GEOLOGICA CARPATHICA, AUGUST 2010, 61, 4, 293–308 doi: 10.2478/v10096-010-0017-0

Microfacies analysis of the Upper Triassic (Norian) "Bača Dolomite": early evolution of the western Slovenian Basin (eastern Southern Alps, western Slovenia)

LUKA GALE

Geological Survey of Slovenia, Dimičeva ulica 14, SI-1000 Ljubljana, Slovenia; luka.gale@geo-zs.si

(Manuscript received November 3, 2009; accepted in revised form March 11, 2010)

Abstract: The Slovenian Basin represents a Mesozoic deep-water sedimentary environment, situated on the southern Tethyan passive margin. Little is known about its earliest history, from the initial opening in the Carnian (probably Ladinian) to a marked deepening at the beginning of the Jurassic. The bulk of the sediment deposited during this period is represented by the Norian-Rhaetian "Bača Dolomite", which has, until now, been poorly investigated due to a late-diagenetic dolomitization. The Mount Slatnik section (south-eastern Julian Alps, western Slovenia) is one of a few sections where the dolomitization was incomplete. Detailed analysis of this section allowed us to recognize eight microfacies (MF): MF 1 (calcilutite), MF 2 (pelagic bivalve-radiolarian floatstone/wackestone to rudstone/packstone), MF 3 (dolomitized mudstone) with sub-types MF 3-LamB and MF 3-LamD (laminated mudstone found in a breccia matrix and laminated mudstone found in thin-bedded dolomites, respectively) and MF 3-Mix (mixed mudstone), MF 4 (bioturbated radiolarian-spiculite wackestone), MF 5 (fine peloidal-bioclastic packstone), MF 6 (very fine peloidal packstone), MF 7 (bioclastic wackestone) and MF 8 (crystalline dolomite). The microfacies and facies associations indicate a carbonate slope apron depositional environment with hemipelagic sedimentation punctuated by depositions from turbidites and slumps. In addition to the sedimentary environment, two "retrogradation-progradation" cycles were recognized, each with a shift of the depositional setting from an inner apron to a basin plain environment.

Key words: Norian, Slovenian Basin, "Bača Dolomite", microfacies analysis, slope apron.

Introduction

Winkler (1923) was the first to recognize the existence of a Mesozoic deep-sea sedimentary environment in central Slovenia, later named the Julian Trough, the Slovenian Trough, the Tolmin Trough or the Slovenian Basin. Comprehensive research by Aubouin (1960, 1963), Cousin (1970, 1973, 1981) and Buser (1986, 1989, 1996) was recently improved by Šmuc & Čar (2002), Goričan et al. (2003), Rožič (2005, 2006, 2008, 2009), Rožič & Popit (2006), Rožič & Šmuc (2006, 2009) Buser et al. (2008), and Rožič et al. (2009).

The Slovenian Basin was located on the south Tethyan passive continental margin (Fig. 1A). It was situated between the Julian Carbonate Platform (the Julian High since the Late Pliensbachian; Šmuc 2005) to the present north and the Dinaric Carbonate Platform (Adriatic Carbonate Platform of Vlahović et al. 2005) to the present south (Buser 1986). The evolution of the Slovenian Basin can be divided into two parts (Rožič et al. 2009). An initial opening during the Carnian (probably already in the Ladinian or even Late Anisian) and a progressive shallowing in the Carnian, was followed by a marked deepening from the Late Triassic/Early Jurassic to a final closure at the end of the Cretaceous (Buser 1986, 1989, 1996). The beginning of each stage was related to extensional tectonics, probably related to the opening of the Meliata part of the Neotethys to the east (Haas et al. 1995; Schmid et al. 2008) and the Piedmont-Ligurian Ocean to the west (Bosellini 2004; Vlahović et al. 2005).

While the second phase of the evolution of the Slovenian Basin has been greatly clarified by recent studies, the initial stage of its evolution, during the Late Triassic, remains poorly investigated.

The Upper Triassic succession of the Slovenian Basin consists of the Carnian "Amphiclina beds", followed by the Norian-Rhaetian "Bača Dolomite", which in the northernmost part of the basin laterally and vertically passes into limestones of the Slatnik Formation of Late Norian–Rhaetian age (Rožič et al. 2009).

The present paper focuses on the "Bača Dolomite". Despite its great thickness (around 300 m; Buser 1979) and basin-wide presence, this informal lithostratigraphic unit has been poorly investigated due to a strong late-diagenetic dolomitization, which has almost completely obliterated primary sedimentological structures and textures. However, as noted by Buser (1986) and confirmed by Rožič (2006), in the most proximal parts of the basin, lying adjacent to the Julian Carbonate Platform, some limestone beds escaped dolomitization. They are now intercalated between the dolomite beds of the "Bača Dolomite", offering an opportunity for a more detailed study of the depositional environment. Such development is exposed in the Mt Slatnik section (south-eastern Julian Alps, western Slovenia) (Fig. 1B,C,D). Rožič (2006) examined the upper 32 m of the Norian "Bača Dolomite" in this section. He concluded that the deposition took place via turbidity currents, and noted that grain composition points to a shallow-water origin of the material (Rožič 2006; Rožič et al. 2009). However,

Fig. 1. A — The paleogeographic position of the Slovenian Basin, the Julian and the Dinaric Carbonate Platforms during the Norian (simplified after Haas et al. 1995). **B, C** — Position of the investigated area. The smaller rectangle in B is shown in C. **D** — Generalized nappe structure of the area shown in C (after Buser 1986; and M. Demšar, pers. comm.). The Kobla, Rut and Podmelec Nappes belong to the Tolmin Nappe, where rocks of the Slovenian Basin are preserved. Triangles in B, C and D represent mountain summits.

the predominant part of the "Bača Dolomite" in this section remained unexamined.

The aims of this paper are:

— description of the total exposed sequence of the "Bača Dolomite" from the Mt Slatnik section;

— presentation of the microfacies analyses of the "Bača Dolomite";

— comparison of the "Bača Dolomite" with the overlying Slatnik Formation;

— interpretation of the results in terms of the depositional environment.

Previous research on the "Bača Dolomite"

Kossmat (1901, 1914) was the first to describe the dark dolomites and limestones with lenses and nodules of chert ("*Hornsteindolomit*"). He placed them into the Carnian–Norian, probably Rhaetian, according to their superposition and rare fossil remains. Cousin (1973) placed the "*Hornsteindolomit*" or "*dolomie siliceuse*" into the Norian–Hettangian. The name "Bača Dolomite" was introduced by Buser (1979). Following this, Buser (1986) presented a more detailed study of the "Bača Dolomite", according to which it is usually dolomicritic, although coarser varieties can also be encountered. Its main characteristic is the abundance of black and light grey chert in the form of layers and nodules up to 30 cm thick. Dolomitic breccias with clasts of dolomite and chert are present locally (Buser 1986).

Rožič (2006) described the upper parts of the "Bača Dolomite" from several sections from Mt Slatnik to Kobarid (Fig. 1B). The bedded dolomites are locally intercalated with breccias. The primary textures and structures are usually completely obliterated by the dolomitization. Parallel and wavy lamination is commonly visible, reflecting different sizes of dolomite crystals, as well as variations in the amount of clay minerals (Rožič 2006). Silification took place prior to dolomitization, so that primary textures were partly preserved in the chert (Rožič 2006; Skaberne, pers. comm.). Rožič (2006) concluded that sedimentation took place in calm, deeper water as well as by settling from low-density turbidity currents. The breccias were interpreted as intraformational, formed via sliding/slumping and/or debris flows (Rožič 2006).

The Norian age for the lower part of the "Bača Dolomite" has been proved by conodonts (Kolar-Jurkovšek 1982) and the bivalve *Halobia distincta* Mojsisovics (Buser 1986). It was previously assumed that the upper boundary of the "Bača Dolomite" generally represents the Triassic/Jurassic boundary. However, Rožič & Kolar-Jurkovšek (2007) and Rožič et al. (2009) proved the Late Norian–Rhaetian age for several tens of meters of limestones overlying the "Bača Dolomite" in the northernmost part of the basin, which were previously assumed to be of Early Jurassic age. They named this unit the Slatnik Formation (Rožič et al. 2009). The "Bača Dolomite" is thus proximal to the Julian Carbonate Platform of the Norian, and distal from it of the Norian–Rhaetian age.

The Lower to Middle Norian (Lacinian 1 to Alaunian) bedded dolomites with chert in the Hahnkogel (Klek) Unit in the Southern Karavanke Mountains (Fig. 1B) were also named the Bača (*"Baca"*) Formation (Krystyn et al. 1994; Lein et al. 1995; Schlaf 1996). A series of deposits around 170 m thick was interpreted as allodapic slope deposits (Schlaf 1996). Krystyn et al. (1994) considered the Hahnkogel Unit and the Slovenian Basin as parts of the same basin. This theory remains to be proved since the time of opening of these two units, as well as their lithological successions as a whole, seem to differ (see also Rožič et al. 2009).

Geological setting

The studied Mt Slatnik section is situated in the Kobla Nappe, which, with two more units (the Rut Nappe and the Podmelec Nappe), is part of the higher-order Tolmin Nappe (Buser 1986) (Fig. 1D), containing sedimentary rocks of the Slovenian Basin. The succession of the Kobla Nappe was deposited closest to the Julian Carbonate Platform, whereas the succession of the Podmelec Nappe was formed relatively far away from it (Rožič 2009).

The whole succession of the Kobla Nappe comprises the Upper Triassic "Amphiclina beds", the "Bača Dolomite" and the Slatnik Formation, the Jurassic Krikov, the Perbla and Tolmin Formations, the Upper Jurassic–Lower Cretaceous "Biancone Limestone" and finally the Cretaceous "Lower Flyschoid Formation" (Buser 1986; Rožič et al. 2009) (Fig. 2).

The Tolmin Nappe is overlain to the north by the Julian Nappe, containing mainly sedimentary rocks of the Julian Carbonate Platform and the Julian High. It is bordered to the south by the Southalpine front, which separates it from the External Dinarides with the sedimentary rocks of the Dinaric Carbonate Platform (Placer 1999).

The original geometry of the basin was greatly obliterated by the Late Eocene to Early Oligocene NE to SW Dinaric thrusting and by the Middle Miocene and later Alpine N to S thrusting (Placer & Čar 1998; Placer 2008). The tectonic situation was further complicated by the Pliocene–recent strike-slip deformation that displaced previous fold and thrust structures (Vrabec & Fodor 2006; Kastelic et al. 2008; Šmuc & Rožič 2009).

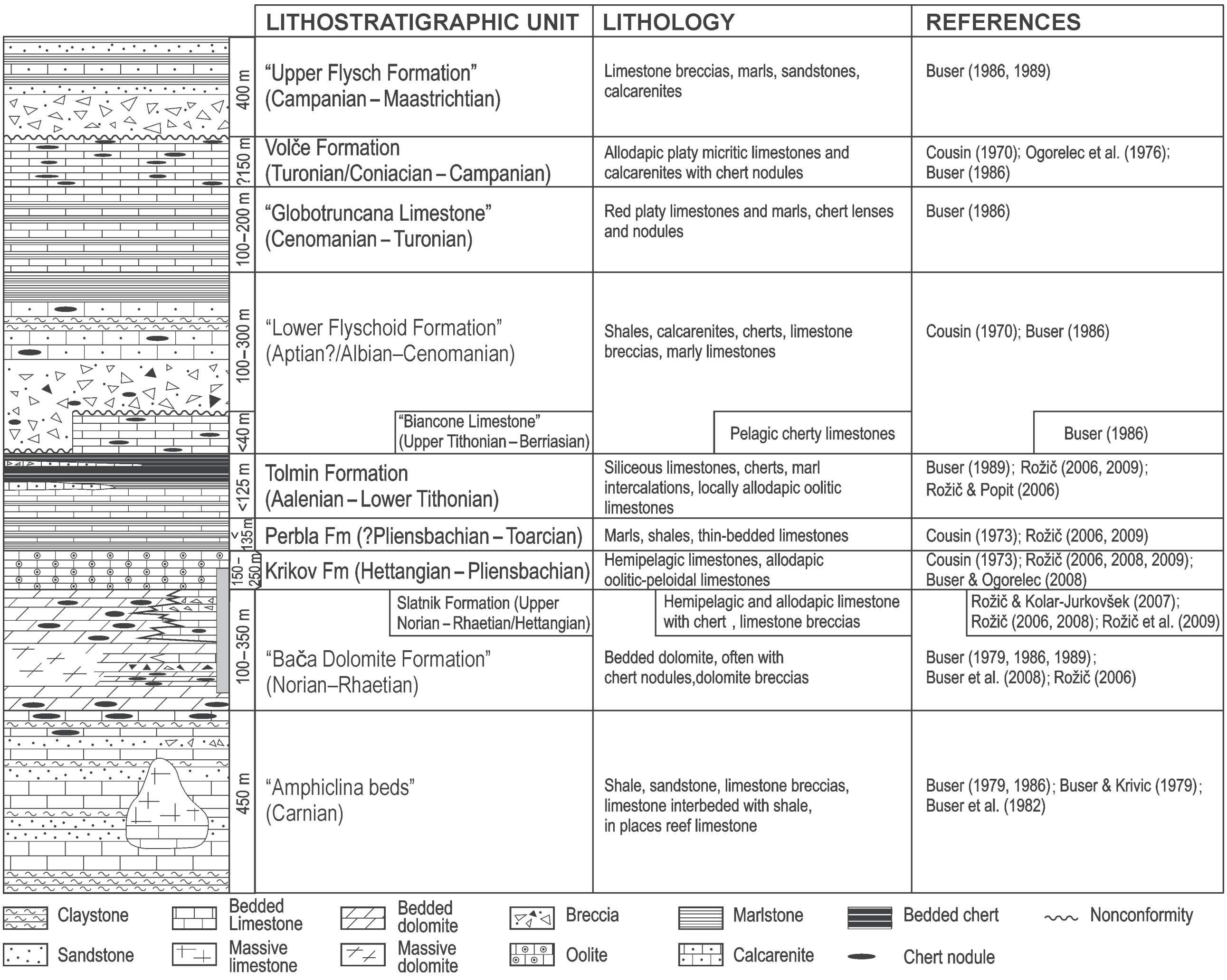

Fig. 2. A schematic stratigraphic column for the Slovenian Basin, with a short description of the units. For the references see the column on the right. Informal stratigraphic units are placed in quotation marks. The grey bar in the stratigraphic column marks the schematic position of the Mt Slatnik section. Note that only the "Bača Dolomite" part of the section is discussed in this paper.

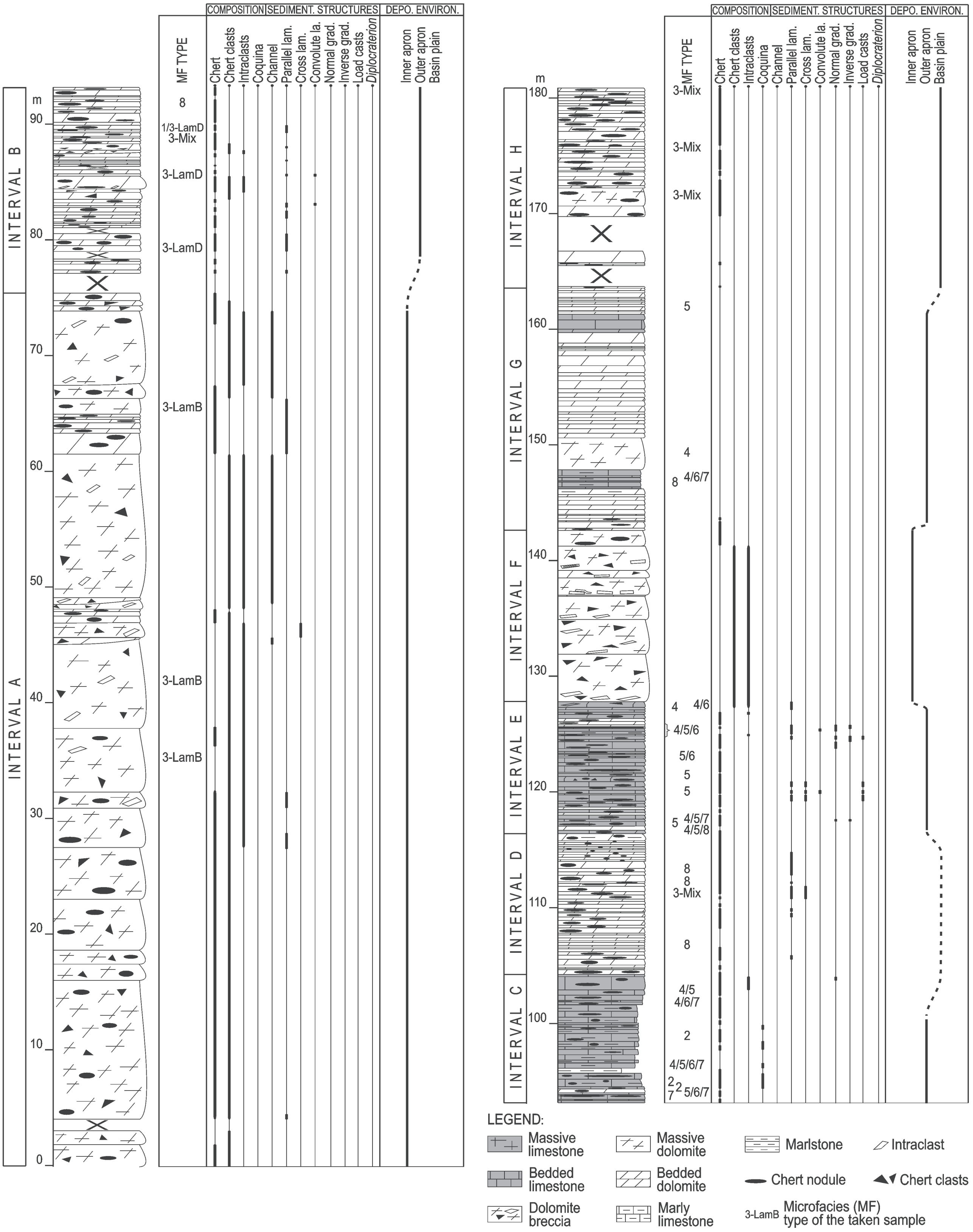

Fig. 3. A — (Continued in Fig. 3B). The Mt Slatnik section. Only the "Bača Dolomite" is drawn, with indicated position of the overlying Slatnik Formation, which is figured in Rožič et al. (2009). Though several faults are indicated, only the one separating the "Bača Dolomite" from the Slatnik Formation is of a greater importance (Rožič, pers. comm.). The "Composition" and the "Sedimentary structures" refer to the macroscopic observations only, whilst results of the microscope analysis are expressed as the microfacies (MF) types. Limestone beds of the "Bača Dolomite" are shaded. See text for a detailed description of the section.

Methods

The studied section is exposed along the mountain path on the southern flanks of Mt Slatnik (Y = 5420550, X = 5121670, 1609 m a.s.l.) (Fig. 1C; Fig. 7–1). The “Bača Dolomite” was investigated bed-by-bed and 79 thin-sections of 47×28 mm in size were prepared for detailed investigation with an optical microscope. The textural classification followed Dunham (1962). In wackestones and packstones at least 300 grains were counted under the ×63 magnification using the area method to determine relationships between individual grain types. Grain-to-matrix relationships were estimated with the comparison charts of Bacelle & Bosellini (1965 in Flügel 2004). Description of the dolomite crystals followed Sibley & Gregg (1987). In Fig. 3, the field observations are separated from microscope observations (presented by microfacies type) and are grouped in columns “Composition” and “Sedimentary structures”.

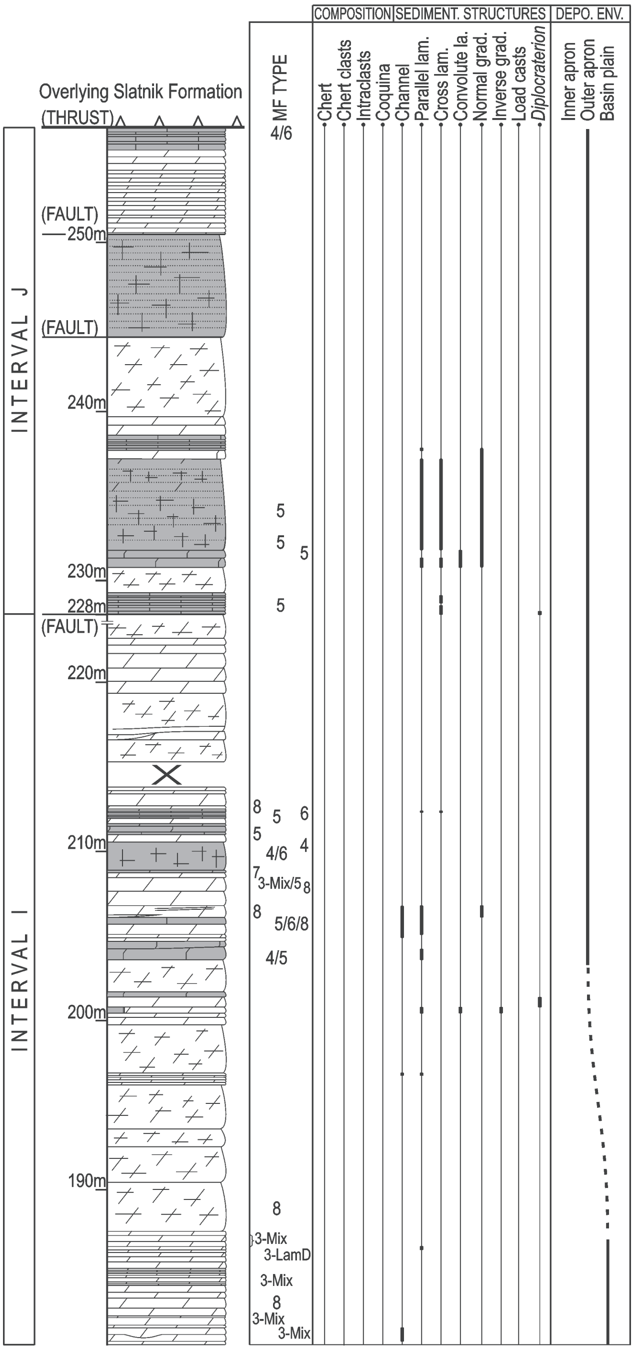

Fig. 3. B — *Continued from Fig. 3A.*

Description of the “Bača Dolomite” from the Mt Slatnik section

The Mt Slatnik section is exposed for around 330 m, only slightly covered (around 6 %) with individual beds laterally exposed for several meters (Fig. 7.1). It contains three lithostratigraphic units: the “Bača Dolomite” (260 m), the Slatnik Formation (50 m) and the Krikov Formation (20 m). This study only focused on the “Bača Dolomite”. The upper 32 m of the “Bača Dolomite” was already investigated by Rožič (2006) and Rožič et al. (2009). Some minor faults are present, but presumably without significant displacement (Rožič, pers. comm.). The lower boundary of the “Bača Dolomite” is not exposed. The older formations are not exposed in the studied section. However, in a similar section not far away, 40 m of grey limestones with mudstone and wackestone, subordinately packstone textures, Carnian in age (Kolar-Jurkovšek, unpublished) occur below the “Bača Dolomite”. At its upper boundary the “Bača Dolomite” is separated from the Slatnik Formation by a minor thrust.

Based on the conodonts and supported by sponges, corals and foraminifers, the overlying Slatnik Formation is of the Late Norian to Rhaetian age (Rožič & Kolar-Jurkovšek 2007; Rožič et al. 2009). Accordingly, the exposed “Bača Dolomite” can be assigned to the Norian, also confirmed by ongoing foraminiferal research by the author.

The description of the profile is divided into two parts: the first part is based solely on field observations, whilst the second part describes thin-sections.

General description of the section

The investigated section was subdivided into ten intervals (*A–J*, Fig. 3) by lithological characteristics. The characteristics of each Interval are given in Fig. 4:

Interval A: The basal part of the investigated section is made up of 75 m of poorly sorted mud-supported breccias with a light grey marly dolomicritic or dolomicrosparitic matrix. The bedding planes are sharp, planar or chanellized (Fig. 7.2). Massive (maximum thickness 1240 cm) and very-thick beds predominate, but some thick (50–100 cm) and medium-thick (10–50 cm) beds also occur. Oblique sigmoidal laminae were also found in the matrix in the upper part of one bed. Altogether, three types of clast are present. Very elongated chips of marly dolomite with a parallel or cross-lamination and normal grading mark the first group. They show no preferred orientation, and can even be perpendicular to the bedding plane. The second group of clasts is represented by more than 10 cm large clusters of angular pieces of chert, that are slightly disintegrated chert nodules (“mosaic

INTERVAL	CHARACTERISTICS	MF TYPES	DEPO. ENVIRON.
A	Massive to medium-thick mud-supported intraclastic slump breccias	3-LamB	Inner apron
B	Increase in the clay content; breccias are rare; medium-thick beds of marly dolomite predominate	1, 3-LamD, 3-Mix, 8	Outer apron
C	Alternating thin beds of limestone with coquinas and marlstone in cyclic patterns	2, 4, 5, 6, 7	Outer apron
D	Reduced clay content; medium-thick dolomite beds with chert, subordinately limestones	3-Mix, 8	Basin plain
E	Medium-thick limestone beds predominate over dolomites; chert nodules	4, 5, 6, 7	Outer apron
F	Massive clast-supported intraclastic slump breccias	(no samples)	Inner apron
G	Medium-thick dolomite beds, in the lower part few with chertnodules; subordinately limestones	4, 5, 6, 7, 8	Outer apron
H	Medium to very thick-bedded dolomites with chert nodules	3-Mix	Basin plain
I	Medium-thick dolomite beds	3-Mix, 4, 5, 6, 7, 8	Bas. plain - out. apron
J	Thin to medium-thick limestone and dolomite beds	1, 3-LamD, 4, 5, 6, 7	Outer apron

Fig. 4. Summarized characteristics of the individual Intervals distinguished in the “Bača Dolomite” from the Mt Slatnik section. See text for more detailed descriptions.

chert”). Undeformed chert nodules are also present. Some cherts contain clasts of older chert, or partly preserved primary sedimentary structures.

Interval B: In this, around 19 m thick interval consisting of up to 60 cm thick beds, the marly content increases. The breccias become subordinate and are only encountered as medium-thick beds with convex-downwards lower and sharp flat upper boundaries. The matrix is a light grey dolomicrospar, the clasts are mosaic cherts and elongated clasts of marly dolomite with parallel lamination. Most beds are light grey marly dolomicrosparites and occasionally dolosparites. The boundary planes are flat and sharp; the individual beds seem to be composed of several wavy thinner amalgamated beds. Amalgamated units are separated by laminated marlstone up to 5 mm thick. Parallel and convolute lamination can be seen. Most beds contain black, white, grey or red chert nodules, sometimes with preserved parallel lamination. Occasionally, only the outer rim of the nodule is silicified. Beds of black, amalgamated and cherty microsparitic limestone are also present.

Interval C: This interval represents an around 10 m thick package of alternating thin beds of black, locally silicified limestone, and light brown marlstone (Fig. 7.3). A cyclic pattern was recognized. The cycles begin with thicker limestone beds, upwards gradually becoming more clay-rich and are capped by a more prominent marlstone bed. The individual cycles are 40 cm to 110 cm thick. The boundaries between the limestone beds are sharp, but wavy, often more clayey. Parallel lamination is common and compactional stylolites occur locally. The limestones are mudstones to packstones. The latter contain juvenile thin-shelled bivalves, forming lens-shaped coquinas. Individual shells are oriented with their convex or concave sides upwards, or irregularly grouped in clusters. In some cases they are silicified. Nodules of black chert are present in the limestone as well as in the marlstone beds. The marlstone beds are up to 5 cm thick and usually laminated. Thicker beds can contain limestone nodules. Fragmented terrestrial plant remains also occur.

Interval D: This interval measures 11.5 m in thickness. The clay content is markedly reduced and medium–thick beds predominate again. Some micritic to microsparitic bioturbated limestone beds in the lower part are amalgamated. The bedding-plane boundaries are sharp, wavy or straight. The limestones are texturally mudstones to wackestones. Strongly recrystallized green algal thalli and normal grading are visible. The rest of this interval contains light grey dolosparites and dark grey dolomicrosparites. Parallel, cross or convolute laminations can be found, especially in the latter. The dolomites also contain chert nodules. An internal amalgamation of the individual beds becomes more prominent towards the top of this interval.

Interval E: In this 11.5 m thick interval, limestones begin to predominate again, although the bed thickness remains the same. A lateral transition from limestone to coarse-grained dolomite was observed in one bed. The limestones are texturally mudstones or wackestones. The bed boundaries are sharp, straight or wavy, and sometimes dolomitized. Beds are internally amalgamated, sometimes with clayey laminae. Most limestone beds contain chert nodules. Normal and inverse grading, parallel, cross, and convolute laminations are common (Fig. 7.4). Possible ripples were observed in the upper part of one bed. Load-casts and “sand”-balls were also found. A geopetal structure was observed in an unidentified fossil remnant with a circular cross-section (perhaps green algae).

Interval F: This interval consists of 13 m of very thick and massive, up to 4 m thick, clast-supported breccia beds (Fig. 3). The bedding planes are sharp and irregular. Along with loose mosaics of chert clasts there are dolomite intraclasts with clearly visible parallel and cross-laminations. The dolomite clasts are abundant, especially near the base of the breccia beds (Fig. 7.5). They are oriented approximately parallel to the lower boundaries and locally imbricated.

Interval G: Interval F is followed by some medium-thick coarse-grained dolomite beds with chert nodules, then by a 20 m thick succession of medium- to thick-bedded coarse dolomites without chert, with only one massive dolomite bed and two limestone packages. The lower one consists of thin and medium–thick beds of a marly pink-grey micritic limestone with a hardly distinguishable amalgamation. Parallel and convolute laminations are visible, as well as a strong stylolitization. The upper limestone package consists of a few medium to thick beds with parallel lamination. Amalgamations are pronounced near the lower and upper bed boundaries.

Interval H: This interval is 17 m thick. Chert nodules are common. The succession consists of medium- to thick-bedded coarse dolomites with chert, and a single massive bed. Elliptical nodules of white, red or black chert are mostly located near the lower bed boundaries.

Interval I: The following 47 m are dominated by medium-bedded, light grey coarse dolomites. The limestone packages are subordinate, and there are a few massive (up to 520 cm thick) dolomite beds. Dolomite beds have sharp boundaries, mostly flat, but in some cases convex downwards. Some beds contain markedly more porous bands with straight boundaries, up to 10 cm thick, laterally discontinuous and with a slightly steeper dip. Within the beds normal grading and parallel lamination were recognized. Limestone beds contain more sedimentary structures. Parallel lamination was observed, which passed upwards into a convolute lamination, followed by few deformed clayey laminae. Parallel lamination and inverse grading followed on top. The limestones have packstone or wackestone textures. The individual beds are amalgamated. Some are dolomitized near the upper or lower boundaries.

Interval J: This interval is separated from the rest of the investigated section by a minor fault (presumably without a noteworthy displacement (Rožič, pers. comm.)). It starts with a few thin limestone beds, some of them dolomitized in the lower part, with mudstone to packstone textures. Some of them exhibit cross-lamination and bioturbations (*Diplocraterion*). Juvenile ammonites were also found. Dolomitization obviously took place from the bed boundaries towards the interior of the beds, sometimes extending only to the first stylolite (Fig. 7.6).

A massive dolomite bed follows, then two thicker beds of limestone, strongly stylolized. Small (1 cm thick) lenses with a packstone texture and a normal grading occur within the wackestones. The wackestones are typified by a parallel, cross or convolute lamination, dolomitized at the upper boundary. A single, seemingly massive (540 cm), bed follows, but different textures (10 to 100 cm thick packstone and wackestone horizons, separated by pronounced stylolites) indicate several depositional events, in a short time, with the sediment from each being compressed together during compaction (i.e. pounded). Parallel, cross-lamination and normal grading are visible. Another compacted bed follows, but with individual beds more clearly separated into 10–15 cm thick parts with wackestone and packstone textures.

Amalgamated medium–thick beds of dolomite, an amalgamated “massive” limestone bed and a massive (perhaps pounded thinner beds) dolomite bed follow. The uppermost part of the investigated section consists of medium–thick dolomite beds and some limestone (mudstone) beds.

Microfacies analyses

Eight microfacies types (MF) were distinguished (Fig. 5): MF 1 (calcilutite), MF 2 (pelagic bivalve-radiolarian floatstone/wackestone to rudstone/packstone), MF 3 (dolomitized

MF TYPE	NAME	CHARACTERISTICS	FIG.	Flügel (2004)
MF 1	Calcilutite	Laminated calcilutite with rare echinoderms	8.1	
MF 2	Pelagic bivalve-radiolarian floatstone/wackestone to rudstone/packstone	Alternation of floatstone/wackestone with rare thin-shelled bivalves and radiolarians and bivalve coquinas (rudstone/packstone or boundstone)	8.3	SMF 3-Lam
MF 3-LamB	Laminated mudstone breccia matrix	Completely dolomitized; parallel or oblique lamination visible due to the different sizes of the dolomite crystals and the organic content	8.2	?SMF 1 (slumped)
MF 3-LamD	Laminated mudstone of bedded dolomites			?SMF 1
MF 3-Mix	Mixed mudstone	Completely dolomitized, probably bioturbated		SMF 1-Burrowed
MF 4	Bioturbated radiolarian-spiculite wackestone	Wackestone with radiolarians, sponge spicules, thin-shelled bivalves; commonly bioturbated	8.4	SMF 1-Burrowed
MF 5	Fine peloidal-bioclastic packstone	Mean grain-size 125–250 µm; shallow-water derived material; locally larger intraclasts; common gradation and imbrication	8.5	SMF 4
MF 6	Very fine peloidal packstone	Mean grain size 70–90 µm; well sorted	8.6	SMF 4
MF 7	Bioclastic wackestone	Wackestone with mixed shallow- and deep-water (radiolarians, spicules, pelagic bivalves) fossils	8.7	SMF 4-SMF 3-Fil (transitional)
MF 8	Crystalline dolomite	Sedimentary structures & textures not preserved	8.8	

Fig. 5. Summarized characteristics of the recognized microfacies (MF) types. Comparison with the Standard Microfacies Types (SMT) after Flügel (2004) is given in the last column.

mudstone) with three sub-types, MF 3-LamD (laminated breccia mudstone matrix), MF 3-LamB (laminated mudstone of bedded dolomites) and MF 3-Mix (mixed mudstone), MF 4 (bioturbated radiolarian-spiculite wackestone), MF 5 (fine peloidal-bioclastic packstone), MF 6 (very fine peloidal packstone), MF 7 (bioclastic wackestone) and MF 8 (crystalline dolomite). Two of these, namely MF 3 and MF 8, represent completely dolomitized samples. Accordingly, their primary sedimentary textures are not preserved and their interpretation is therefore speculative. The composition of the rest of the MF types is summarized in Fig. 6.

MF 1 (calcilutite) (*Fig. 8.1*)

Characterization: Laminated calcilutite with rare echinoderm remains.

Components: Echinoderm remains (5 %).

Detailed description: The MF 1 was found in the upper, non-dolomitized, limestone microspar part of a 12 cm thick bed of marly dolomite with chert nodules in Interval B. The lower part of the same bed is dolomitized and included in the MF 3-LamD. The MF 1 was also found in a thin limestone bed in the lower part of Interval J (Fig. 3). The micritic matrix is finely laminated. Echinoderm grains have syntaxial overgrowths (neomorphic spar).

MF 2 (pelagic bivalve-radiolarian floatstone/wackestone to rudstone/packstone) (*Fig. 8.3*)

Characterization: Alternations (less than 5 mm spacing) of floatstones/wackestones with rare thin-shelled bivalves and radiolarians and bivalve coquinas (rudstones/packstones or boundstones).

COMPONENTS	MF 1	MF 2	MF 4	MF 5	MF 6	MF 7
Matrix (%)	95	60	85–90	45	50	75
Peloids		◍	◦	●	⬤	•
Thin-shelled bivalves		•	○			◍
Radiolarians		•	◍			○
Sponge spicules		○	○			○
Shell fragments			◦	◦	◦	○
Spherulites (ooids)				○	○	○
Green algae					○	
Sponges & *Cayeuxia*					○	
Microgastropods					○	○
Brachiopods			○	○	○	○
Echinoderms	◍	○	◍	◦	◦	◦
Foraminifera		○	○	○	○	○
Ostracods		○	○	○		○
Intraclasts		○	○	○	○	

○ Very rare ◦ Rare ◍ Sparse • Common ● Very common ⬤ Abundant

Fig. 6. Relative proportions of constituents in the distinguished MF types (MF 3 and 8 are not shown, as no constituents could be distinguished due to the late-stage dolomitization).

Components: Juvenile thin-shelled bivalves and radiolarians are the main constituents. The bivalves (5–40 %, average 25 % of an area) form up to 0.5 cm thick coquinas or are dispersed in the micritic matrix. Their valves are up to 5 mm long but in some horizons they are smaller than 500 μm (wackestone and packstone). Valves are connected or separated. They are slightly curved, with smooth or costate convex sides. The inner structure of the valves is occasionally preserved, with a thicker inner prismatic layer composed of slightly curved calcite columns. In other cases the shells are silicified and consist of microcrystalline quartz (subangular grains, up to 7 μm in diameter, sometimes elongated, with the longer axis perpendicular to the rim of the valve) or fibrous chalcedony (in larger voids).

Around 100 (up to 500) μm large spheres, completely filled by microcrystalline quartz or calcite spar were interpreted as radiolarians (1–30 %, on average 10 %). Simple spines were observed in a few cases.

Peloids (1–15, on average 5 %), intraclasts, small benthic foraminifers (nodosariids), echinoderm fragments and small ostracods are subordinate. The peloids are well sorted, rounded to subangular, up to 180 μm in size. Larger intraclasts consist of micritic matrix with radiolarians and sponge spicules/radiolarian spines.

The micritic matrix, on average, represents 60 % (locally up to 98 %, but sometimes less than 40 %) of the area.

Detailed description: The MF 2 was recognized in Interval C in thin-bedded black limestones with chert nodules, intercalated with marlstones (Fig. 3; Fig. 7.3). Due to the alternation of floatstone/wackestone and rudstone/packstone textures, this microfacies is heterogeneous. The transition from the bivalve dominated rudstone/packstone to the bivalve-radiolarian floatstone/wackestone is sharp, but the rudstone/packstone sometimes passes into the floatstone/wackestone more gradually, probably due to a bioturbation.

The MF 2 has a distinctly laminated appearance also because of the horizontally oriented bivalve valves, which are oriented with their convex sides up or down. Among the rare foraminifers, lagenids and *Variostoma* sp. were recognized. The former species is present in the coquina layers, while the latter occurs directly beneath the coquina and in the floatstone/wackestone lamina.

Some horizons are clearly bioturbated, with valves pushed aside and oblique to the bedding plane. Shelter porosity was often present beneath the valves, later filled with a spar (Fig. 8.3). Silicification is restricted to very narrow horizons, but does not seem to be related to the proportion of radiolarians in thin-section. Calcitic and silicified laminae thus appear close together. Small stylolites and dissolution seams are parallel or oblique to the bedding. Small euhedral crystals of dolomite usually occur in small quantities (less than 1 %), with rare exceptions of almost totally dolomitized horizons. An enhanced dolomitization was observed among and along stylolites, while the silicification seems to avoid dissolution seams.

Remarks: The MF 2 corresponds to the SMF 3-Fil (“Thin-shelled pelagic bivalve (‘filaments’) wackestone”) of Flügel (2004). The coquina horizons might represent periodic blooms of pelagic bivalves (note that the bivalves are juvenile), alternating with periods of only background deposition of hemipelagic mud and radiolarians. The latter are also present in the

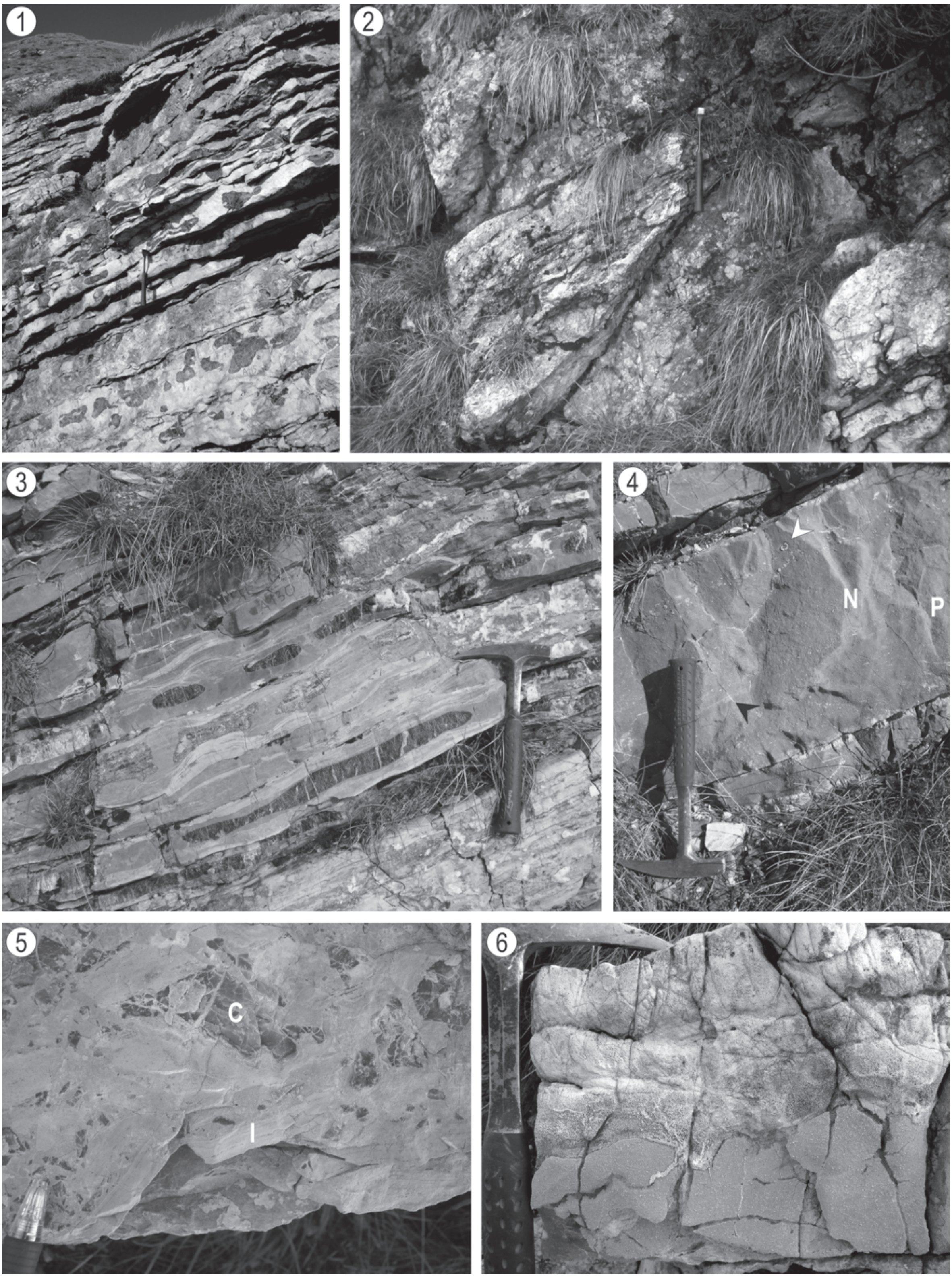

Fig. 7. **1** — View of part of the Mt Slatnik section. Bedded dolomites with chert nodules of the "Bača Dolomite". **2** — A channel (scour) structure in the "Bača Dolomite". **3** — Intercalations of marlstone, marly limestone and thin-bedded limestone with chert nodules. Limestone beds are rich in small thin-shelled bivalves (MF 2). **4** — A limestone bed with numerous sedimentary structures, including parallel lamination (P), load-casts (black arrow-head) and normal grading (N). Several closely-spaced depositional events are possible. Larger bioclasts (white arrow head) near the upper bedding plane probably settled late from suspension due to a larger buoyancy. **5** — Clast-supported debris flow breccias. Clasts are angular cherts (C) and laminated fine-grained dolomites (intraclasts; I). **6** — Late-stage dolomitization, advancing from the upper bedding-plane towards the interior of the limestone bed, but mostly stopped by the stylolite.

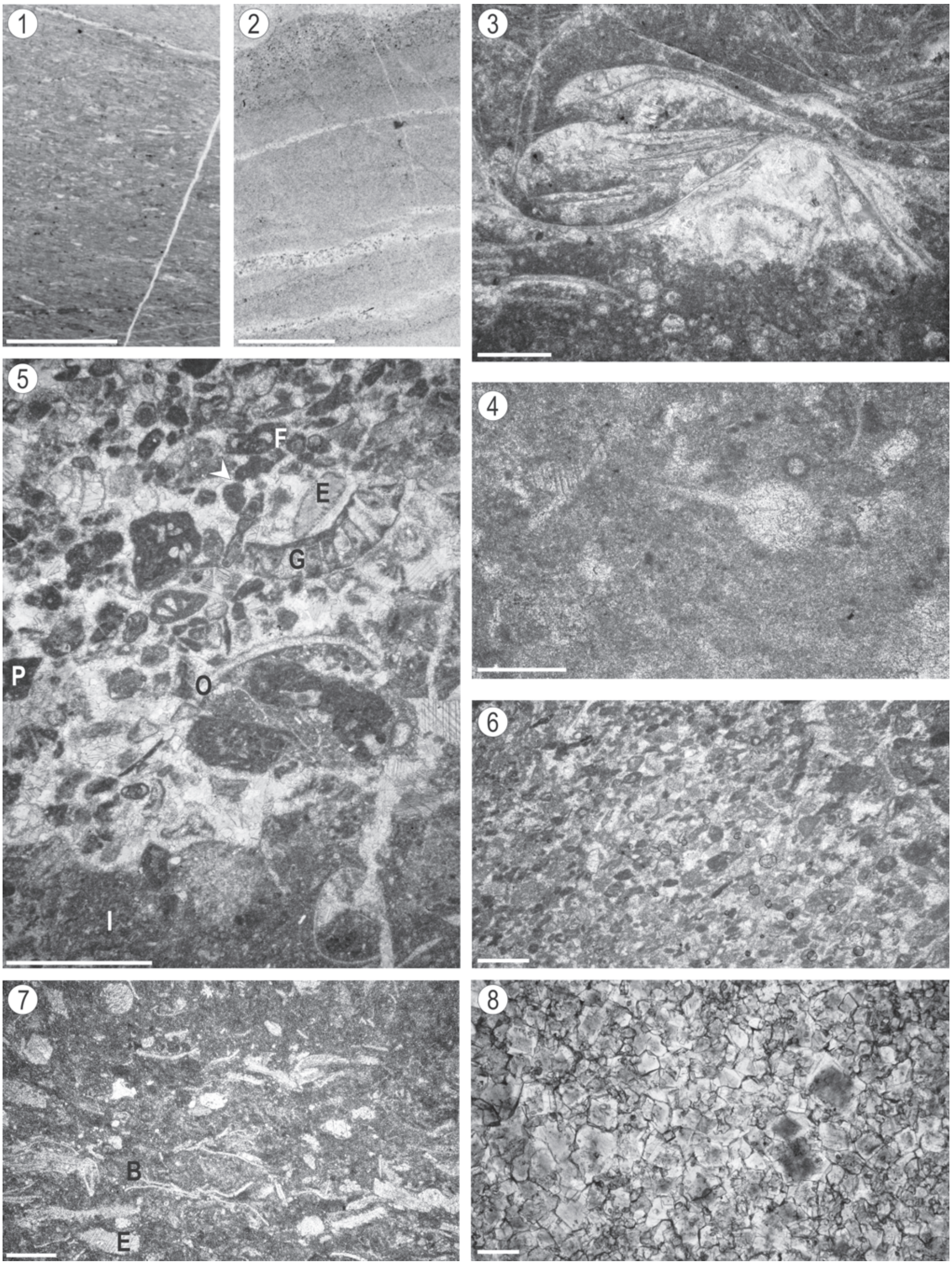

Fig. 8. **1** — A thin-section of MF 1 (calcilutite). Scale bar is 5 mm. **2** — A thin-section of laminated dolomite from the breccia matrix (MF 3-LamB). Sedimentary structures are mostly visible, while textures are completely obliterated by dolomitization. Scale bar is 5 mm. **3** — The pelagic bivalve-radiolarian rudstone (MF 2). The shelter-type umbrella porosity is developed beneath valves. Radiolarians are calcified. Scale bar is 1 mm. **4** — Radiolarian-spiculite wackestone (MF 4). A calcified radiolarian with simple spines is in the centre. Scale bar is 200 μm. **5** — Fine peloidal-bioclastic packstone (MF 5) with a micritic matrix partly winnowed away. Peloids (P), green algal genicula (G), small foraminifers (F), echinoderm fragments (E) and ostracod valve (O) can be seen. Note the point contacts between the grains (arrow head) and the slight imbrications towards the right. Part of a large intraclast (MF 4) is visible at the bottom (I). Scale bar is 1 mm. **6** — Very fine peloidal packstone (MF 6) with a micritic matrix partly winnowed away (perhaps recrystallized). Note the imbrications towards the right. Scale bar is 200 μm. **7** — Bioclastic wackestone (MF 7) of the transitional character, having large allochthonous particles (mostly echinoderm fragments; E) admixed with pelagic biota (in this case thin-shelled bivalves; B). Scale bar is 500 μm. **8** — Late-stage dolomite of MF 8. No sedimentary structures and textures are preserved. Scale bar is 200 μm.

coquina layers, indicating that the (hemi)pelagic settling also took place during the bivalve blooms. An alternative explanation would be the presence of weak bottom currents, also indicated by the parallel orientation of the valves and the somewhat lens-shaped accumulations. Alternatively, the bivalve shells, as well as some radiolarians, could be accumulated by storm waves, but no evidence (for example no hummocky cross-stratification) for the latter has been found. The presence of bottom currents, supplying oxygen to the sea bottom, could also be indicated by intense burrowing.

Stylolites and dissolution seams that are parallel to the bedding-plane are compactional in nature, whereas oblique ones are tectonically induced. The majority of peloids are probably micritized clasts or rip-up clasts (intraclasts).

The SMF 3 indicates a basin or an open deep-sea environment (Flügel 2004).

MF 3 (dolomitized mudstone)

Three submicrofacies types, which were greatly obliterated by dolomitization, are joined in microfacies type MF 3. Sedimentary textures in MF 3 can no longer be recognized, but unlike in MF 8, the structures are still visible. Submicrofacies MF 3-LamB and MF 3-LamD are virtually indistinguishable in thin-sections. However, they are kept separated as they occur in markedly different types of beds (namely in different facies). All subtypes of MF 3 probably represent autochthonous deep-water deposits which were in the case of the MF 3-LamB deformed soon after deposition (i.e. prior to total lithification, but after the formation of chert nodules, as these are brecciated).

Submicrofacies MF 3-LamB (laminated mudstone breccia matrix) (Fig. 8.2) and MF 3-LamD (laminated mudstone of bedded dolomites)

Characterization: Completely dolomitized microfacies with recognizable (mostly parallel) lamination.

Components: No primary constituents were preserved.

Detailed description: The MF 3-LamB was found in the matrix of the massive breccias in Interval A, whilst MF 3-LamD was encountered in the thin-bedded marly dolomite of Intervals B and J. It was also found in the dolomitized part of a thin bed with MF 1 in its upper, limestone part. The lamination is parallel or oblique to the bedding and is caused by differences in size of the dolomite crystals, as well as by lenses and bands (laminae) enriched in organic matter. Calcite veins are sometimes inserted in laminae partings. The dolomite crystals are subhedral and closely linked together. Three size-classes were recognized: 15–20 μm, 35 μm and 55–70 μm. Most of the crystals have brown-stained cores. Stylolites are present.

Remarks: The MF 3-LamB could represent a dolomitized equivalent of the SMF 1 (“Spiculite wackestone or packstone, often with a calcisiltite matrix”) of Flügel (2004).

Submicrofacies MF 3-Mix (mixed mudstone)

Characterization: A completely dolomitized microfacies with a mixed appearance, most probably due to a bioturbation.

Components: Not preserved, with the rare exception of echinoderm remains.

Detailed description: The subtype MF 3-Mix appears in some thin- and medium-bedded dolomite and marly dolomite beds. In one example, MF 3-Mix was in sharp contact with MF 5. As in MF 3-Lam, different sizes of dolomite crystals allowed recognition of probable bioturbations in hand specimens. Convolute lamination cannot be excluded. Subhedral dolomite crystals measure 15 μm, 35 μm, 50–60 μm and 90 μm in diameter. Stylolites are present.

Remarks: Caution also regards this MF type. However, it is possible, that the MF 3-Mix corresponds to Flügel’s (2004) SMF 1-Burrowed (“Burrowed bioclastic wackestone with abundant fine pelagic and benthic biodetritus”). Bioturbation would indicate an oxygenated bottom. The SMF 1-Burrowed occurs in basin, open-sea shelf and outer-ramp environment (Flügel 2004).

MF 4 (bioturbated radiolarian-spiculite wackestone) (Fig. 8.4)

Characterization: Wackestone with radiolarians, sponge spicules and rare thin-shelled bivalves, with an admixture of allochthonous material, mostly echinoderms. Bioturbations are common.

Components: The MF 4 is characterized by a large proportion of micritic matrix (85–90 %), relatively numerous radiolarians (4–7 %) and sponge spicules (0.5–3 %). The radiolarians are calcified and 90–290 μm in diameter. Other components include angular, 50 μm large peloids (3 %), subangular, 160 μm large intraclasts, echinoderm remains (7 %), thin-shelled bivalves, sparitic shell (bivalves) and brachiopod fragments, and foraminifers.

Detailed description: The MF 4 often occurs in association with MF 5 and the MF 6 in thin- or medium-bedded limestones with a parallel lamination and a gradation in Intervals C, E, G and J. When overlain by MF 5 or 6, the boundary is erosional. The boundaries are sometimes stylolized. The MF 4 is often bioturbated. Locally, lenses of MF 6 are present and sometimes an imbrication occurs. A weakly expressed parallel lamination is occasionally visible. Foraminifers *Duotaxis nanus* (Kristan-Tollmann), trochamminids, *Lenticulina* sp. and *Dentalina* sp. were recognized.

An intraparticle cement includes blocky, sometimes mosaic, spar.

Remarks: The MF 4 corresponds to the SMF 1-Burrowed of Flügel (2004). The mixing of autochthonous and allochthonous material might be the result of bioturbation and/or weak current activity (as indicated by the lenses of MF 6 and local imbrications). The bioturbation points towards an oxygenated bottom and relatively slow sedimentation.

MF 5 (fine peloidal-bioclastic packstone) *(Fig. 8.5)*

Characterization: Fine peloidal-bioclastic packstone, locally with large intraclasts (floatstone), commonly graded and imbricated. A micritic matrix is in places winnowed or recrystallized.

Components: Up to 20 μm large intraclasts, which represent 25 % of the thin-section area are characteristic of this

MF type. They are often limited to the basal part of MF 5 and closely resemble the other MF types, namely MF 1, MF 4, MF 6 or dolomitized micritic clasts.

The majority of the volume is occupied by a fine (mean size 125–250 µm) peloidal-bioclastic packstone. It consists of 40–50 % of matrix, 25–52 (average 40 %) of peloids, 1–5 % (3 %) of echinoderms, 1–8 % (3.5 %) of recrystallized shell fragments (molluscs), 1 % of foraminifers and 1 % of spherulites. Intraclasts, ostracods and brachiopod fragments each represent 0.5 % of the grains, while microgastropods, green algae, sponge fragments and calcimicrobe ?*Cayeuxia* are rarely found. The peloids are 40–450 µm large (mean size 250 µm), well sorted and rounded or subrounded. The bioclasts commonly have micritic envelopes and abraded (rounded) edges. The spherulites are most probably radiaxial ooids, up to 700 µm large, but mostly smaller than 200 µm. Some concentric laminae are visible.

Detailed description: The MF 5 was recognized in Intervals C, E, G, I and J in black, amalgamated, thin, medium and in one case thick-bedded limestone, whose lower part was completely dolomitized. It is closely associated with MF 4 (MF 5 overlies MF 4 with a sharp, erosional contact), MF 6 (MF 5 is below MF 6; the contact with MF 6 is sharp, but probably not erosional) and MF 7 (MF 5 gradually passes into MF 7). Intraclasts are most often directly derived from the underlying MF 4 and represent the largest particles, being in sharp contrast to the rest of the sediment as the latter is very well sorted. Normal grading, imbrication and geopetal textures are most common, while inverse grading is rare. Shelter porosity was later filled by cement. Several normally-graded horizons up to 1 cm thick may follow one another, or exchange with MF 6. Grains are in point or line contacts. In the latter case, fragmentation of elongated grains (namely brachiopod shells) is observed.

Several foraminiferal taxa were recognized, among them *Galeanella panticae* Zaninetti & Brönnimann in Brönnimann, Cadet, Ricou & Zaninetti, *Galeanella tollmanni* Kristan, *Palaeolituonella meridionalis* (Luperto), *Endotriada tyrrhenica* Vachard, Martini, Rettori & Zaninetti, *Planiinvoluta deflexa* Leischner, *Tolypammina* sp. and Duostominidae.

Syntaxial overgrowth cement is common around echinoderm fragments and intraskeletal spaces are filled with blocky calcite. Where micrite is winnowed, grains are lined with isopachous rims of equant calcite and the intergranular spaces are filled with blocky spar, sometimes dolospar. A microquartz locally replaces parts of the matrix (small patches, bands). Euhedral dolomite crystals are locally abundant. Some bioclasts, especially the central parts of echinoderm plates and shells, are silicified. When present, stylolitization is strong, with an amplitude of several centimeters, bringing MF 5 into sharp, sutured contact with MF 4 and MF 6.

Remarks: Both MF 5 and MF 6 have a packstone texture, although the micritic matrix is partly winnowed and the pores are filled by orthospar or recrystallized into pseudospar. The distinction between MF 5 and MF 6 is based on grain size.

The MF 5 corresponds to the SMF 4 (“Microbreccia, bioclastic-lithoclastic packstone or rudstone”) of Flügel (2004).

Arenaceous allochems in MF 5 are of a shallow-water origin, probably derived from an adjacent carbonate platform. Sponges, ?*Cayeuxia* and some foraminifers in particular (for example, *Galeanella* and *Planiinvoluta*) indicate the coeval existence of a reef. Several reefs are indeed known to have rimmed the Julian Carbonate Platform (Buser et al. 1982; Turnšek & Buser 1991). Intraclasts, on the contrary, originate very close to the place of final deposition. A longer transport path of the sandy material is indicated by its sorting as well. Micritic envelopes, fragmentation and abrasion indicate a pre-reworking taphonomic history for these particles.

Normal grading, the occurrence in laminae (sometimes in several successive events) and small grain size correspond to very distal turbidity current deposits (Tucker 2001). The imbrications and the winnowed micritic matrix also point towards some kind of current control (Watts 1987). The inversely-graded horizons may be interpreted as modified grain-flow deposits (Watts 1987).

The SMF 4 occurs in basinal and toe-of-slope settings (Flügel 2004).

MF 6 (very fine peloidal packstone) (Fig. 8.6)

Characterization: Very fine, well-sorted peloidal packstone. The micritic matrix is winnowed in places.

Components: Grains represent 50 % of the area and are dominated by peloids (40 %). These probably include peletoids, as well as true faecal pellets. Their average size is 70–90 µm. Other constituents are subordinate: echinoderms (3 %), neomorphically altered shell fragments with micritic envelopes (4 %), foraminifers, ooids and ostracods (each 1 %), very rare intraclasts, brachiopods and gastropods.

Detailed description: The MF 6 is mainly found in thin- and medium-bedded, often amalgamated, occasionally partially dolomitized limestones in Intervals C, E, G, I and J. It is in a sharp, planar contact with MF 4 or MF 5. It can also appear as small lenses in MF 4. Inverse and normal grading is visible, as well as imbrication. Peloids are well sorted and in a point-contact. Some bioclasts have been silicified. Pores are filled with syntaxial and blocky spar.

Remarks: The MF 6 corresponds to the SMF 4 of Flügel (2004). It is interpreted as a distal turbidity deposit, finer-grained than MF 5. The erosive potential was weaker than that of MF 5, thus no rip-up clasts (intraclasts) were incorporated in the flow. Lenses of MF 6 in MF 4 could indicate redeposited material via bottom currents or bioturbation.

MF 7 (bioclastic wackestone) (Fig. 8.7)

Characterization: Wackestone with mixed shallow and deep-water (radiolarians, spicules, thin-shelled bivalve) fossils.

Components: The micritic matrix represents 70–80 % of the area. Grains are thin-shelled bivalves (7 %), peloids (11 %), echinoderms (4.5 %), neomorphically replaced shell fragments (1.5 %), foraminifers (0.5 %), brachiopods (0.5 %), radiolarians, spicules and spherulites (ooids). Echinoderm grains are the largest.

Detailed description: The MF 7 was found in Intervals C, E, G, I and J. It often lies above MF 5 and MF 6. The transition from these two MF types is gradual, marked by an increase in the matrix proportion, larger but fewer grains, and the presence of pelagic fauna. A bioturbation is sometimes visible, occasionally reaching into the underlying MF types.

Remarks: The MF 7 represents the transition from allochthonous (MF 5, 6) to autochthonous deposition. The rate of allochthonous deposition decreased and background hemipelagic sedimentation took over, allowing benthos to populate the sea bottom after disturbance by turbidites (MF 5, 6).

MF 8 (crystalline dolomite) *(Fig. 8.8)*

Completely dolomitized samples without preserved structures and textures were classified into this microfacies type. It was found in Intervals B, D, G and I. Three types of dolomite crystals were distinguished: 1) planar-euhedral, brown-stained crystals; 2) subhedral crystals with polymodal size distribution and 3) anhedral, vug-filling dolomite.

The planar-euhedral dolomite crystals were probably the first to form. They are rhomb-shaped, with straight, planar boundaries and brown-stained due to an increased Fe content. The crystals are not in contact with each other and are either rare or abundant. They are always included in the cores of the dolomite crystals of the second generation, namely in the planar-subhedral dolomite crystals. These are predominant, in close contact and completely obscure primary sedimentary structures. Very few ghosts of echinoderms are found. Crystals display a polymodal size distribution, with the main size classes of 35 μm, 50 μm, 90 μm and 180 μm. When facing pores (vugs), crystal faces are well developed. Banding in outer parts is sometimes visible in such cases, probably as the result of the evolving composition of pore fluid.

The separation of the first and the second generations of dolomite is based on the following arguments: not all subhedral crystals contain euhedral cores; euhedral cores (first generation dolomite) have abundant inclusions of previous carbonate, while these are rare in clear, subhedral crystals and in rare cases subhedral crystals are poikilotopic, that is they include several brown rhombic euhedral crystals of the first generation. The third generation of dolomite is rarely present in the form of anhedral crystals filling rare vugs. The presence of at least three generations of dolomite was recently confirmed using cathodoluminescence, but more data is needed.

Several phases of silification are also present. The first phase is characterized by the formation of chert nodules and the silica-replacement of some fossils penecontemporaneously with the first dolomite generation. The second phase is of a late-stage origin, filling voids after the second and possibly the third generation of dolomite.

Discussion

Sedimentary evolution of the Slovenian Basin during the Norian

The observed MF types are strikingly similar to the association from the Middle Triassic of the Dolomites, Italy (in Flügel 2004). Unit A1 (“basal lithobioclastic grainstone”) corresponds to MF 5 and is interpreted as a proximal calciturbidite. Unit A2 (“admixture of pelagic biota and echinoderms”) and/or Unit D2 (“alternation of platform-derived material and pelagic grains”) correspond to MF 7. Unit B (“radiolaria packstone with bioturbations”) is equivalent to MF 4, while Unit C (“lithobioclastic packstone” with smaller and better sorted clasts than in Unit A) corresponds to MF 6. Unit D1 (“coquina floatstone”) can be considered a bioturbated version of MF 2.

Thin-sections of the matrix of the lower breccias (Interval A) belong to MF 3-LamB. Chert nodules are brecciated (brittle deformation), as they were lithified prior to displacement, while the laminae of the matrix are only distorted (plastic deformation), thus the sediment was not completely lithified. The fitting of the chert clasts (mosaic chert) and the preserved lamination of the matrix indicate a relatively minor internal deformation of the sediment and a very short transport. Accordingly, the breccias may have been formed via slides (only minor internal deformations) or slumps (internally deformed), which had not yet progressed into debris flows (see Stow et al. 1996). Nebelsick et al. (2001) noticed slightly inclined, fine-bedding towards the top of some of the debrites in the Oligocene of Austria, similar to oblique-to-bedding laminae at the top of one of the breccia beds in the Mt Slatnik section.

The bedded dolomite above the breccias (Interval B), displaying MF 3-LamD microfacies, possibly represents an undisturbed, stable sea-floor sediment, perhaps due to abated tectonic activity or simply to a deeper depositional environment. The fine lamination suggests oxygen-depleted conditions (Haas 2002), distal turbidites or (more likely) weak bottom currents.

The MF 2 is found only in limestones of Interval C. These sediments were probably deposited in a quieter environment, sporadically disturbed by distal turbidites (MF 5, 6, 7). A similar alternation of hemipelagic limestones and marlstones was recorded by Watts (1987). Siliciclastic intervals might represent periods of reduced carbonate sedimentation, increased carbonate dissolution or increased influx of terrigenous mud (Watts 1987). According to plant remains, the last explanation seems the most likely in our case. Calcareous mud with pelagic bivalves and radiolarians (MF 2) thus represents background sedimentation, occasionally punctuated by turbidite deposition and increased river runoff. An enhanced terrigenous influx might indicate a period of a more humid and seasonal (monsoonal) climate (Watts 1987).

The next few meters (Interval D) are made up of medium- and thin-bedded cherty dolomite beds characterized by MF 3. Virtually absent turbidite deposits and a predominance of thin-bedded dolomites with chert might indicate deposition on a basin plain. The limestone beds of Interval E contain MF 4, 5, 6 and 7, indicating enhanced turbidite deposition. The final slope progradation is marked by the second breccias interval (Interval F). Because the matrix is still laminated, the term slump would be the most appropriate. The intraclasts are angular, yet often plastically deformed and were not completely lithified. The depositional basin started to progressively deepen for the second time. The predominant turbidity deposits (MF type 6), interfingering with the autochthonous hemipelagic sediments (MF 4, transitional MF 7 in Interval G), gradually progressed into the cherty bedded-dolomites with microfacies type MF 3 of Interval H. The predomination of subtype MF 3-Mix indicates oxygenated sea-floor. The appearance of MF 5 and 6, interfingering with the autochthonous deposits (MF 3-Mix, 4, 7), marks a new progradation phase (Intervals I and J). Some of the turbidite sediments were re-deposited by grain flows, as indicated by the thin bands with straight boundaries (around 205th m in Fig. 3). The depositional system became shallower, with the "Bača Dolomite" passing upwards into the Slatnik Formation, which contains thicker and coarser-grained limestone beds.

Depositional environment

No transitional zone between the Slovenian Basin and the Julian Carbonate Platform has been found so far for the Upper Triassic, but Rožič & Šmuc (2006, 2009) have recognized such a zone for the Jurassic sediments in the neighbouring tectonic block, showing no by-pass zone. The observed MF association fits into the Facies Zone 1 ("Deep sea or cratonic deep-water basin") of Flügel's (2004) rimmed carbonate slope apron model.

Two facies shifts (retrogressive-progressive cycles) were recognized: from the inner apron with the mud-supported debris flow breccias ("Facies F"), into the turbidite-dominated ("Facies D") outer apron, and in turn to the basin plain with the distal turbidites ("Facies D") interbedded with the peri-platform or pelagic oozes ("Facies G"), then back in reverse order to finish each cycle.

A similar interpretation has been offered for the Upper Triassic Hármashatár-hegy Basin in the Buda Hills of Hungary, with proximal toe-of-slope (breccias), distal toe-of-slope (fine-grained wackestones and turbidites), oxygen-depleted basin (laminated carbonates and marlstones) and oxygenated basin (peloidal wackestones, sponge-spicule, radiolarian and bioturbated wackstones-packstones) settings (Haas 2002).

Several previously mentioned depositional features, namely imbrication, the alignment of pelagic bivalve shells and spicules, the occasionally observed cross-lamination and ripples, bioturbation and the lack of a micritic matrix due to winnowing, point towards occasionally present weak bottom currents. The Dachstein-type reef-rims around neighbouring platforms (Buser et al. 1982; Turnšek & Buser 1991) also imply good water circulation (Iannace & Zamparelli 2002). The above mentioned data, as well as the long-term existence of the Slovenian Basin are in contrast to the shallower, more restricted intraplatform basins (see for example Cozzi & Podda 1998; Iannece & Zamparelli 2002; Tomašových 2004).

Recognition of the regular variations in the input material, namely in the redeposited grains of calciturbidites, as was done by Reijmer et al. (1991), is probably not possible due to dolomitization of most beds, but a strong predominance of reef-derived foraminifers (see Senowbari-Daryan 1980; Wurm 1982; Kuss 1983; Martini et al. 2009) in some of the studied samples suggests that such variations do exist.

The "Bača Dolomite" compared to the Slatnik Formation

At the type locality (Mt Kobla; Fig. 1C) the Slatnik Formation consists of a finer-grained lower part (predominantly micritic limestones and turbidites) and a coarser-grained upper part (limestone conglomerates, calcarenites and hemipelagic limestones) (Rožič 2006). At Mt Slatnik, following the described section of the "Bača Dolomite", the Slatnik Formation predominantly consists of calcarenites, pebbly calcarenites and clast-supported conglomerates, subordinately hemipelagic limestones (Rožič et al. 2009). As the lower boundary with the "Bača Dolomite" is a thrust, some doubt exists as to whether only the upper part of the Slatnik Formation is preserved. However, Rožič et al. (2009) concluded that the dislocation along the thrust is minor. In any case, the Slatnik Formation at Mt Slatnik contains thicker and coarser-grained beds. Deposition took place on the inner apron, passing to the upper slope (Rožič et al. 2009), thus in a shallower environment than for the underlying "Bača Dolomite" (this paper).

Furthermore, within the general trend of the progradation, three lower-order retrogressive-progressive cycles were recognized in the upper 32 m of the "Bača Dolomite" and the Slatnik Formation. Based on the conodonts, the first of these cycles is of the Late Norian (middle Sevatian) age (Rožič et al. 2009). Combined with the two cycles recognized in the investigated "Bača Dolomite" from the same section, five lower-order cycles can be assumed for the whole Norian-Rhaetian sequence.

Conclusions

The "Bača Dolomite" represents bedded or massive dolomites with chert, deposited in the Slovenian Basin during the Norian and Rhaetian (Buser 1986) and has been poorly investigated until now. In the Mt Slatnik section, some carbonate beds within the "Bača Dolomite" have not been dolomitized, offering a unique opportunity for research into its depositional environment.

The following conclusions were reached:

— Eight microfacies types (MF) were recognized: MF 1 (calcilutite), MF 2 (pelagic bivalve-radiolarian floatstone/wackestone to rudstone/packstone), MF 3 (dolomitized mudstone) with three sub-types, MF 3-LamB (laminated mudstone breccia matrix), MF 3-LamD (laminated mudstone of bedded dolomites) and MF 3-Mix (mixed mudstone), MF 4 (bioturbated radiolarian-spiculite wackestone), MF 5 (fine peloidal-bioclastic packstone), MF 6 (very fine peloidal packstone), MF 7 (bioclastic wackestone) and MF 8 (crystalline dolomite).

— The MF 1, 2, 3, 4 and 7 represent predominantly hemipelagic sediments. The latter two types contain admixed redeposited clasts. The MF 5 and 6 formed via diluted, low-density turbidite currents.

— Distribution of the MF types throughout the section corresponds to the facies distribution. Together they reflect shifts in the depositional environment. Two complete retrogressive-progressive cycles were recognized: from a proximal slope apron (massive debris-flow breccias; MF 3-LamD), to a more distal slope apron (hemipelagic deposits — medium-bedded cherty dolomites or limestones of MF 1, 3-LamD, 4, 7 and thin-bedded cherty coquina limestones of MF 2, exchanging with distal turbidites — thin- to medium-bedded limestones with or without chert and MF types 5 and 6), to a basin plain (thin- and medium-bedded dolomites with chert, MF 3-Mix), followed by the reverse trend.

— The "Bača Dolomite" was deposited in a more distal setting than the overlying Slatnik Formation, thus a general trend of progradation is proposed.

— Five lower-order retrogressive-progressive cycles were recognized in the Norian and Rhaetian sediments of the Slovenian Basin, two of them being recorded for the first time.

Acknowledgments: This research was financially supported by a grant from the Slovenian Research Agency. My sincere thanks go to Dr. B. Rožič from the Faculty of Natural Sciences and Engineering, University of Ljubljana, Dr. D. Skaberne, Dr. B. Ogorelec and J. Atanackov from the Geological Survey of Slovenia for their guidance and for their comments on the draft version of this paper. Special thanks go to the reviewers, Dr. J. Michalík, Prof. Dr. J. Haas and Dr. C. Scheibner for their very constructive remarks.

References

Aubouin J. 1960: Essai sur l'ensemble italo-dinarique et ses rapports avec l'arc alpin. *Bull. Soc. Geol. France* 7, 2, 487–526.

Aubouin J. 1963: Essai sur la paléogéographie post-triasique et l'evolution secondaire et tertiaire du versant sud des Alpes orientales (Alpes méridionales; Lombardie et Vénétie, Italie; Slovénie occidentale, Yougoslavie). *Bull. Soc. Géol. France* 7, 5, 730–766.

Bosellini A. 2004: The western passive margin of Adria and its carbonate platforms. In: Crescenti U., D'Offizi S. & Sacchi R. (Eds.): The geology of Italy. *Soc. Geol. Ital. Spec. Vol. for the IGC 32 Florence-2004*, Roma, 79–92.

Buser S. 1979: Triassic beds in Slovenia. In: Drobne K. (Ed.): 16th European micropaleontological colloquium, Zagreb–Bled, Yugoslavia, 8th–16th September 1979. *Croatian Geol. Soc., Slovenian Geol. Soc.*, Ljubljana, 17–25.

Buser S. 1986: Explanatory book, Sheet Tolmin and Videm (Udine) L33-64, L33-63. Basic geological map of SFRJ 1 : 100,000. *Zvezni Geol. Zavod*, Beograd, 1–103 (in Slovenian with English summary).

Buser S. 1989: Development of the Dinaric and the Julian carbonate platforms and of the intermediate Slovenian Basin (NW Yugoslavia). *Boll. Soc. Geol. Ital.* 40, 313–320.

Buser S. 1996: Geology of Western Slovenia and its paleogeographic evolution. In: Drobne K., Goričan Š. & Kotnik B. (Eds.): The role of impact processes and biological evolution of planet Earth-International workshop. *ZRC Publ., ZRC SAZU*, Ljubljana, 111–123.

Buser S. & Krivic K. 1979: Excursion M, Hudajužna in the Bača Valley — Carnian stage. In: Drobne K. (Ed.): 16th European micropaleontological colloquium, Zagreb–Bled, Yugoslavia, 8th–16th September 1979. *Croatian Geol. Soc., Slovenian Geol. Soc.*, Ljubljana, 229–232.

Buser S. & Ogorelec B. 2006: Pelagic Jurassic beds from Mt. Kobla. In: Režun B., Eržen U., Petrič M. & Gantar I. (Eds.): Book of abstracts, 2nd Slovenian geological congress. *Idrija Mercury Mine in Closing*, Idrija, 42 (in Slovenian).

Buser S. & Ogorelec B. 2008: Deep-water Triassic and Jurassic beds from Mt. Kobla (W Slovenia). *Geologija* 51, 2, 181–189 (in Slovenian with English summary).

Buser S., Ramovš A. & Turnšek D. 1982: Triadische Riffe in Slowenien. *Facies* 6, 15–24.

Buser S., Kolar-Jurkovšek T. & Jurkovšek B. 2008: The Slovenian Basin during the Triassic in the light of conodont data. *Boll. Soc. Geol. Ital.* 127, 2, 257–263.

Cousin M. 1970: Esquisse géologique des confins italo-yougoslaves: leur place dans les Dinaride set les Alpes méridionales. *Bull. Soc. Geol. France* 7, 12 (6), 1034–1047.

Cousin M. 1973: Le Sillon Slovene: les formations triasiques, jurassiques et neocomiennes au Nord-Est de Tolmin (Slovenie occ., Alpes mer.) et leurs affinites Dinariques. *Bull. Soc. Geol. France* 7, 15, 326–339.

Cousin M. 1981: Les rapports Alpes-Dinarides; Les confins de l'Italie et de Yougoslavie. Vol. I. *Soc. Géol. Nord* 5, 1–521.

Cozzi A. & Podda F. 1998: A platform to basin transition in the Dolomia principale of the M. Pramaggiore area, Carnia Prealps, northern Italy. *Mem. Soc. Geol. Ital.* 53, 387–402.

Dunham R.J. 1962: Classification of carbonate rocks according to depositional texture. In: Han W.E. (Ed.): Classification of carbonate rocks. A symposium. *Amer. Assoc. Petrol. Geol. Mem.*, Tulsa, 108–121.

Flügel E. 2004: Microfacies of carbonate rocks: Analysis, interpretation and application. *Springer-Verlag*, Berlin, Heidelberg, 1–976.

Gianolla P., De Zanche V. & Roghi G. 2003: An Upper Tuvalian (Triassic) platform-basin system in the Julian Alps: the start-up of the Dolomia Principale (Southern Alps, Italy). *Facies* 49, 125–150.

Goričan Š., Šmuc A. & Baumgartner P.O. 2003: Toarcian Radiolaria from Mt. Mangart (Slovenian-Italian border) and their paleoecological implications. *Mar. Micropal.* 49, 275–301.

Haas J. 2002: Origin and evolution of Late Triassic backplatform and intraplatform basins in the Transdanubian Range, Hungary. *Geol. Carpathica* 53, 3, 159–178.

Haas J., Kovács S., Krystyn L. & Lein R. 1995: Significance of Late Permian-Triassic facies zones in terrane reconstructions in the Alpine-North Pannonian domain. *Tectonophysics* 242, 19–40.

Iannace A. & Zamparelli V. 2002: Upper Triassic platform marine biofacies and the plaeogeography of Southern Apennines. *Palaeogeogr. Palaeoclimatol. Palaeoecol.* 179, 1–18.

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.

Kolar-Jurkovšek T. 1982: Conodonts from Amphiclina beds and Bača dolomite. *Geologija* 25, 1, 167–188 (in Slovenian with English summary).

Kossmat F. 1901: Geologisches aus dem Bačathale im Küstenlande. *Verh. Geol. R.–A.* 4, 103–111.

Kossmat F. 1914: Geologie des Wocheiner Tunnels und der Südlichen Anschlusslinie. *Denkschr. Mat.-Naturwiss. Kl.* 82, 6–142.

Krystyn L., Lein R., Schlaf J. & Bauer F.K. 1994: Über ein neues obertriadisch-jurassisches Intraplattformbecken in den Südkarawanken. *Jubiläumsschrift 20 Jahre Geologische Zusammenarbeit Österreich–Ungarn* 2, 409–416.

Kuss J. 1983: Faziesentwicklung in proximalen Intraplattform-Becken: Sedimentation, Palökologie und Geochemie der Kössener Schichten (Ober-Trias, Nördliche Kalkalpen). *Facies* 9, 61–172.

Lein R., Schlaf J., Müller P.J., Krystyn L. & Jesinger D. 1995: Neue Daten zur Geologie des Karawanken-Strassentunnels. *Geol. Paläont. Mitt.* 20, 371–387.

Martini R., Peybernes B. & Moix P. 2009: Late Triassic foraminifera in reefal limestones of SW Cyprus. *J. Foram. Res.* 39, 3, 218–230.

Mullins H.T. & Cook H.E. 1986: Carbonate apron models: Alternatives to the submarine fan model for paleoenvironmental analysis and hydrocarbon exploration. *Sed. Geol.* 48, 37–79.

Nebelsick J.H., Stingl V. & Rasser M. 2001: Autochthonous facies and allochthonous debris flow compared: Early Oligocene carbonate facies patterns of the Lower Inn Valley (Tyrol, Austria). *Facies* 44, 31–46.

Ogorelec B., Šribar L. & Buser S. 1976: On lithology and biostratigraphy of Volče Limestone. *Geologija* 19, 125–151 (in Slovenian with English summary).

Placer L. 1999: Contribution to the macrotectonic subdivision of the border region between Southern Alps and External Dinarides. *Geologija* 41, 223–255.

Placer L. 2008: Principles of the tectonic subdivision of Slovenia. *Geologija* 51, 2, 205–217.

Placer L. & Čar J. 1998: Structure of Mt. Blegoš between the Inner and the Outer Dinarides. *Geologija* 40, 305–323.

Reijmer J.J.G., Ten Kate W.G.H.Z., Sprenger A. & Schlager W. 1991: Calciturbidite composition related to exposure and flooding of a carbonate platform (Triassic, Eastern Alps). *Sedimentology* 38, 1059–1074.

Rožič B. 2005: Stratigraphic evolution of the western part of the Slovenian Basin in the Jurassic. *Geol. Zbornik* 17, 107–111 (in Slovenian).

Rožič B. 2006: Stratigraphy, sedimentology, and geochemistry of Jurassic rocks in the western part of the Slovenian Basin. *Ph. D. Thesis, University of Ljubljana, Faculty of Natural Sciences and Engineering, Department of Geology*, Ljubljana, 1–149 (in Slovenian with English summary).

Rožič B. 2008: Upper Triassic and Lower Jurassic limestones from Mt Kobla in the northern Tolmin Basin: tectonically repeated or continuous succession? *Materials and Geoenvironment* 55, 3, 345–362.

Rožič B. 2009: Perbla and Tolmin formations: revised Toarcian to Tithonian stratigraphy of the Tolmin Basin (NW Slovenia) and regional correlations. *Bull. Soc. Geol. France* 180, 5, 409–423.

Rožič B. & Kolar-Jurkovšek T. 2007: Upper Triassic limestone development of the Slovenian Basin on Mt. Kobla and Mt. Slatnik. *Geol. Zbornik* 19, 96–99 (in Slovenian).

Rožič B. & Popit T. 2006: Resedimented limestones in Middle and Upper Jurassic succession of the Slovenian Basin. *Geologija* 49, 2, 219–234.

Rožič B. & Šmuc A. 2006: Jurassic sedimentary evolution of the transition zone between the Slovenian Basin and the Julian Carbonate Platform (Triglav Lakes Valley and Mt. Kobla). In: Režun B., Eržen U., Petrič M. & Gantar I. (Eds.): Book of abstracts, 2nd Slovenian geological congress. *Idrija Mercury Mine in Closing*, Idrija, 39–40 (in Slovenian).

Rožič B. & Šmuc A. 2009: Initial stages of carbonate platform drowning: a Lower Jurassic example from the easternmost southern Alps (NW Slovenia). In: Pascucci V. & Andreucci S. (Eds.): IAS 2009, 27th Meeting Sedimentary Environments of Mediterranean Island(s), Alghero, Italy. Book of Abstracts. *Editrice Democratica Sarda*, Sassari, 665.

Rožič B., Kolar-Jurkovšek T. & Šmuc A. 2009: Late Triassic sedimentary evolution of Slovenian Basin (eastern Southern Alps): description and correlation of the Slatnik Formation. *Facies* 55, 1, 137–155.

Schlaf J. 1996: Ein obertriadisches Intraplattformbecken aus den Südkarawanken (Kärnten, Östereich). *Mitt. Gesell. Geol. Bergbaustud. Österr.* 39, 40, 1–14.

Schmid S.M., Bernoulli D., Fügenschuh B., Matenco L., Schefer S., Schuster R., Tischler M. & Ustaszewski K. 2008: The Alpine-Carpathian-Dinaric orogenic system: correlation and evolution of tectonic units. *Swiss J. Geosci.* 101, 139–183.

Senowbari-Daryan B. 1980: Fazielle und paläontologische Untersuchungen in oberrhätischen Riffen (Feictenstein- und Gruberriff bei Hintersee, Salzburg, Nördliche Kalkalpen). *Facies* 3, 1–237.

Sibley D.F. & Gregg J.M. 1987: Classification of dolomite rock textures. *J. Sed. Petrology* 57, 6, 967–975.

Stow D.A.V., Reading H.G. & Collinson J.D. 1996: Deep seas. In: Reading H.G. (Ed.): Sedimentary environments: processes, facies and stratigraphy. 3rd ed. *Blackwell Publishing Company*, Malden–Oxford–Carlton, 395–453.

Šmuc A. 2005: Jurassic and Cretaceous stratigraphy and sedimentary evolution of the Julian Alps, NW Slovenia. *ZRC Publishing, ZRC SAZU*, Ljubljana, 1–98.

Šmuc A. & Čar J. 2002: Upper Ladinian to Lower Carnian sedimentary evolution in the Idrija-Cerkno region, western Slovenia. *Facies* 46, 205–216.

Šmuc A. & Rožič B. 2009: Tectonic geomorphology of the Triglav Lakes Valley (easternmost Southern Alps, NW Slovenia). *Geomorphology* 103, 4, 597–604.

Tomašových A. 2004: Microfacies and depositional environment of an Upper Triassic intra-platform carbonate basin: the Fatric Unit of the West Carpathians (Slovakia). *Facies* 50, 77–105.

Tucker M. 2001: Sedimentary petrology. 3rd ed. *Blackwell Science*, Osney Nead, Oxford, 1–262.

Turnšek D. & Buser S. 1991: Norian-Rhaetian coral reef buildups in Bohinj and Rdeči Rob in southern Julian Alps (Slovenia). *Razprave IV. Razreda SAZU* 32, 7, 215–257.

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, 333–360.

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 Science Series, IV, Earth and Environmental Sciences* 61, 151–168.

Watts K.F. 1987: Triassic carbonate submarine fans along the Arabian platform margin, Sumeini Group, Oman. *Sedimentology* 34, 43–71.

Winkler A. 1923: Ueber den Bau der östlichen Südalpen. *Mitt. Österr. Geol. Gesell.* 16, 1–272.

Wurm D. 1982: Mikrofazies, Paläontologie und Palökologie der Dachsteinriffkalke (Nor) des Gosaukammes, Österreich. *Facies* 6, 203–296.