic floatstone with peloidal-bioclastic wackestone-packstone matrix

Present in medium to very thick beds, in places with erosional lower bedding planes.

Grains measuring 2–5 mm represent up to 25 % of the thin section area (Fig. 10.3–10.4). They consist of bivalve fragments, rarely gastropods, brachiopod shells, and aggregate grains. Fossils are neomorphically altered into mosaic or granular spar. Some are rounded due to abrasion/bioerosion, strongly bored at the surface or have micritic coatings. The supporting matrix is represented by peloidal-bioclastic wackestone-packstone with 30-50 % of grains (Fig. 10.5). These are dominated by peloids (80 % of grains). Common are mollusc shell fragments (10–15 % of grains), which are angular, without micritic outlines. Foraminifera (up to 5 % of grains diverse small and large benthic forms) and echinoderms (2.5 % of grains) are always present, whereas amount of superficial ooids varies (0–5 %). Gastropods (Fig. 10.6), ostracods, dasyclad green algae, and brachiopods are rare to very rare. Almost 2 mm wide stromatactis-like cavities are rarely present, filled with blocky spar.

Remark: This MF could alternatively be assigned to SMF 11 (Coated bioclastic grainstone), occuring in winnowed platform edge sands, rarely in inner- and middle-ramp settings. In Table 1, it is attributed to SMF 10 (Bioclastic packstone and grainstone with worn skeletal grains).

Figure 9. Microfacies types of the Podpeč limestone.

1 – Mudstone with fenestrae, partly filled with crystal silt (arrowhead). Thin section 416.

2 –3 Lithiotid rudstone. Thin section 412.

4 –5 *Thaumatoporella* wackestone-packstone. *Thaumatoporella* thallus is marked with the arrowhead. Thin section 426.

6 –7 Peloidal wackestone to packstone. Thin section 336.

8 – Bivalve rudstone. Thin section 323.
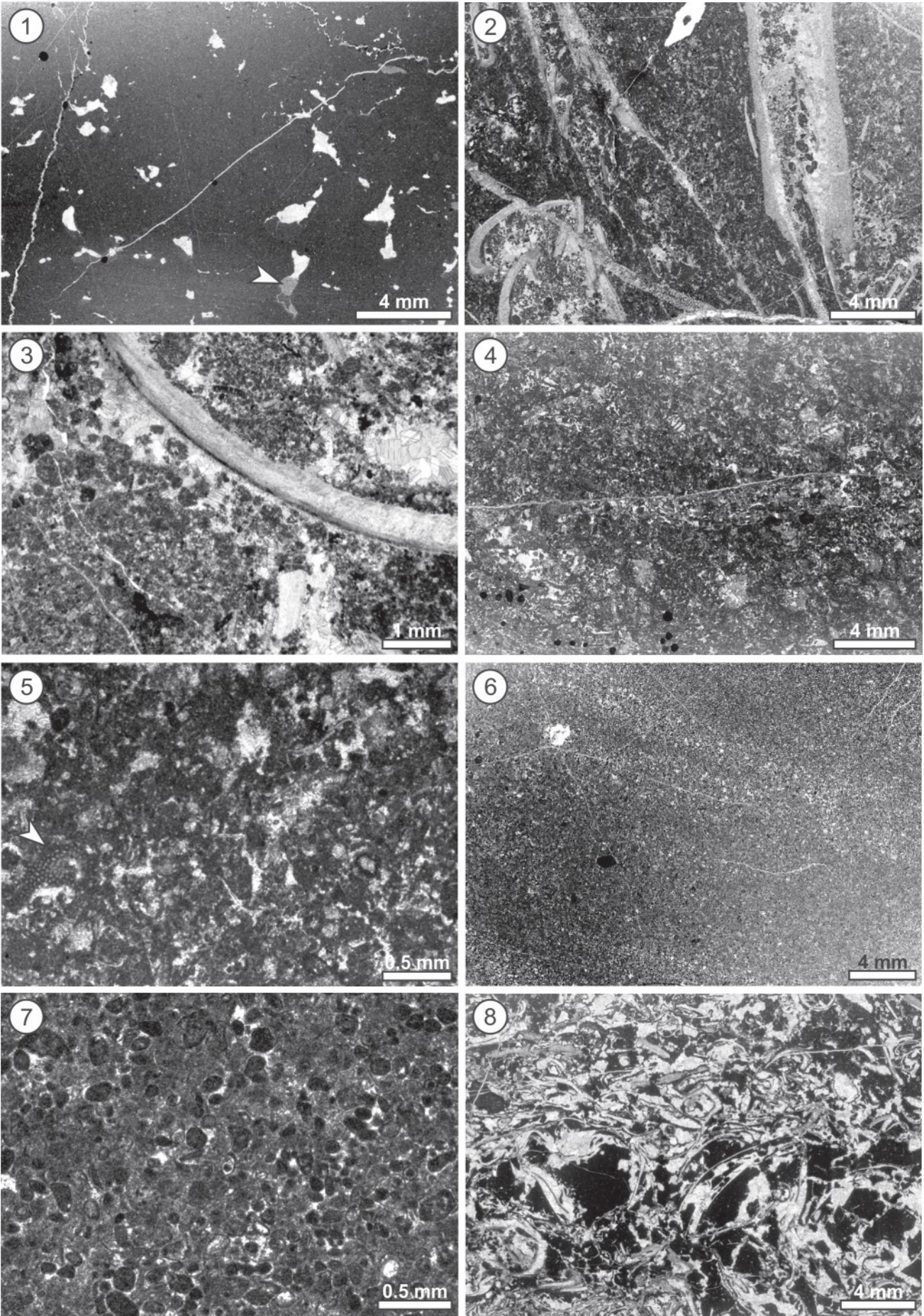
MF 8 – Peloidal grainstone

Present in medium thick beds with cross-lamination, and massive beds.

This MF is distinguished from MF 7 in the smaller amount of clasts larger than 2 mm, and a lack of micritic matrix.

Up to 4 mm large clasts (up to 5 % of the surface) comprise mudstone and wackestone intraclasts, fragmented bivalve shells with microborings on the outer surface, gastropods, and large benthic foraminifera. Clasts are parallel to the bedding and are floating in peloidal grainstone.

Around 50 % of the peloidal grainstone consists of grains. These are well to very well sorted (Fig. 10.7–10.8). Rounded, 0.1–0.2 mm or 0.2–0.35 mm large peloids (in this case "pseudo-ooids") predominate (70 % of clasts). Subordinate are cortoids of small mollusc fragments (10 % of grains), replaced by spar, sub-rounded to angular in shape, and sub-elongated or isometric in form. Superficial ooids (10 % of grains) have nuclei of mollusc fragments, echinoderms or peloids. Echinoderms, foraminifera and lumps comprise each 5 % of grains. Gastropods and calcimicrobes are very rare.

Grains are surrounded by circumgranular bladed spar. The remaining intergranular space is filled with mosaic spar. Sintaxial cement is present around echinoderm plates.

MF 9 – Cortoid floatstone to rudstone with peloidal-bioclastic grainstone matrix

This is a very common microfacies, building medium to very thick beds. The latter are often normally graded, with large bioclasts concentrated in the lower part. Indistinct grading may be present, with rudstone passing into floatstone. Larger bivalve shells are usually parallel to bedding, but variably concave- to convex-upwards. Geopetal structures may be present in gastropod shells. Lamination due to differences in grain size is in places present in the grainstone matrix.

Clasts larger than 2 mm (up to 11 mm in diameter) comprise 10–50 % of the rock volume. They are mostly bivalve shells with micritised outer surfaces and replaced by mosaic spar (Fig. 11.1-

11.2). Micritic coatings are also present. Packstone or mudstone matrix clings to some shells. Some large intraclasts with keystone vugs are locally present (Fig. 11.5). A minor part of larger clasts belongs to abraded and on the outside micritised gastropods. Their lumen is filled with packstone or with mudstone. Large benthic foraminifera, calcimicrobe *Cayeuxia*, dasyclad green algae geniculi, echinoderms, and packstone intraclasts represent a smaller amount of large grains.

The described large clasts float in peloidal-bioclastic grainstone (Fig.11.3–11.4). The mean size of peloids is around 0.2 mm, whereas bioclasts measure 0.5-1 mm. Grains are well rounded, sub-elongated to spherical in shape. Peloids or superficial ooids predominate (around 80 % of smaller grains). The rest of the smaller grains are echinoderms (some with micritised outlines), mollusc fragments, benthic foraminifera, dasyclad green algae, brachiopod fragments, and aggregate grains.

Grains are surrounded by fibrous to bladed circumgranular cement.The remaining intergranular space is filled with mosaic spar. Larger vugs and umbrella-type vugs beneath some bivalve shells are filled with drusy mosaic spar. Echinoderms are enclosed in sintaxial cement.

Remark: There is no single SMF type to describe rudstone to floatstone with grainstone matrix. Instead, comparable lithology is interpreted as storm deposit (Pl. 127, fig. 2 in FLÜGEL, 2004; see also CARACUEL et al., 2005).

MF 10 – Bimodal poorly to medium sorted ooid-peloidal grainstone

This type of microfacies was recognised in thin beds, in very thick beds with inverse-to-normal grading, or in very thick beds with bivalve accumulations at the base. It was also encountered as lense-shaped accumulations.

Grains represent 60% of the volume and are bimodally distributed (Fig.11.6–11.7). Sorting is poor to moderately good. Grains are in point contacts. Larger grains (diameter 0.3 or 0.5–0.8 mm) are represented by ooids and aggregate grains. Interstices between larger grains are more or less densely filled with smaller ooids (diameter 0.05–0.07 mm) and peloids.

Figure 10. Microfacies types of the Podpeč limestone.

1 – Oncoidal floatstone with packstone matrix. Thin section 524.

2 – Oncoidal floatstone with wackestone matrix. Thin section 518.

3 – Floatstone with packstone matrix. Thin section 328.

4 – Floatstone with dense wackestone matrix. Thin section 424a.

5 – Wackestone matrix of floatstone. Fragmented fossils, ostracods and peloids. Thin section 423.

6 – Gastropod shell replaced by drusy mosaic spar. Crossed nicols. Floatstone with wackestone matrix. Thin section 423.

7 – Peloidal grainstone. Thin section 534.

8 – Peloidal grainstone. Note a small radial ooid (white arrowhead) and spar-replaced bioclasts (black arrowhead), the majority of which have micritic outline. Thin section 331.
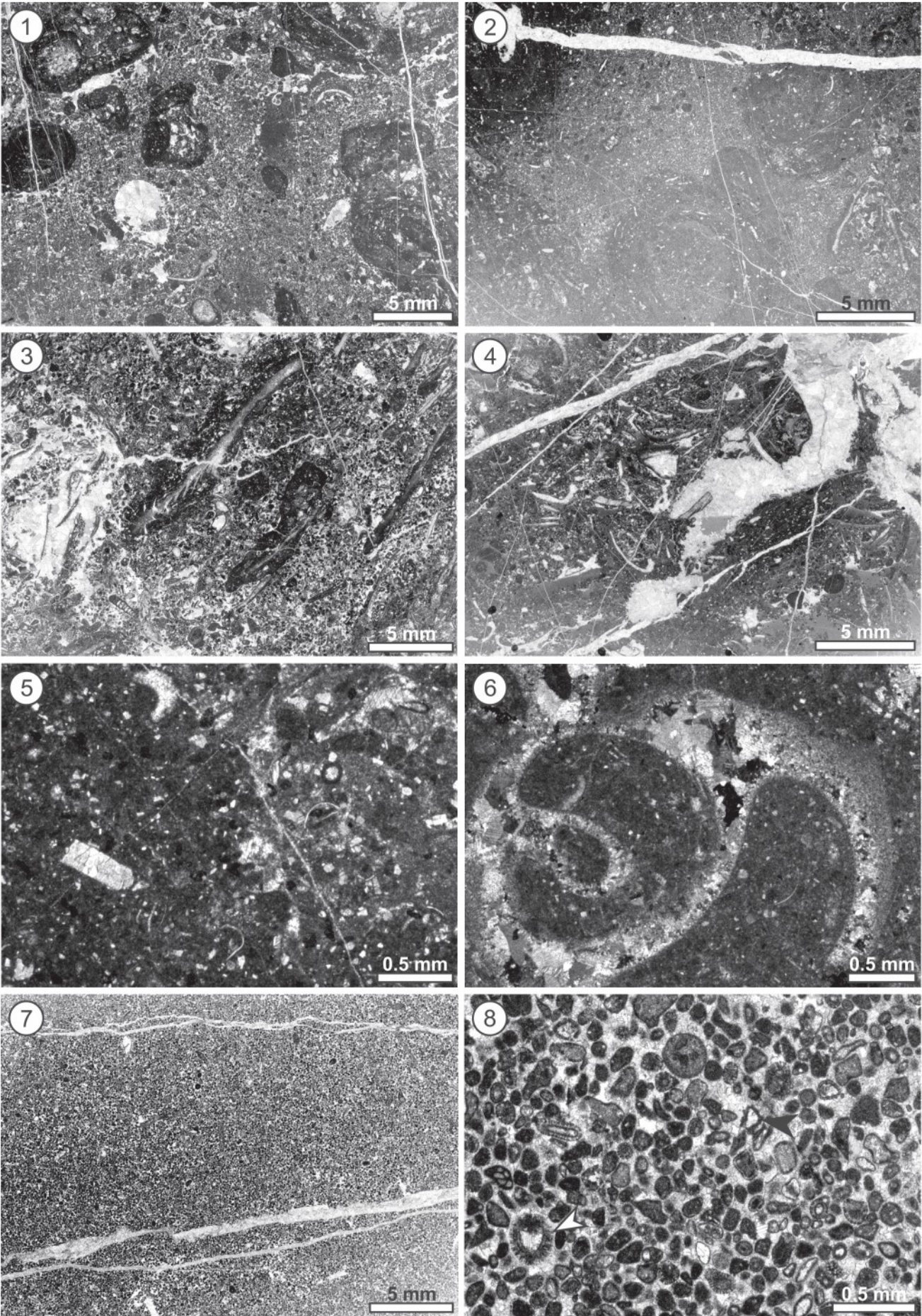
Peloids account for 40 % of grains. They are very well rounded and have hazy outlines. They are often grouped into small patches. Aggregate grains (lumps and mature lumps) represent around 30 % of grains. They consist of ooids, bounded by micritic meniscus cement. Spheroidal ooids represent approximately 20 % of grains. They are largely micritised and partly recrystallised; it is thus difficult to distinguish whether they were concentric or radial. Their nuclei include neomorphically altered shell fragments, echinoderm plates, rarely small gastropods, but most are micritic/micritised. The cortex (often micritised) consists of 9–15 or more laminae, each 8–10 µm thick. The cortex/nucleus ratio is 41–56 %. Superficial ooids, formed around large benthic foraminifera, and a few spiny ooids are also present (Fig. 12.1). A minor amount of grains belongs to intraclasts of peloidal packstone. Cortoids (up to 5 % of clasts) are mostly small fragments. Some larger bivalve shell fragments have strongly micritised outer surfaces. Some have uneven micritic coatings. The shells themselves are replaced by spar. Isolated (i.e., not included into ooids) benthic foraminifera are rarely found. Gastropods are rare.

Intergranular space is filled with drusy mosaic spar.

MF 11 – Well-sorted ooid grainstone

This type is present in medium thick beds with slight cross lamination, in thick and very thick beds (also following bivalve shell accumulation at the base), and as lens-like accumulations.

Grains represent 50 % of the volume. Sorting is good to very good (Fig. 12.2–12.3, 12.5). Grains are in point contacts. Two MF 11 subtypes are distinguished on the basis of the prevalent ooids sizes: MF11a with 0.15-0.35 mm (mean size 0.30 mm) large ooids (Figs. 12.2-12.3, 12.5), and MF11b with 0.35-0.55 mm (mean size 0.40 mm) large ooids (Figs. 12.4, 12.6). In places, lamination is visible due to a slight change in grain size and packing (Fig. 12.3). The lamina boundaries may be slightly undulating and sharp (Fig. 12.5).

Ooids are spheroidal and present 95 % of grains (Fig. 12.4). Nuclei are usually micritic, although small benthic foraminifera, mollusc fragments and echinoderm remains are present. As in MF 10, ooids are mostly strongly micritised, but there appears to be fewer (up to nine) laminae in cortices. The ratio cortex:nucleus amounts to up to 45 % for the thickest ooids. Few superficial ooids, formed around shell fragments, foraminifera and echinoderms, are also present. Spiny ooids are very rare, as well as broken and half-moon ooids.

The remaining grains are neomorphically altered shell fragments (mostly free of micritic coating), echinoderms, gastropods, aggregate grains, and very rare green algae, ostracods, and brachiopod fragments. Foraminifera were found only as ooid nuclei.

Grains are rimmed by fibrous to bladed spar (Fig. 12.6), succeeded by drusy mosaic intergranular cement (Fig. 12.4). Sintaxial cement is present around echinoderm plates, and ooids are partly recrystallised. Keystone vugs, filled with drusy mosaic spar are common. Slightly irregular laminae of crystal silt are sometimes present within grainstone (Fig. 12.6).

Discussion

Interpretation of the studied sections

Reddish colouration of upper bedding planes, thin irregular intercalations of claystone and in one case subvertical pipes filled with yellowish claystone correspond to palaeosol and palaeokarst surfaces (MARTINUŠ et al., 2012; see also BUSER & DEBELJAK, 1996), and suggest deposition in a very shallow sea, frequently interrupted by emersions. Spiny ooids are also indicative of vadose conditions (FLÜGEL, 2004). On the basis of the thickest bed (7 m in Podpeč section), and the abundance of paleosol horizons in the Podpeč section, the water depth might have been only a few meters.

Lithiotid bivalves preserved in living position in the lower part of the Podpeč section suggest a short transport of lithiotid shells found in slightly

Figure 11. Microfacies types of the Podpeč limestone.

1 – Bioclastic floatstone-rudstone with peloidal grainstone matrix. Note the neomorphic replacement of mollusc shells by drusy mosaic spar (arrowhead) and the sindepositional pore space beneath the shell, filled by spar (S). Thin section 523.

2 – Bioclastic rudstone with peloidal grainstone matrix. Thin section 429d.

3 – Details of the grainstone matrix. Note the highly micritised bioclasts (B), a large rounded micritic clast (completely recrystallised bioclast?) and a fragment of benthic foraminifera (arrowhead). Thin section 417.

4 – Details of the grainstone matrix. Note the crude lamination due to the difference in grain size and sorting (arrowhead points at the sub-horizontal boundary). Thin section 528.

5 – Large lithified intraclast (peloidal grainstone with large keystone vugs (K) – cemented beachrock) in bioclastic rudstone. Arrowhead points at the intensely cemented intraclast boundary. Thin section 420.

6 – Bimodal poorly to medium sorted ooid grainstone. Note large bivalves (B), keystone vugs (K) partly filled with internal sediment and some aggregate grains (arrowhead). Thin section 413.

7 – Bimodal poorly to medium sorted ooid grainstone. Note crude lamination (laminae running from top left to lower right) suggested by grain density. Thin section 429c, not oriented.
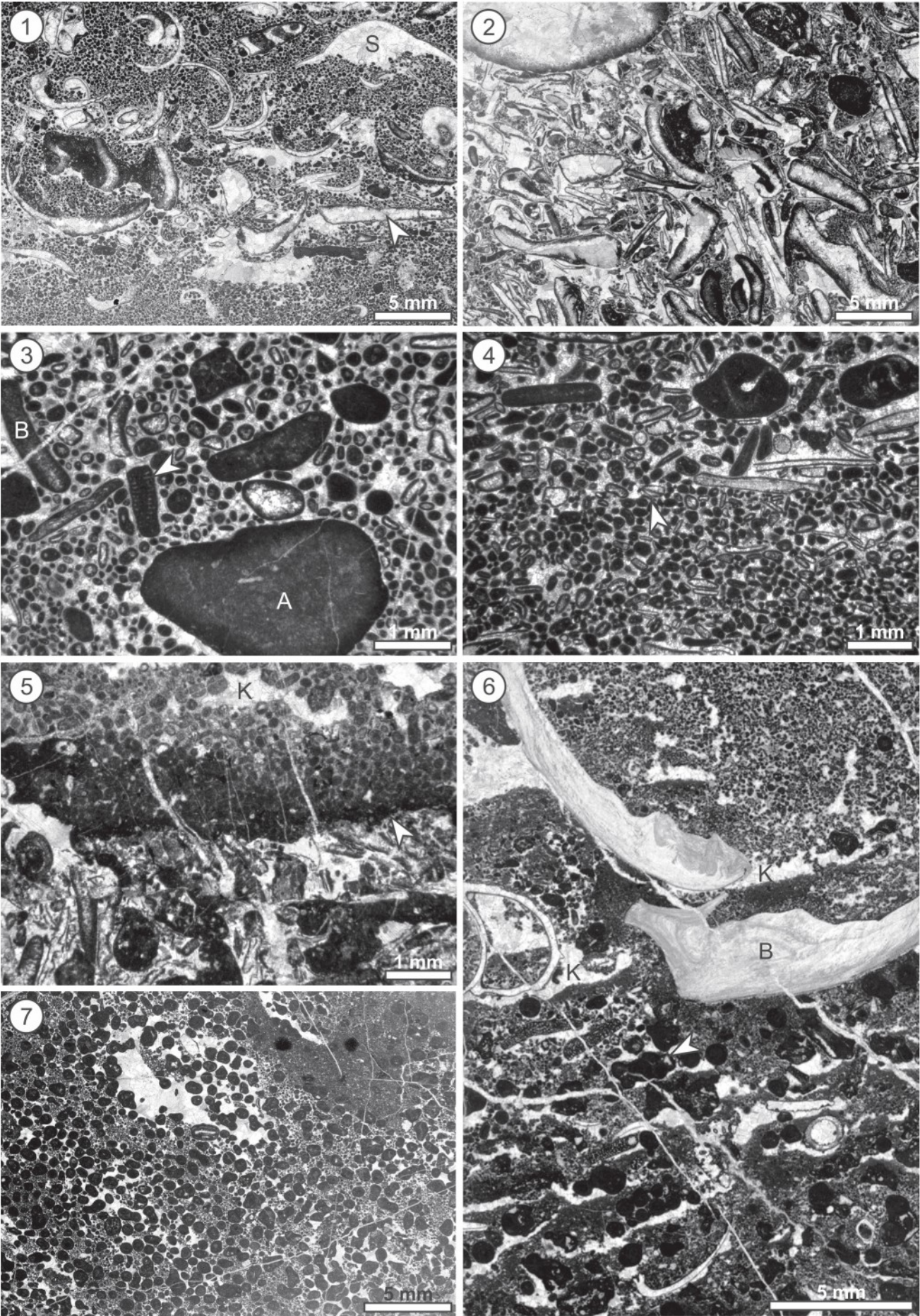
younger claystone beds. It is also possible that accumulations of lithiotid shells in claystone result from subaerial exposure of the entire buildup, resulting in its demise, so these individuals may also be preserved in situ (hence the preservation of both valves).

Birdseyes vugs and cortoids further agree with deposition in a very shallow marine setting (FLÜGEL, 2004). A mixture of high- and low-energy environment and/or events is suggested by the co-presence of ooids and oncoids (turbulent water) and micritic limestone (stagnant water), and is reflected in the mixture of high and low energy microfacies types. Chaotic accumulations of mollusc shells suggest occasional influence of high water-energy events, such as storms (MASETTI, 2002; FLÜGEL, 2004).

The microfacies (MF) association agrees with the interpretation of the shallow-marine sedimentary environment (Table 1). Although MF types 1, 2, 3 and 5 were described only from the Podpeč section, and MF 6 only from the Zalopate section, this is attributed to the sampling bias, because only a small proportion of beds were sampled for microscopy.

The northern part of the Adriatic Carbonate Platform

On the basis of several schematic sections, BUSER and DEBELJAK (1996) suggested a rimmed carbonate platform model. They positioned the Podpeč area close to the oolitic margin of the platform. A similar position was envisaged for the Špik section in Trnovski gozd. The ooid-rich margin of the platform is followed landward by a restricted lagoon in which mud-rich limestone with low energy index deposited (BUSER and DEBELJAK, 1996). DOZET (1999) later described lithiotid limestone near Kočevje, where lithiotid-bearing dolomite is intercalated with thin layers of fine-grained intraformational breccia and coal-bearing horizons.

In contrast, ČRNE and GORIČAN (2008) suggested the ramp type model on the basis of similarities of the Kovk section with the Rumija in Montenegro. The lithiotid limestone in the Kovk section was divided into three units (ČRNE and GORIČAN, 2008). The lowermost of these comprises thick bedded peritidal limestone (subtidal wackestone, rarely packstone, inter- to supratidal fenestral mudstone or fenestral peloidal packstone, rarely peloidal grainstone with few ooids) with lithiotid bivalves. The second subunit consists of peloidal grainstone with ooids, and the third of peritidal wackestone and packstone with bivalves of the lithiotid facies. According to ČRNE and GORIČAN (2008), Kovk section belongs to the inner ramp setting.

The herein described association of microfacies types agrees with both interpretations (Table 1), and may correspond to the inner-ramp setting, or to the open and restricted lagoon interior of the rimmed platform model (FLÜGEL, 2004). However, the rimmed platform model is herein preferred due to the following reasons:

(1) cortoids and aggregate grains are more common on a rimmed platform (FLÜGEL, 2004), although they are not excluded from ramps;
(2) a rimmed platform would be more prone to small sea-level falls, and emersions are common in recorded sections, especially in the Podpeč sections;
(3) the ramp model suggests that all known localities of the lithiotid limestone belong to the inner ramp setting (Fig. 13.1); this also suggests that an entire middle and outer ramp are currently missing due to latter thrusting or breaking of the AdCP margin;
(4) the rimmed carbonate platform model on the contrary suggests a more widespread palaeogeographic distribution of localities (Fig. 13.2), and a less drastic post-Cretaceous crust shortening.

Conclusions

The microfacies association recorded in the Late Sinemurian – Pliensbachian lithiotid bivalves-bearing limestone at the northern margin of the Adriatic Carbonate Platform comprises: (1) mudstone, (2) lithiotid floatstone

---

Figure 12. Microfacies types of the Podpeč limestone.

1 – Bimodal poor to medium sorted ooid grainstone. Note the common aggregate grains (A) and a spiny ooid (S), typical of sands cemented in a vadose environment (see FLÜGEL, 2004, p. 148). Thin section 334.

2 – Well sorted ooid grainstone. Unimodal size distribution of ooids suggests pre-depositional sorting of grains. Note moldic porosity formed through total dissolution of some bivalve shells (black arrowhead). A few cortoids (white arrowhead) and intraclasts (I) are also present. Thin section 322.

3 – Unimodally sorted ooid grainstone with at least four laminae (L1-L4) with blurred boundaries, suggesting changes in water energy conditions. Note normal grading in laminae L3 and L4. Obliquely cut sample. Thin section 335.

4 – Detail of ooid grainstone with a small bivalve. Note circumgranular and intragranular fibrous cement (arrowhead) and the blocky spar (B) filling the remaining inter- and intragranular space. Thin section 421.

5 – Well sorted ooid grainstone. Arrowheads point at wavy boundaries reflecting short-term changes in water energy conditions. Thin section 536.

6 – Lamina within ooid grainstone, where the pore space between grains (oolites, aggregate grains, bivalve fragment with micritic outline) is filled with marine phreatic fibrous circumgranular cement (arrowhead) and crystal silt, suggesting occasional vadose conditions (see Fig. 14.20 in FLÜGEL, 2004). Thin section 427.
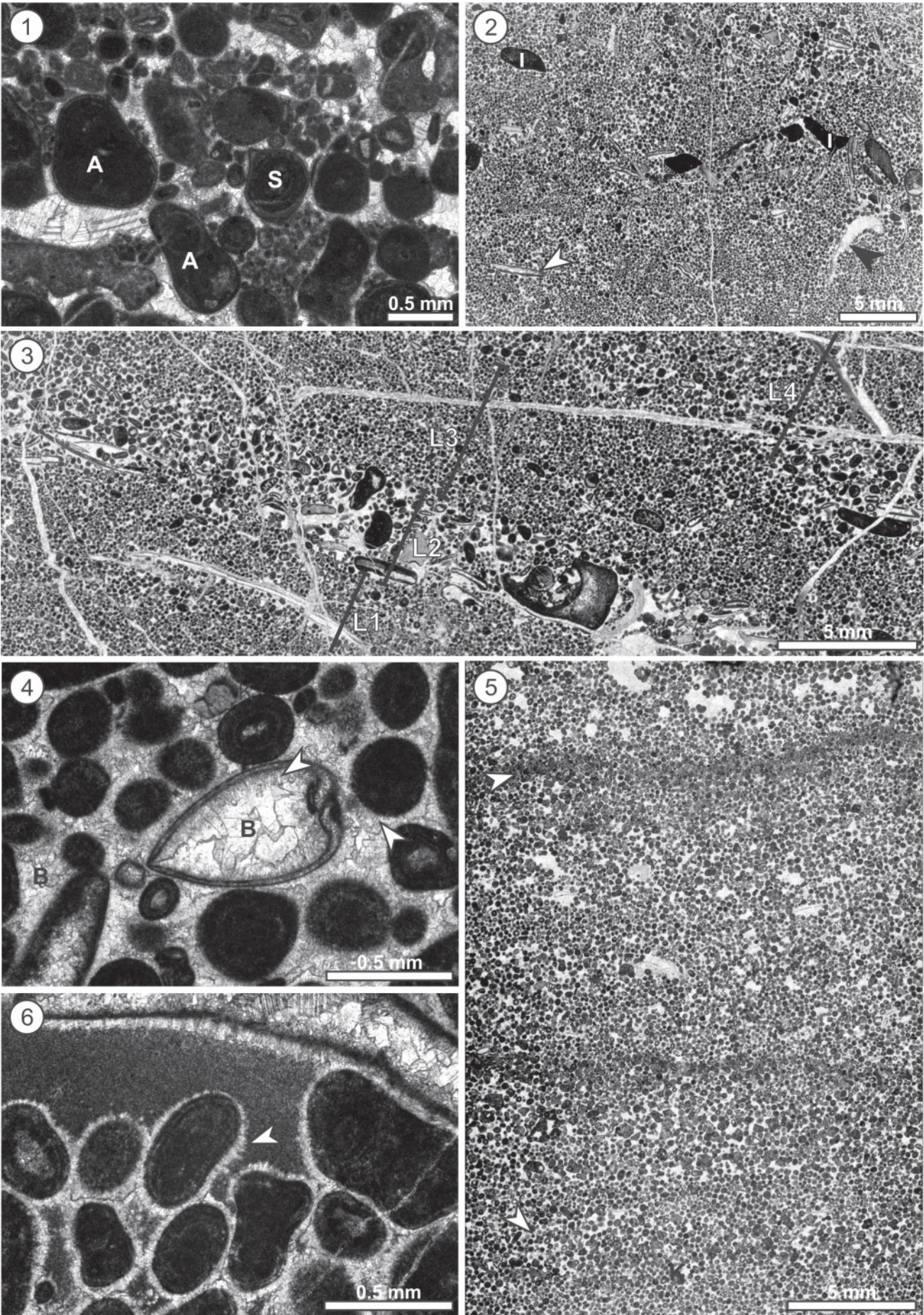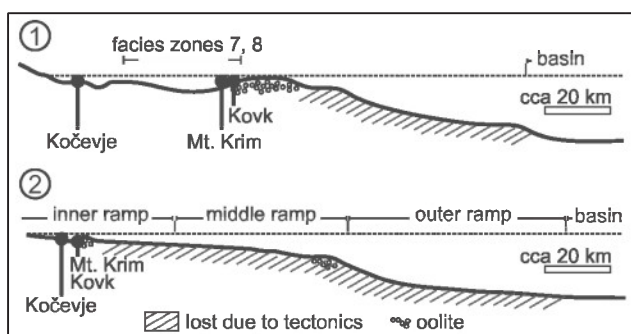
Figure 13. Discussed possible models for the northern part of the Adriatic Carbonate Platform. 1 – Rimmed platform. 2 – Carbonate ramp. Modified after FLÜGEL (2004).

to rudstone, (3) peloidal wackestone-packstone with *Thaumatoporella*, (4) peloidal wackestone to packstone, (5) bivalve floatstone to rudstone, (6) oncoidal-peloidal floatstone, (7) coated bioclastic floatstone with peloidal-bioclastic wackestone-packstone matrix, (8) peloidal grainstone, (9) cortoid floatstone to rudstone with peloidal-bioclastic grainstone matrix, (10) bimodal poorly to medium sorted ooid-peloidal grainstone, and (11) well sorted ooid grainstone.

The most common type of grains are ooids, aggregate grains and various skeletal particles (bivalve shells, large benthic foraminifera). Cortoids are common. Rare spiny ooids indicate occasional vadose conditions, and subaerial exposure surfaces point to occasional emersion. The most common type of cement, present in washed-out patches of micritic matrix or among grains in higher-energy facies types, is blocky or drusy mosaic spar. In several MF types, it is preceded by circumgranular fibrous to bladed spar.

The facies association corresponds to restricted and open marine interior (facies zones 8 and 7) of a platform bordered by marginal sand shoals, or to the inner ramp setting (FLÜGEL, 2004). This study does not give the final answer concerning the type of the platform due to the lack of seismic-scale profiles. However, the platform bordered by oolitic shoals and with a steep transition to the Slovenian Basin to the north may be a better model than the ramp model.

Acknowledgements

References

AZERÊDO, A.C., MANUPPELLA, G. & RAMALHO, M.M. 2003: The Late Sinemurian carbonate platform and microfossils with Tethyan affinities of the Algarve Basin (south Portugal). Facies, 48: 49–60.

BACELLE, L. & BOSELLINI, A. 1965: Diagrammi per la stima visiva della composizione percentuale nelle rocce sedimentarie. Ann. Uni. Ferrara, N.S., Sez. IX: Sci. Geol. Paleontol., 1: 59–62.

BARATTOLO, F. & ROMANO, R. 2005: Shallow carbonate platform bioevents during the Upper Triassic-Lower Jurassic: an evolutive interpretation. Boll. Soc. Geol. It. (Ital. J. Geosci), 124: 123–142.

BLOMEIER, D.P.G. & REIJMER, J.J.G. 1999: Drowning of a Lower Jurassic carbonate platform: Jbel Bou Dahar, High Atlas, Morocco. Facies, 41: 81–110.

BOSENCE, D., PROCTER, E., AURELL, M., BEL KAHLA, A., BOUDAGHER-FADEL, M., CASAGLIA, F., CIRILLI, S., MEHDIE, M., NIETO, L., REY, J., SCHERREIKS, R., SOUSSI, M. & WALTHAM, D. 2009: A dominant tectonic signal in high-frequency, peritidal carbonate cycles? A regional analysis of Liassic platforms from western Tethys. J. Sed. Res., 79: 389–415.

BRIGAUD, B., VINCENT, B., CARPENTIER, C., ROBIN, C., GUILLOCHEAU, F., YVEN, B. & HURET, E. 2014: Growth and demise of the Jurassic carbonate platform in the intracratonic Paris Basin (France): Interplay of climate change, eustasy and tectonics. Marine Petrol. Geol., 53: 3–29.

BUCKOVIĆ, D., JELASKA, V. & CVETKO TEŠOVIĆ, B. 2001: Facies variability in Lower Liassic carbonate successions of the western Dinarides (Croatia). Facies, 44: 151–162.

BUSER, S. 1965: Stratigrafski razvoj jurskih skladov na južnem Primorskem, Notranjskem in zahodni Dolenjski (dissertation). University of Ljubljana, Faculty of Natural Sciences and Technology, Department for Mineralogy and Geology, Ljubljana: 101 p.

BUSER, S. 1968: Basic Geological Map SFRY 1 : 100.000, The Ribnica Sheet, L 33-78. Zvezni geološki zavod Beograd.

BUSER, S. 1989: Development of the Dinaric and the Julian carbonate platforms and of the intermediate Slovenian Basin (NW Yugoslavia). In: CARULLI, G.B., CUCCHI, F. & RADRIZZANI, C.P. (eds.): Evolution of the karstic carbonate platform: relation with other periadriatic carbonate platforms. Mem. Soc. Geol. Ital., 40 (1987): 313–320.

BUSER, S. & DEBELJAK, I. 1996: Lower Jurassic beds with bivalves in South Slovenia. Geologija, 37–38: 23–62, doi:10.5474/geologija.1995.001.

BUSER, S., GRAD, K. & PLENIČAR, M. 1967: Basic Geological Map of SFRY 1 : 100.000, The Postojna Sheet, L 33-77. Zvezni geološki zavod, Beograd.

BUSER, S., KOLAR-JURKOVŠEK, T. & JURKOVŠEK, B. 2008: The Slovenian Basin during the Triassic in the light of conodont data. Boll. Soc. Geol. It. (Ital. J. Geosci.), 127: 257–263.

CARACUEL, J.E., GIANNETTI, A. & MONACO, P. 2005: Multivariate analysis of taphonomic data in Lower Jurassic carbonate platform (northern Italy). C. R. Palevol, 4: 653–662.

COBIANCHI, M. & PICOTTI, V. 2001: Sedimentary and biological response to sea-level and palaeoceanographic changes of a Lower-Middle Jurassic Tethyan platform margin (Southern Alps, Italy). Palaeogeogr., Palaeoclimatol., Palaeoecol., 169: 219–244.

ČADJENOVIĆ, D., KILIBARDA, Z. & RADULOVIĆ, N. 2008: Late Triassic to Late Jurassic evolution of the Adriatic Carbonate Platform and Budva Basin, southern Montenegro. Sed. Geol., 204: 1–17.

ČRNE, A.E. & GORIČAN, Š. 2008: The Dinaric Carbonate Platform margin in the Early Jurassic: a comparison between successions in Slovenia and Montenegro. Boll. Soc. Geol. It. (Ital. J. Geosci.), 127: 389–405.

DEBELJAK, I. & BUSER, S. 1997: Lithiotid bivalves in Slovenia and their mode of life. Geologija, 40: 11–64. doi:10.5474/geologija.1997.001.

DOZET, S. 1992: Litostratigrafske enote in značilne mikrofacije Kočevske jure. Min. Mettal. Quarterly, 39: 287–305.

DOZET, S. 1993: Lofer cyclothems from the Lower Liassic Krka limestone. Riv. Ital. Paleont. Strat., 99: 81–100.

DOZET, S. 1996: Foraminiferal and algal biostratigraphy of the Jurassic beds in southeastern Slovenia. Min. Mettal. Quarterly, 43: 3–10.

DOZET, S. 1999: Lower Jurassic dolomite-limestone succession with coal in the Kočevski Rog and correlation with neighbouring areas (southeastern Slovenia). Geologija, 41: 71–101, doi:10.5474/geologija.1998.004.

DOZET, S. 2009: Lower Jurassic carbonate succession between Predole and Mlačevo, Central Slovenia. RMZ – Materials and Geoenvironment, 56/2: 164–193

DOZET, S. & STROHMENGER, C. 2000: Podbukovje Formation, central Slovenia. Geologija, 43/2: 197–212, doi:10.5474/geologija.2000.014.

DRAGIČEVIĆ, I. & VELIĆ, I. 2002: The northeastern margin of the Adriatic Carbonate Platform. Geol. Croat., 55: 185–232.

DUNHAM, R.J. 1962: Classification of carbonate rocks according to depositional texture. In: HAM W.E. (ed.): Classification of carbonate rocks. Tulsa, Oklahoma, AAPG Mem., 1: 108–121.

EMBRY, A.F. & KLOVAN, J.E. 1971: A Late Devonian reef tract on northeastern Banks Island, N.W.T. Bull. Can. Petrol. Geol., 19: 730–781.

EREN, M., TASLI, K. & TOL, N. 2002: Sedimentology of Liassic carbonates (Pirencik Tepe measured section) in the Aydincik (Içel) area, southern Turkey. J. Asian Earth Sci., 20: 791–801.

FLÜGEL, E. 2004: Microfacies of carbonate rocks: Analysis, interpretation and application. Springer-Verlag, Berlin Heidelberg, New York: 984 p.

FRASER, N.M., BOTTJER, D.J. & FISCHER, A.G. 2004: Dissecting "lithiotis" bivalves: Implications for the Early Jurassic reef eclipse. Palaios, 19: 51–67.

FRIEDMAN, G. M. 2003: Classification of sediments and sedimentary rocks. In: MIDDLETON, G. V. (ed.): Encyclopedia of sediments and sedimentary rocks. Springer: 127–135.

FUGAGNOLI, A. 2004: Trophic regimes of benthic foraminiferal assemblages in Lower Jurassic shallow water carbonates from northeastern Italy (Calcari Grigi, Trento Platform, Venetian Prealps). Palaeogeogr., Palaeoclimatol., Palaeoecol., 205: 111–130.

FUGAGNOLI, A. & LORIGA BROGLIO, C. 1998: Revised biostratigraphy of Lower Jurassic shallow water carbonates from the Venetian Prealps (Calcari Grigi, Trento Platform, Northern Italy). Studi Trentini Sci. Natur. Acta Geol., 73: 35–73.

GALE, L. 2014: Lower Jurassic foraminiferal biostratigraphy of Podpeč Limestone (External Dinarides, Slovenia). Geologija, 57/2: 119–146, doi:10.5474/geologija.2014.011.

GALLI, G. 1993: "Calcari Grigi" Formation, Jurassic, Venetian Alps. In: GALLI, G. (ed.): Temporal and Spatial Patterns in Carbonate Platforms. Springer-Verlag, Berlin Heidelberg: 97–129.

GREENE, S.E., MARTINDALE, R.C., RITTERBUSH, K.A., BOTTJER, D.J., CORSETTI, F.A. & BERELSON, W.M. 2012: Recognizing ocean acidification in deep time: An evaluation of the evidence for acidification across the Triassic-Jurassic boundary. Earth-Sci. Rev., 113: 72–93.

HALLAM, A. 2001: A review of the broad pattern of Jurassic sea-level changes and their possible causes in the light of current knowledge. Palaeogeogr., Palaeoclimatol., Palaeoecol., 167: 23–37.

HAUTMANN, M., BENTON, M. J. & TOMAŠOVÝCH, A. 2008: Catastrophic ocean acidification at the Triassic-Jurassic boundary. N. Jb. Geol. Paläont. Abh., 249: 119–127.

JAMŠEK RUPNIK, P., POPIT, T., JEŽ, J. & BAVEC, M. 2015: Field trip: Quaternary dynamics of the Ljubljana Basin. In: Quarternary Geology in Croatia and Slovenia, 4th scientific meeting, Zagreb, 25-26 March 2015. Croatian National INQUA Committee & Slovenian National INQUA Committee, Zagreb & Ljubljana.

KASTELIC, V. & CARAFA, M.M.C. 2012: Fault slip rates for the active External Dinarides thrust-and-fold belt. Tectonics, 31: TC3019.

KASTELIC, V., VRABEC, M., CUNNINGHAM, D. & GOSAR, A. 2008: Neo-Alpine structural evolution and present-day tectonic activity of the eastern Southern Alps: The case of the Ravne Fault, NW Slovenia. J. Struct. Geol., 30: 963–975.

KRAMAR, S., BEDJANIČ, M., MIRTIČ, B., MLADENOVIĆ, A., ROŽIČ, B., SKABERNE, D., GUTMAN, M., ZUPANČIČ, N. & COOPER, B. 2015: Podpeč limestone: a heritage stone from Slovenia. Geol. Soc. London Spec. Publ., 407: 219–231.

KRAMER, E. 1905: Das Laibacher Moor. Kleinmayr & Fed. Bamberg, Ljubljana: 205 p.

LIPOLD, M.V. 1858: Bericht über die geologische Aufnahme in Unter-Krain im Jahre 1857. Jb. Geol. R.-A., 9: 257–276.

MARTINUŠ, M., BUCKOVIĆ, D. & KUKOĆ, D. 2012: Discontinuity surfaces recorded in shallow-

marine platform carbonates: an example from the Early Jurassic of the Velebit Mt. (Croatia). Facies, 58: 649–669, doi:10.1007/s10347-011-0288-7.

MASETTI, D. 2002: Some remarks about facies and cyclicity in the Rotzo Member of the Calcari Grigi Formation (Trento Platform, Venetian Prealps, Middle Lias). Atti Ticinensi Sci. Terra, 43, 119–128.

MASETTI, D., CLAPS, M., GIACOMETTI, A., LODI, P. & PIGNATTI, P. 1998: I Calcari Grigi della piattaforma di Trento (lias inferiore e medio, Prealpi Venete). Atti Tic. Sc. Terra, 40: 139–183.

MILER, M. & PAVŠIČ, J. 2008: Triassic and Jurassic beds in Krim Mountain area (Slovenija). Geologija, 51/1: 87–99, doi:10.5474/geologija.2008.010.

MILER, M., PAVŠIČ, J. & DOLENEC, M. 2007: Determination of T/J boundary by δ^{13}C and δ^{18}O stable isotope analysis (Krim Mountain, Slovenia). RMZ – Materials and Geoenvironment, 54/2: 189–202.

OGORELEC, B. 2009: Spodnje jurske plasti v Preserju pri Borovnici. Geologija, 52/2: 193–204, doi:doi:10.5474/geologija.2009.019.

OGORELEC, B. & ROTHE, P. 1993: Mikrofazies, Diagenese und Geochemie des Dachsteinkalkes und Hauptdolomits in Süd-West-Slowenien. Geologija, 35: 81–181.

PLACER, L. 1999: Contribution to the macrotectonic subdivision of the border region between Southern Alps and External Dinarides. Geologija, 41: 223-255, doi:10.5474/geologija.1998.013.

PLACER, L. 2008: Principles of the tectonic subdivision of Slovenia. Geologija, 51/2: 205-217, doi:10.5474/geologija.2008.021.

POMONI-PAPAIOANNOU, F. & KOSTOPOULOU, V. 2008: Microfacies and cycle stacking in Liassic peritidal carbonate platform strata, Gavrovo-Tripolitza platform, Peloponnesus, Greece. Facies, 54/3: 417–431, doi:10.1007/s10347-008-0142-8.

RADOIČIĆ, R. 1966: Microfacies du jurassiques des Dinarides externes de la Yugoslavie. Geologija, 9: 5–337.

RAMOVŠ, A. 2000: Podpeč limestone, black and colorful Lesno Brdo limestone through time. Mineral, Ljubljana: 115 p.

RUIZ-ORTIZ, P.A., BOSENCE, D.W.J., REY, J., NIETO, L.M., CASTRO, J.M. & MOLINA, J.M. 2004: Tectonic control of facies architecture, sequence stratigraphy and drowning of a Liassic carbonate platform (Betic Cordillera, Southern Spain). Basin Res., 16: 235–257.

SABATINO, N., VLAHOVIĆ, I., JENKYNS, H.C., SCOPELLITI, G., NERI, R., PRTOLJAN, B. & VELIĆ, I. 2013: Carbon-isotope record and palaeoenvironmental changes during the early Toarcian oceanic anoxic event in shallow-marine carbonates of the Adriatic Carbonate Platform in Croatia. Geol. Mag., 150/6, 1085–1102 doi:10.1017/S0016756813000083.

SCHEIBNER, C. & REIJMER, J.J.G. 1999: Facies patterns within a Lower Jurassic upper slope to inner platform transect (Jbel Bou Dahar, Morocco). Facies, 41: 55–80.

STROHMENGER, C. & DOZET, S. 1991: Stratigraphy and geochemistry of Jurassic carbonate rocks from Suha krajina and Mala gora mountain (Southern Slovenija). Geologija, 33: 315–351, doi:10.5474/geologija.1990.008.

ŠMUC, A. 2005: Jurassic and Cretaceous stratigraphy and sedimentary evolution of the Julian Alps, NW Slovenia. ZRC SAZU, Ljubljana 98 p.

ŠRIBAR, L. 1966: Jurassic sediments between the villages Zagradec and Randol in Krka Valley. Geologija, 9: 379–384.

ŠTUKOVNIK, P., DOBNIKAR, M. & ŽARNIĆ, R. 2011: Podpeški apnenec v modelu prenove stebriščne lope centralnega stadiona v Ljubljani. Gradbeni vestnik, 60: 193–197.

THIERRY, J. 2000: Late Sinemurian (193-191 Ma). In: DERCOURT, J., GAETANI, M., VRIELYNCK, B., BARRIER, E., BIJU-DUVAL, B., BRUNET, M.F., CADET, J.P., CRASQUIN, S. & SANDULESCU, M. (eds.): Peri-Tethys atlas, paleogeographical maps. CCGM/GGMW, Paris: map 7.

TIŠLJAR, J., VLAHOVIĆ, I., VELIĆ, I. & SOKAČ, B. 2002: Carbonate platform megafacies of the Jurassic and Cretaceous deposits of the Karst Dinarides. Geol. Croat., 55: 139–170.

TUCKER, M. E. 2001: Sedimentary petrology: an introduction to the origin of sedimentary rocks (3rd edition). Blackwell Science, Oxford and Northampton: 262 p.

TURNŠEK, D. & KOŠIR, A. 2000: Early Jurassic corals from Krim Mountain, Slovenia. Razprave IV. Razreda SAZU, 41: 81–113.

TURNŠEK, D., BUSER, S. & DEBELJAK, I. 2003: Liassic coral patch reef above the "Lithiotid limestone" on Trnovski gozd plateau, west Slovenia. Razprave IV. Razreda SAZU, 44: 285–331.

VELIĆ, I. 2007: Stratigraphy and palaeobiogeography of Mesozoic benthic Foraminifera of the Karst Dinarides (SE Europe). Geol. Croat., 60: 1–113.

VERWER, K., MERINO-TOMÉ, O., KENTER, J.A.M. & DELLA PORTA, G. 2009: Evolution of a high-refief carbonate platform slope using 3D digital outcrop models: Lower Jurassic Djebel Bou Dahar, High Atlas, Morocco. J. Sed. Res., 79: 416–439, doi:10.2110/jsr.2009.045.

VETTERS, H. 1933: Geologische Manuskriptkarte Radmannsdorf 1: 75.000. Geologische Bundesanstalt, Wien.

VLAHOVIĆ, I., TIŠLJAR, J., VELIĆ, I. & MATIČEC, D. 2002: The Karst Dinarides are composed of relics of a single Mesozoic platform: Facts and consequences. Geol. Croat., 55: 171–183.

VLAHOVIĆ, I., TIŠLJAR, J., VELIĆ, I. & MATIČEC, D. 2005: Evolution of the Adriatic Carbonate Platform: Palaeogeography, main events and depositional dynamics. Palaeogeogr., Palaeoclimatol., Palaeoecol., 220/3–4: 333–360, doi:10.1016/j.palaeo.2005.01.011

VRABEC, M. & FODOR, L. 2006: Late Cenozoic tectonics of Slovenia: structural styles at the Northeastern corner of the Adriatic microplate. In: PINTER, N., GRENERCZY, G., WEBER, J., STEIN, S. & MEDEK, D. (eds.): The Adria microplate: GPS geodesy, tectonics and hazards. NATO Sci. Ser., IV, Earth Environ. Sci., 61: 151–168.

WILMSEN, M. & NEUWEILER, F. 2008:. Sedimentology, 55/4: 773–807, doi: 10.1111/j.1365-3091.2007.00921.x.