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Composition and importance of Upper Triassic (Upper Ladinian – Lower Carnian) breccia in stratigraphy of External Dinarides

Sestava in pomen zgornje triasnih (zgornje ladinijskih – spodnje karnijskih) breč v stratigrafiji Zunanjih Dinaridov

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Abstract

A sequence of boulder breccia, separated by several emersion horizons is recognized as part of the Upper Ladinian – Lower Carnian Cassian Dolomite and Limestone Formation in the area of Medvedica (central Slovenia). The composition of clasts, determined from thin sections in the context of Late Ladinian – Early Carnian platform models suggests their origin in the transition between the inner platform/lagoon and the back-reef area, alternatively in the internally differentiated lagoon with swells. The emergence of the platform is suggested to correspond to the upper sequence boundary of the Car1 depositional sequence from the Southern Alps. The platform growth subsequently continued until the uppermost Julian, when the second emergence (upper sequence boundary of the Car2 depositional sequence) finally terminated the growth of the Cassian platform.

Key words: Dinaric Carbonate Platform, Southern Alps, »Cordevolian limestone and dolomite«, Cassian platform, sequence stratigraphy

Izvleček

Na območju Medvedice (osrednja Slovenija) smo v zgornje ladinijski – spodnje karnijski formaciji kasijanskega dolomita in apnenca prepoznali zaporedje blokovnih breč, ločenih z več emerzijskimi površinami. Sestava klastov, določena na podlagi zbruskov ob upoštevanju modelov zgornje ladinijskih – spodnje karnijskih karbonatnih platform kaže na sedimentacijo apnenca na prehodu iz notranje platforme/lagune v zagrebensko območje ali na notranje diferencirano lagunsko okolje z lokalnim reliefom. Emerzija platforme bi se lahko skladala z zgornjo sekvenčno meje depozicijske sekvence Car1 Južnih Alp. Rast platforme se je nadaljevala do konca jula, ko je bila dokončno prekinjena z drugo emerzijo, ki ustreza zgornji meji depozicijske sekvence Car2 v Južnih Alpah.

Ključne besede: Dinarska karbonatna platforma, Južne Alpe, »cordevolski apnenec in dolomit«, Cassianska platforma, sekvenčna stratigrafija

Introduction

A substantial amount of the carbonate sequence of the External Dinarides and Southern Alps belongs to carbonate platforms established after the cessation of Ladinian volcanism[1, 2]. Until the Early Julian, up to 600 m of limestone deposited, later mostly transformed to dolomite[2]. In terms of lithostratigraphy, these carbonates are known in the Slovenian literature as the »Cordevolian limestone and dolomite«[3–5] or the Diplopora Limestone[6, 7]. The term Cassian Dolomite and Limestone Formation (CDLF) is used herein (see also[8–12]). The debate about the correct interpretation of age of the CDLF mostly revolved around the correct determination of dasycladacean algae[10, 13].

During geological mapping of a smaller area south-west of Grosuplje (central Slovenia), a sequence of breccia with up to 2 m large boulders was noted inside the CDLF along the newly cut forest road. The scope of this paper is to describe and interpret the origin of breccia.

Previous research of the studied area

The first geological mapping of this area was carried out by M. V. Lipold and G. Stache[14]. Their work, however, remained in the form of a manuscript map[15]. Stache[16] and Vetters[17, 18] later produced less detailed maps. In the scope of geological mapping of Yugoslavia, geological mapping was carried out by Buser and co-workers[19, 20]. The area around Županova jama, east of Medvedica, was re-ambulated in the 1980s. The results were published by Gospodarič[21]; however, the supplemented geological map is too general for the purposes of this study. Buser[22] later gave a short description of the geological structure between Št. Jurij and Velike Lipljene. Especially notable is his mention of Ladinian volcanoclastics in Medvedica. The stratigraphy of the wider area south and east of Grosuplje has recently been investigated by Dozet[3–5, 23–26].

Geological setting

Medvedica is a largely forested low hilly area situated on the SW brink of the Grosuplje karst basin (Fig. 1). According to Placer[27, 28], this area structurally belongs to External Dinarides, during the Triassic and Early Jurassic situated on the southern passive continental margin of the Neotethys (Meliata) Ocean[29, 30]. The evolution of this area was strongly affected by the Middle Triassic extension, and, after cessation of tectonic activity, by a gradual recovery of carbonate production and levelling of topography[31, 32]. The following description of lithological units is based on author's personal observations. Reader may further refer to descriptions by Buser[20, 22] and Dozet[23]. The studied area is situated between two major NW-SE directed faults, namely the Dobrepolje fault to the east and the Ortnek fault to the west (Fig. 2). Numerous minor faults create a complex picture of fault-bound blocks. This, however, is in contrast with interpretation made by Buser[19], showing a generally undisturbed Lower to Upper Triassic succession.

The oldest succession belongs to the Lower Triassic Werfen Formation (Fig. 3). The lower part of the formation is missing, while the rest of it consists of light brown or reddish calcisiltite and dark grey silty marlstone, and medium bedded oolite. Small flakes of mica are

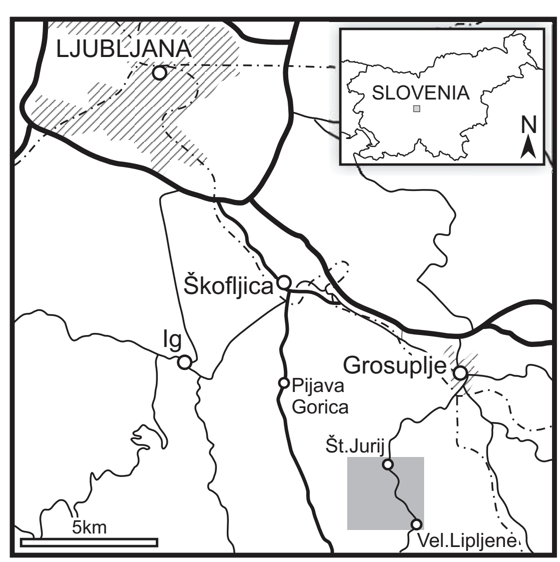

Figure 1: *Position of the studied area. The rectangle represents position of Figure 2.*

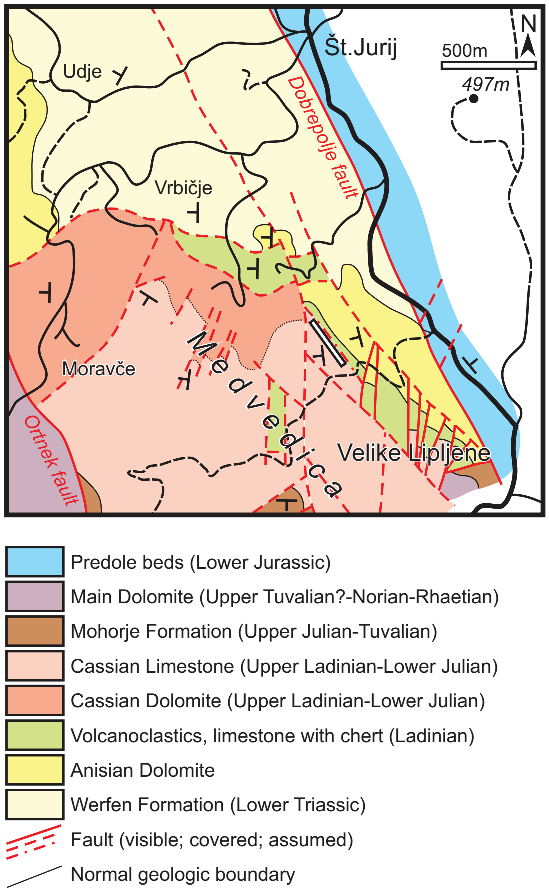

Figure 2: *Geologic map of the studied area. The section with breccia is marked by bar.*

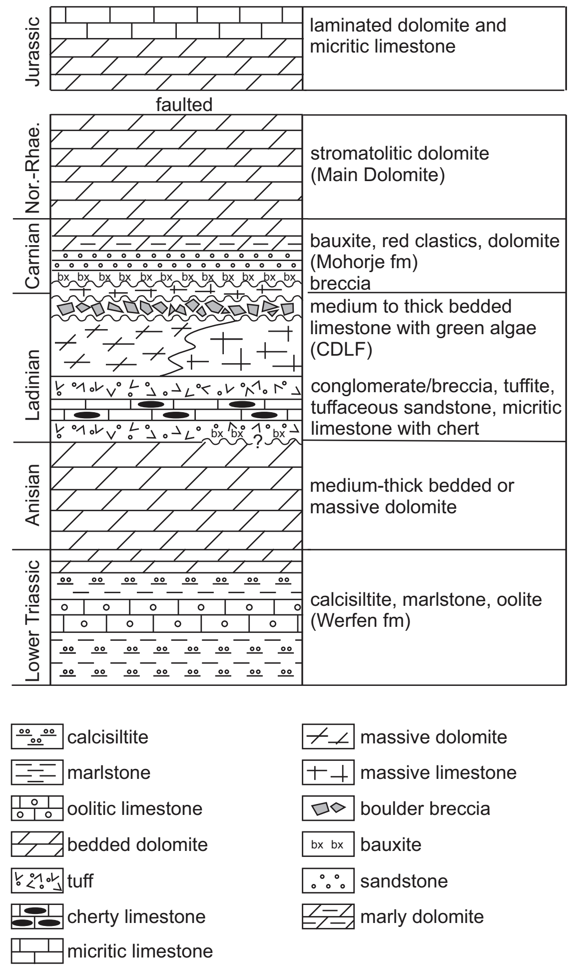

Figure 3: *Schematic lithostratigraphic column for the Medvedica area (not in the scale). Note that the stratigraphic position of the breccia inside the Cassian Dolomite and Limestone Formation (CDLF) is only tentative.*

characteristic. Various bivalves, gastropod *Natiria costata* Munster, ammonite (?*Tirolites* sp.) and ichnogenus *Rhizocorallium* were found. Oolitic limestone may contain numerous small gastropods.

In the upper part of the Werfen Formation, thin to medium bedded dolomite of dusty appearance predominates, gradually passing into medium-thick bedded or seemingly massive coarse dolomite. No attempt has been made to recover microfossils from the latter, and Anisian age is assumed solely on the basis of superposition.

The upper boundary of Anisian dolomite is nowhere preserved, so its continuation into younger units remains interpretative. One assumption is based on a road cut in the area of Medvedica, where an irregular palaeosurface is visible on top of stromatolitic dolomite. The palaeosurface is filled and covered with conglomerate/breccia consisting of dolomitic clasts and limonitic matrix. Poorly exposed greenish tuffite, tuffaceous sandstone, conglomerates, breccias, and black micritic limestone with black chert and claystone partings follow. A silicified ammonite has been found in Medvedica by B. Vičič in 2009, and questionably attributed to the genus *Kellnerites* (L. Krystyn, pers. com. by B. Vičič). According to the Paleobiology Database[33], this genus ranges from Late Anisian to Early Ladinian. Thus, the dolomite below the unconformity is attributed to the upper part of Anisian dolomite, while the following volcanoclastic, clastic and limestone succession represents Lower Ladinian. The local emergence around Anisian-Ladinian boundary has been advocated before by Dozet and Godec[6] in the area of Bloke (southern Slovenia), but the age of the supposed unconformity is not supported by fossils.

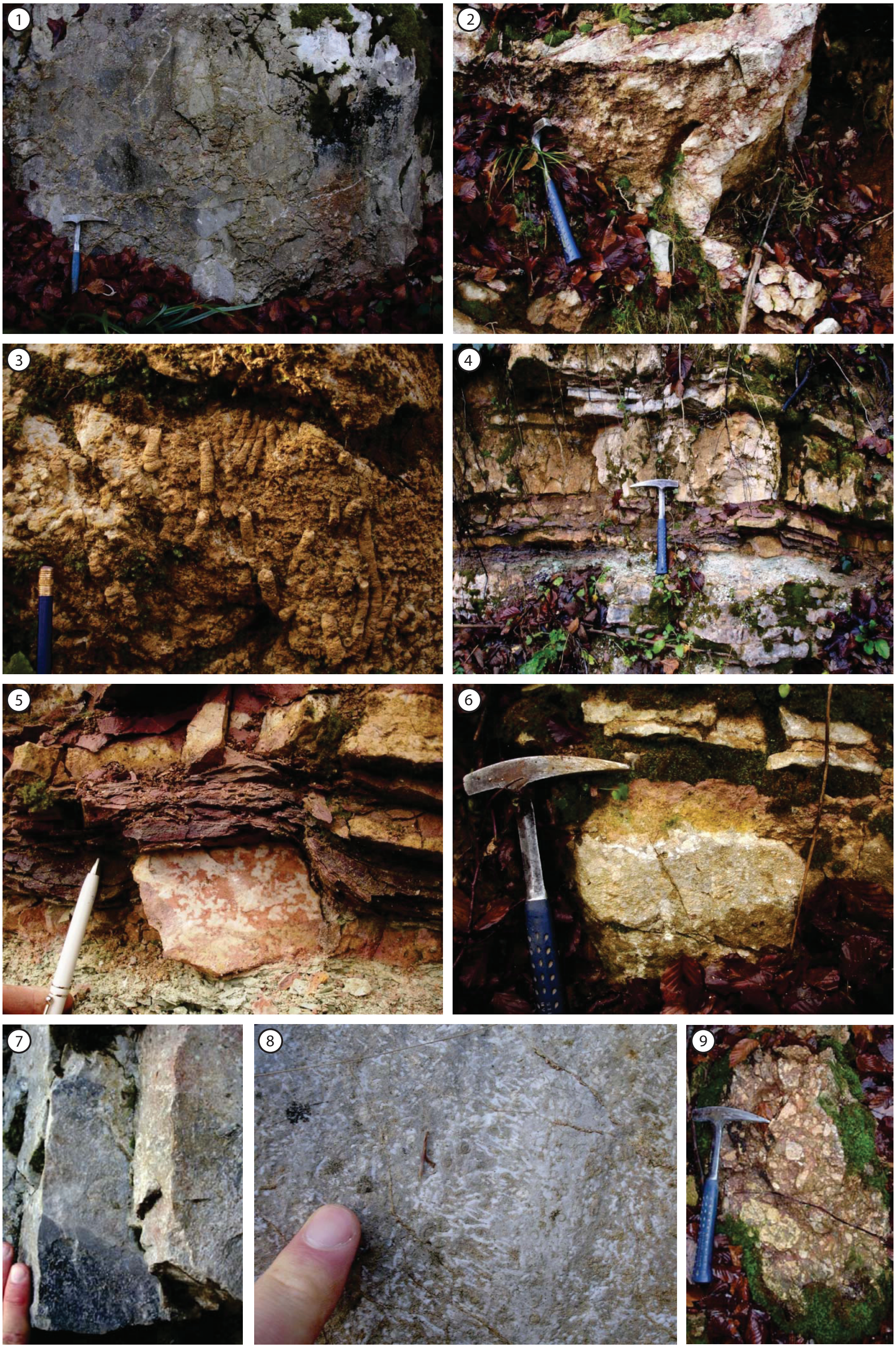

Plate 1: 1 *Poorly sorted boulder breccia.* | **2** *Red surface of brecciated dolomite.* | **3** *Leached-out thalli of dasycladaceans.* | **4** *Red and green mudstone (emersion level).* | **5** *Dolomite clast embedded in mudstone.* | **6** *Emersion on the upper side of calcarenite bed.* | **7** *Interchange of light and dark grey levels with Tubiphytes.* | **8** *Detail from Figure 7.* | **9** *Breccia with bauxite matrix (base of the Mohorje Formation?).*

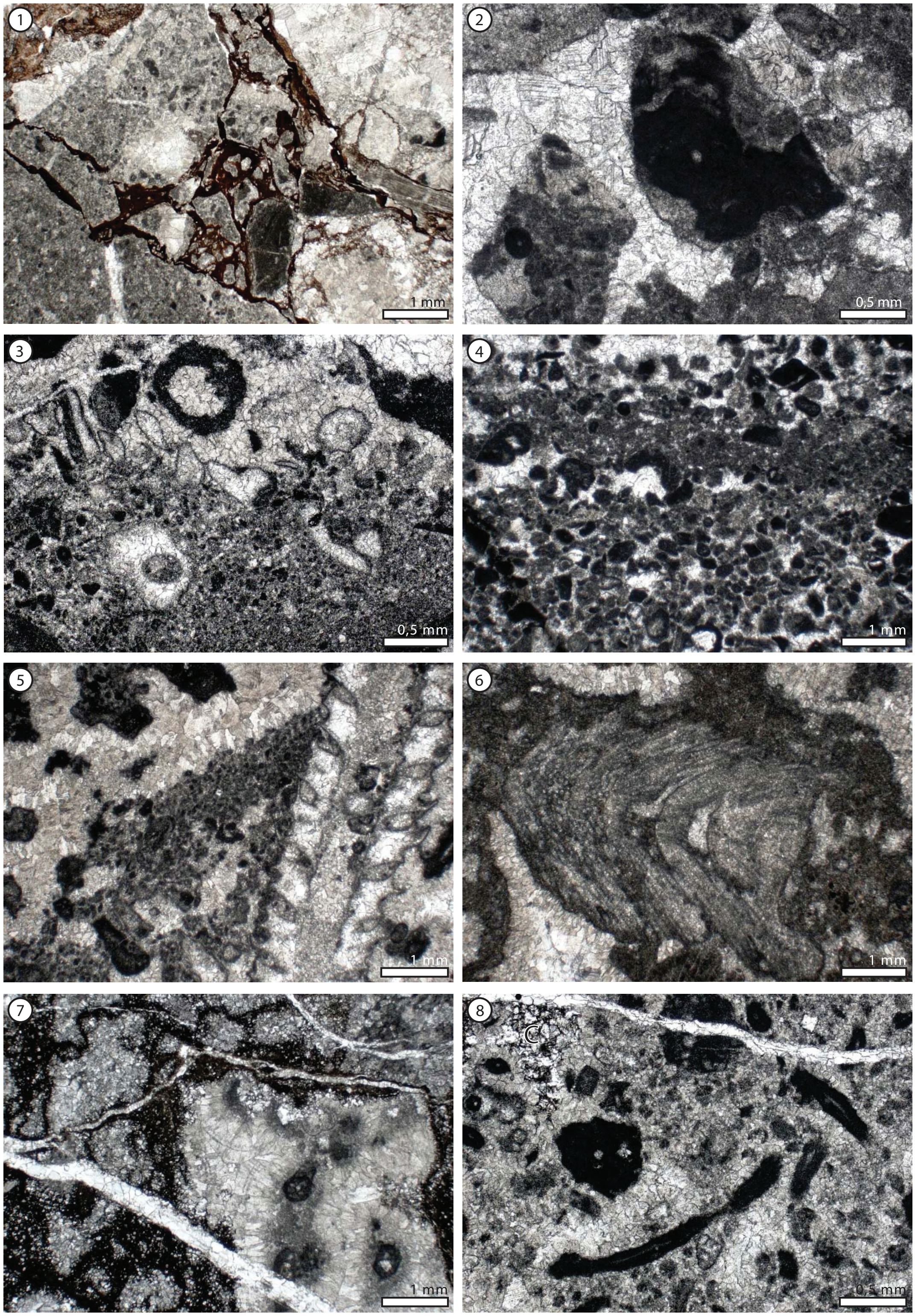

Plate 2: 1 *Fine-grained breccia with reddish »haematitic« matrix. Thin section 207.* | **2** *Angular clasts with Tubiphytes-like micriproblematica. Thin section 207.* | **3** *Recrystallized wackestone passing into bioclastic grainstone. Breccia clast. Thin section 200C.* | **4** *Partly winnowed intraclastic-peloidal packstone. Breccia clast. Thin section 201.* | **5** *Winnowed bioclastic-peloidal packstone with dasycladaceans. Breccia clast. Thin section 202.* | **6** *Dasycladales. Breccia clast. Thin section 208B.* | **7** *Clasts of cementstone with cockades and Tubiphytes in partly dolomitized reddish »haematitic« matrix. Thin section 205.* | **8** *Tubiphytes-like fossils in peloidal grainstone. Note bladed spar encrusting grains and the corrosive cement (C) associated with reddish »haematitic« matrix. Thin section 205.*

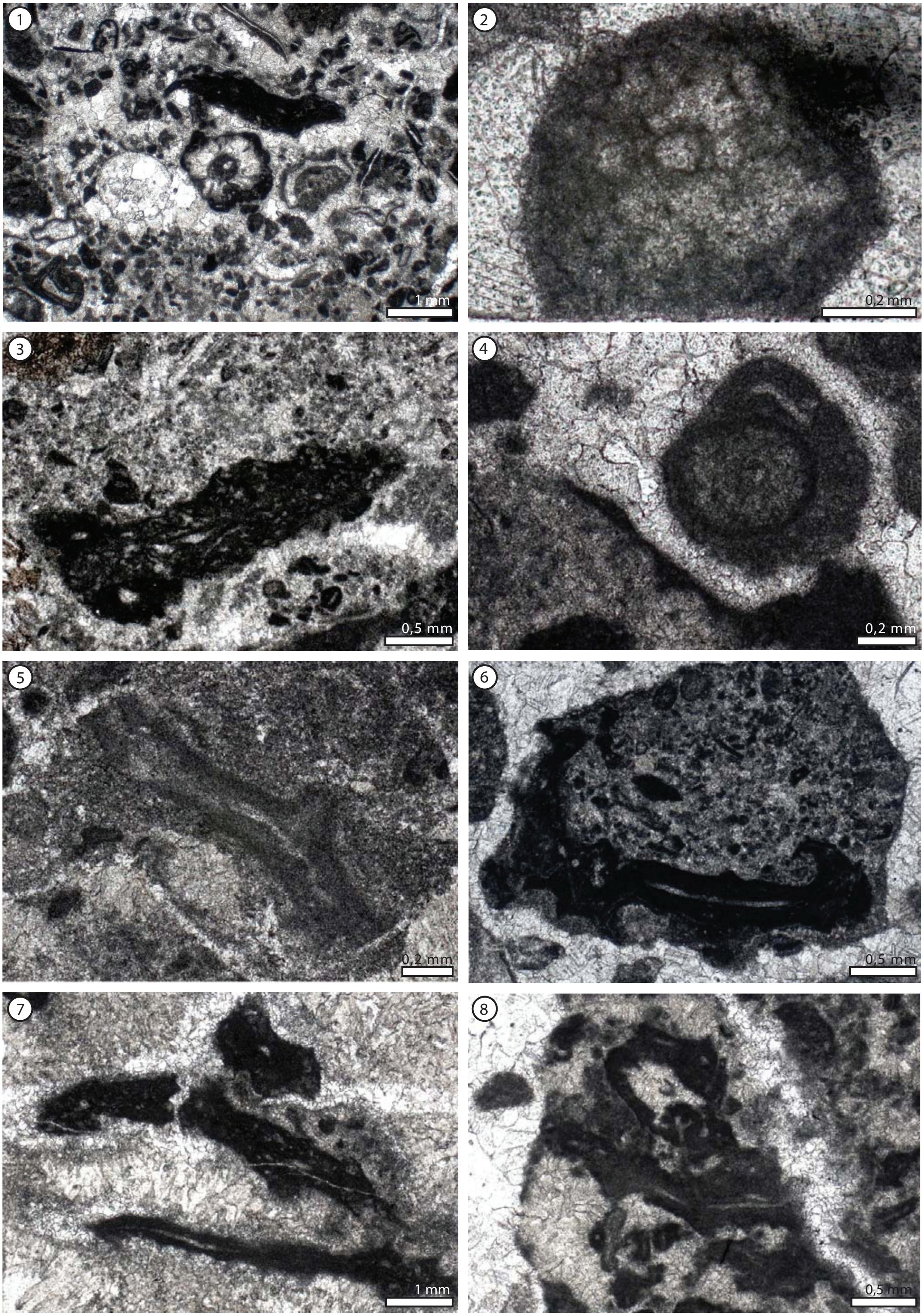

Plate 3: 1 *Recrystallized winnowed bioclastic-peloidal packstone. Thin section 199.* | **2** *Tubiphytes sp. Note the coarse internal network. Thin section 207.* | **3** *Tubiphytes or similar microproblematica. Thin section 211.* | **4** *Tubiphytes sp. Thin section 200A.* | **5** *Tubiphytes sp. Note the internal cavity and the branched habitus. Thin section 207.* | **6** *Tubiphytes sp. in clast. Note the internal cavity and the branched habitus. Thin section 207.* | **7** *Tubiphytes sp. Thin section 208A.* | **8** *Tubiphytes sp. Thin section 207.*

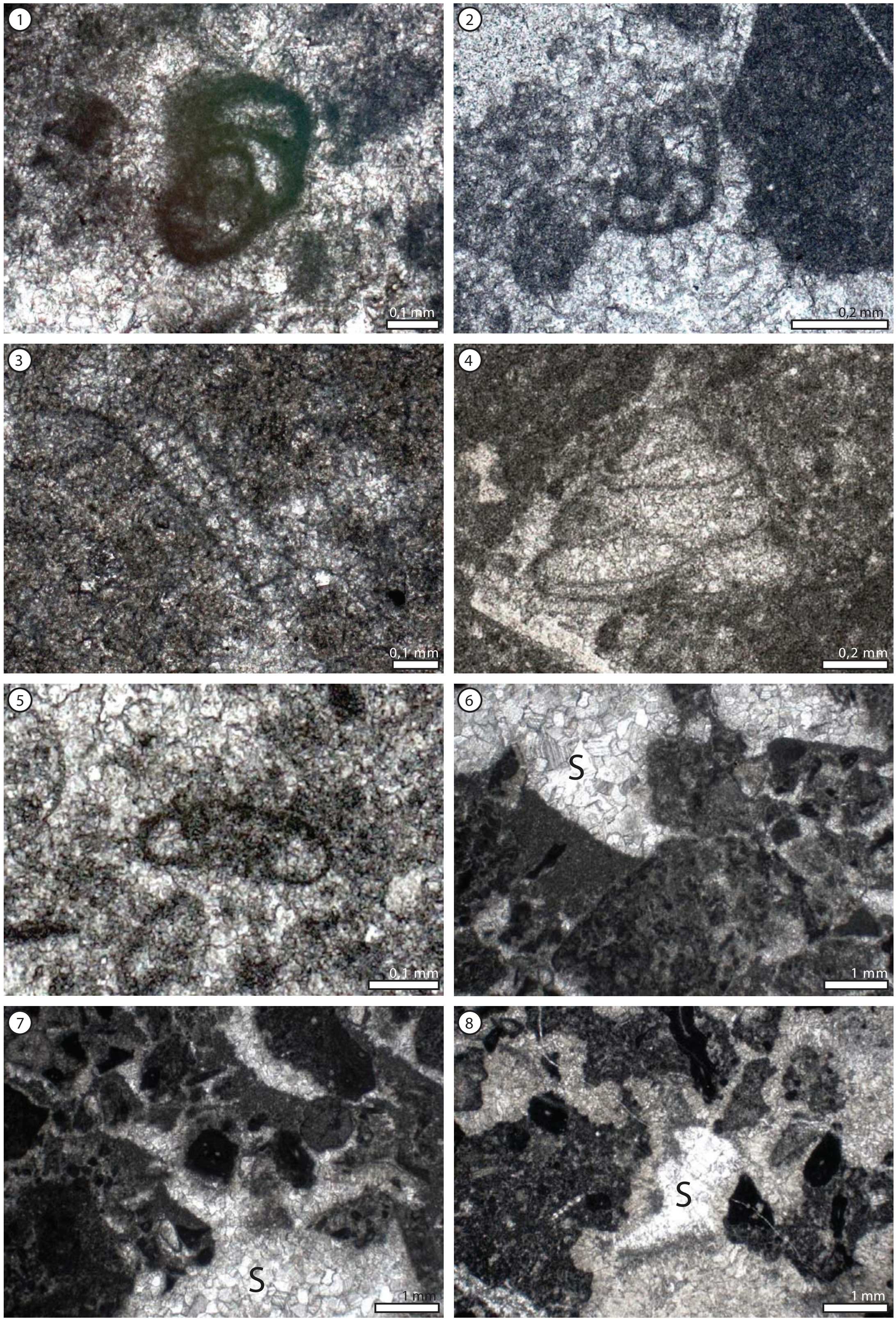

Plate 4: 1 *Endotebanella bicamerata Salaj in Salaj et al. Thin section 204.* | **2** *Endotebanella bicamerata Salaj in Salaj et al. Thin section 200C.* | **3** *Turriglomina mesotriasica (Koehn-Zaninetti). Thin section 208B.* | **4** *Duotaxis sp. Thin section 200C.* | **5** *"Trochammina" jaunensis Brönnimann & Page. Thin section 209.* | **6–7** *Corrosion of matrix and clasts, followed by deposition of clear mosaic spar (S). Thin section 200B.* | **8** *Clear spar (S). Thin section 208A.*

The next lithostratigraphic unit, the Cassian Dolomite and Limestone Formation (CDLF) covers large area, but its lower boundary is faulted. It consists of light gray medium to thick bedded micritic limestone, which frequently contains dasycladaceans and cockade textures. Equally large area is covered by seemingly massive, coarse, very porous white dolomite to the west and south of the studied area (see Buser[19]). The age of the CDLF is a matter of great controversies, fully explained by Celarc[10]. A Late Ladinian and Lower Carnian age is assumed after Pleničar and Premru[34], and Celarc[10].

Along a fresh forest road-cut, a succession of clast-supported boulder breccias, subordinate calcarenites, and green and red claystone is exposed. The breccias consist of up to 1.5 m large blocks of CDLF. The thickness of this succession is at least 15 m, with individual breccia beds at least 9.5 m thick. The breccia can be laterally followed for at least 100 m, and seems to continue with several tens of meters thick CDLF body. The breccia interval, which is here described in detail, was overlooked by previous researchers due to the previous lack of fresh road cut and a strongly karstified surface, which makes the low amount of matrix poorly visible.

The CDLF is overlain by clastics of the Mohorje Formation sensu Dozet[4]. The Mohorje Formation in the surroundings of Medvedica comprises black and red coarse-grained quartz sandstone, red siltstone, black shale, dark brown siltstone, thin-bedded, brown, partly dolomitized and bituminous limestone, red pebbly sandstone with pebbles of lithic grains and quartz, and red and white, cross-laminated lithic-tuffaceous sandstones. Red, rarely also gray, oolitic »bauxite« is common in the lower part of the formation (Pl. 1, Fig. 8). According to division by Dozet[4], these lithologies correspond to the Rupe Member from the middle part of the Mohorje Formation, so a notable stratigraphic gap between the top of the CDLF and the clastics is assumed. No fossils were recovered from the Mohorje Formation during our fieldwork. Julian (i.e., Julian 2)-Tuvalian age was given to formation by Dozet[4]. Transition to the Upper Tuvalian (?) to Norian-Rhaetian Main Dolomite is gradual, marked by medium-bedded dolomite with a decreasing amount of shale partings between beds upsection (see also[4, 8, 12]). This transition, from the uppermost Selo at Rob Member of the Mohorje Formation (bedded dolomite with shale interlayers) to the Main Dolomite (bedded stromatolitic dolomite), is exposed along a steep foot-path east of the studied area, in the vicinity of Pijava Gorica.

The Main Dolomite is distinguished from other dolomitic units by medium to thick bedding and the presence of stromatolites (see[35]).

Finally, the youngest pre-Quarternary rocks belong to Lower Jurassic dolomite and bedded micritic, oolitic and bioclastic limestone, i.e. Predole beds sensu Dozet[4] (also Krka Limestone[36], and Podpeč Limestone[37–39]) .

Materials and methods

The succession of breccias was measured along a forest road at coordinates: 45° 54′ 44″ (lat.), 14° 37′ 23″ (lon.) and elevation 410 m above sea level. Due to several minor faults, the succession could not be reconstructed entirely. To avoid misinterpretation, we present the section in three segments, with no interpretation of succession (Fig. 4). Fourteen thin sections of size 47 mm × 28 mm and one of size 76 mm × 51 mm were made. Dunham[40] classification was followed in describing their texture, and semiquantitative comparison charts[41] used to estimate proportion of individual components.

Description of section

Coarse breccia

The predominant lithology of the measured segments is very poorly sorted coarse breccia, with limestone clasts ranging from less than 1 cm to over 2 m in size (Pl. 1, Figs. 1–2). Bed thickness varies from a few tens of centimetres to over 9 m. Such thick layers may contain hardly discernible irregular internal surfaces. Clasts are very angular or may be subrounded. The amount of matrix is very low. Yellow or reddish »haematitic« matrix is knead among clasts (Pl. 2, Figs. 1, 7), which are in places in stylolitic contacts (stylo-breccia). In other cases, gray spar fills spaces between clasts. Dolomitization obscured a few layers to various degrees, but

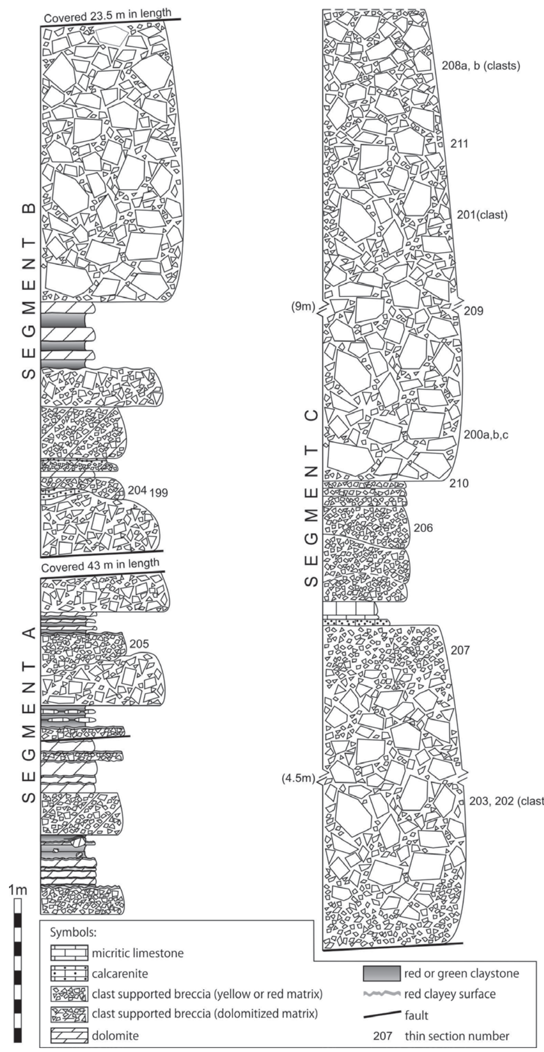

Figure 4: *Geological section of breccia succession.*

composition of clasts can usually be readily observed in thin sections. No fossil remains were found in the matrix of the breccia. In the clasts, the following foraminifera were determined: *Turriglomina mesotriasica* (Koehn-Zaninetti), *»Trochammina« jaunensis* Brönnimann & Page, *Diplotremina placklesiana* Kristan-Tollmann, *Tolypammina* sp., *Reophax* sp., *Endoteba*/*Endotriada* sp., *Duotaxis* sp., and Duostominidae (genus *Krikoumbilica*?).

Clast composition:

— Among clasts, bioclastic-peloidal wackestone, packstone to grainstone with *Tubiphytes* remains is the most common type (Pl. 2, Figs. 2, 8). The matrix is partly winnowed away, and the interstices filled with blocky spar. Peloids and *Tubiphytes* are the most common. Neomorphically altered mollusk shell fragments, echinoderms, foraminifera, green algae, ostracods and brachiopod fragments are subordinate. Thin encrustation by microbiallites is sometimes present.

— In the cementstone, only *Tubiphytes* is recognizable. Specimens are oriented approximately in the same direction, separated by bladed spar. Rarely, peloidal packstone clings to *Tubiphytes*. Cementstone may interchange with bioclastic-peloidal wackestone to packstone with *Tubiphytes* in decimetre-thick layers (Pl. 1, Figs. 7–8).

— Washed-out bioclastic-peloidal wackestone, packstone to grainstone with dasycladacean algae is the next common clast type (Pl. 2, Figs. 5–6). In the field some several centimetres long leached-out bundles of dasycladaceans are visible (Pl. 1, Fig. 3). Dasycladacean thalli are in places partly filled by peloidal packstone, and partly by brownish bladed spar. The intermediate space is filled with intraclastic-peloidal packstone. *Tubiphytes* is common, while benthic foraminifera and fragments of mollusc shells are subordinate. The matrix (%) is rattled by patches of vugs filled with spar and resembling birds' eyes texture.

— The next group of clasts is represented by peloidal and intraclastic partly winnowed packstone to grainstone and fine-grained rudstone (Pl. 2, Figs. 3–4). These two textures may be present in the same clasts, separated by dark, dense, more micritic boundary 1–1.5 mm in thickness, or present individually. In packstone peloids predominate, but a significant proportion is probably of *Tubiphytes* origin. Around 10 % of grains belong to bioclasts other than *Tubiphytes*, such as echinoderms and rare mollusc fragments. In fine-grained breccia, intraclasts with microbialites, microproblematica (*Tubiphytes*), or plain micrite, and peloids predominate. Echinoderms, mollusc fragments and *Tubiphytes* are most notable of rare bioclasts. Dasycladaceans and brachiopod shells are very rare. Few ooids were also noted. Clasts are bound by blocky spar cement. Clear, mosaic spar may also be present as the youngest cement, cutting through older constituents (Pl. 4, Figs. 6–8).

- A special type of clasts is represented by interchanging bioclastic-peloidal wackestone to packstone, and microbialitic bindstone, forming laminated texture. The first type of laminae is similar to already described microfacies types: peloids and intraclasts with *Tubiphytes* predominate over other clasts (*Tubiphytes*, foraminifera, shell fragments, gastropods). Both types of lamina are rattled by vugs (30 % of total area), filled in lower part by calcisiltite and upwards by bioclastic-pelletal packstone, brownish bladed spar and mosaic spar.
- Oncoid rudstone is the next clast type. Other grains besides microbialitic oncoids are *Tubiphytes*, echinoderms and shell fragments.
- Coarse dolospar clasts represent completely dolomitized clasts of variable composition.

Packstone
Subordinate to its coarse-grained variety is packstone to fine-grained rudstone (Pl. 3, Fig. 1). Bed thickness is from 5 cm to 35 cm. Internal bedding and lamination is sometimes present, where massive fine grained and inversely graded horizons interchange. Allochems are represented by peloids, intraclasts (mudstone, pelletal packstone, microbialites), *Tubiphytes*, mollusc fragments, foraminifera (*Endotebanella bicamerata* Salaj in Salaj et al.) (Pl. 4, Figs. 1–2), echinoderms, brachiopod fragments, ostracods, and calcimicrobes. The partly washed-out matrix is recrystallized into microspar.

Fine-grained rudstone
In fine-grained rudstone, reddish »haematitic« matrix is squashed between allochems, or these may be in stylolite contact. Clear blocky spar cross-cuts clasts and matrix. Allochems are mostly intraclasts with microbialites, *Tubiphytes*, fuzzy peloids, and rare bioclasts (echinoderms, rare and questionable sponges).

Calcitulite (mudstone)
Subordinate to other lithological types is dense, gray limestone with horizontal lamination. Bedding is thin, up to 10 cm in thickness.

Dolomite
Coarse dolomite completely replaces limestone in beds of 5–30 cm in thickness. The ghost texture sometimes points at the original breccia, or to horizontally laminated limestone, described above.

Red and green mudstone
Red and light green, up to 10 cm thick beds of mudstone are clearly visible in segments A and B (Pl. 1, Fig. 4). The lower bed boundary may be slightly irregular surface, but this might also be due to differential compaction or dissolution. At least one of these layers contains broken pieces of dolomite, reworked into mudstone (Pl. 1, Fig. 5). The colour of mudstone may change laterally, but it is most often red. More subtle than discrete layers are reddish upper surfaces of other beds (Pl. 1, Fig. 6).

Platform characteristics

Despite its large areal extent[42], the composition of platform carbonates of the CDLF received little attention. Researchers mostly describe macroscopic aspect of dolomite and limestone, without much detailed sedimentological investigation. Platform carbonates are usually dolomitised, and the primary composition is thus strongly obscured. The majority of information regarding composition of Late Ladinian-Early Carnian platforms in the Dolomites area thus derives from the study of isolated, mostly gravity-displaced blocks (cipits) of the platform rim and slope, which were sealed from dolomitizing fluids by the enclosing basinal marls[43–48]. Among these, blocks exhibiting boundstone facies received considerably more attention than other facies types, which might potentially give a better glimpse on the platform interior. In the platform-to-basin transect, Biddle[44] successively shows (from the interior towards basin) subtidal lagoon and dasycladacean meadows, intertidal sand shoals, algae dominated reef flat, organically bound submarine-cemented reef complex, fore reef breccias and muds, and finally a basin plain. Reijmer[49] lists a similar succession of depositional environments: in the inner platform area, dasycladaceans dominate over calcimicrobes, peloids, foraminifera, and micrite lumps; the back reef area is characterized by algal-foraminiferal and sponge-coral patch reefs; the reef margin with abundant *Tubiphytes*, other microproblematica, peloids and »evinosponges«, and the transition to the upper slope with encrusting sponges, corals, peloids and diverse skeletal grains (including dasycladaceans, gastropods, and *Tubiphytes*) follow. Reijmer[49], however, focused his attention on composition of fine-grained slope/basin resediments, with grains of predominantly margin and slope origin. A more detailed analysis of the platform top itself is given by Seeling et al.[50] on the example of Concarena buildup. In the lagoon area, Seeling et al.[50] describe a regular alternation of peritidal carbonate cycles. *Tubiphytes* framestone and early marine cementation were found characteristic for transition from the lagoon to the back reef area. A monotonous cyclic sedimentation of subtidal, peritidal and supratidal carbonate was noted also by Trombetta[48] and Keim and Schlager[51]. Missoni et al.[52] recently investigated Wetterstein-type carbonate platform in Serbia. They could not recognize the platform top, but they do mention abundance of *Tubiphytes* in Ladinian to Lower Carnian platform carbonates. According to Bole[53] the Wetterstein Limestone and Dolomite of the Peca massive deposited in back-reef and reef setting. The former contains intraclastic-bioclastic, and intraclastic-bioclastic-peloidal wackestone and packstone, as well as limestone and dolomite with stromatolites. Among bioclasts, codiaceans are the most common, followed by bivalve fragments, foraminifera and echinoderms. The reef carbonate is built by corals, sponges and also microproblematica. Oncoids are present in almost all facies. In Ladinian-Carnian reef of Calabrian Apennines, Boni et al.[54] distinguished between the reefal boundstone facies with sphinctozoan sponges, biogenic crusts, *Tubiphytes*, other microproblematica and rare corals, the fore-reef debris rudstone facies, and the dasycladacean packstone-grainstone back-reef facies. According to Boni et al.[54], this reef association is similar to the Wetterstein limestone of the Northern Calcareous Alps. The importance of microproblematica at the Wetterstein platform edge was also noted by Brandner and Resch[55], Flügel[56], Henrich[57], and Dullo and Lein[58]. *Tubiphytes* and other microproblematica, however, are associated with sphinctozoan sponges and corals, none of which were found in Medvedica.

To finally summarise, for the time-equivalent platforms a cyclic peritidal sedimentation is characteristic for the innermost platform. No such clasts were found in the Medvedica breccia. The wackestone/packstone with dasycladaceans microfacies type fits well into the inner platform/lagoon area, while the enrichment with *Tubiphytes* probably better corresponds to a slightly more outer position, closer to the reef margin in the Cassian Dolomite model. Oncoid rudstone and more grainy varieties may be placed even slightly more towards higher-energy environment of the back-reef area. Taking the predominance of dasycladacean and *Tubiphytes* rich clasts into account, sedimentation is considered to take place in the transitional zone between the lagoon and the back-reef area or, alternatively, in the internally differentiated lagoon with swells.

Stratigraphic position and genesis of breccia

As already noted, the stratigraphic position of the breccia succession remains dubious due to coverage. The lower boundary is currently interpreted as fault-bound, while the succession seems to continue with the unbreciated CDLF (Fig. 2). The lithology itself gives little opportunity for a more precise determination of age, rather than on the basis of superposition. The only foraminifera found within the matrix in Medvedica is *E. bicamerata*, with stratigraphic range from Anisian[59] to Norian[60, 61] or even Rhaetian[62]. *Endotebanella bicamerata* is the usual element of Middle Triassic assemblages present within clasts[63], so the assemblage within breccia clasts is not markedly different (that is within stratigraphic resolution offered by foraminifera at the time), despite the fact that truncation of calcite veins at the edges of clasts suggests a complete lithification of limestone and their tectonic deformation prior to brecciation. *Turriglomina mesotriasica*, restricted to Anisian and Ladinian[63], provides a pre-Carnian (at most Lower Julian) age of CDLF. Unfortunatelly, we did not try to determine dasycladaceans. The uppermost boundary of the entire CDLF is represented by clastics, variously named as Borovnica beds[11, 32, 64], Grosuplje-Orle beds[23], Raibl beds[8, 9, 12, 65], Zaplaz Formation[3], or as Mohorje Formation[4]. Bivalves found in the lower part of these beds include *Lopha montiscaprilis* (Klipstein) (*Umbrostrea*? *montiscaprilis* in Szente et al.[66]), indicative for the uppermost Julian[67]. The measured succession may thus be very conservatively placed between the uppermost Ladinian and the uppermost Julian.

Poor sorting, angularity of clasts, and small amount of matrix point at short transport of clasts. Green and red mudstone point at subaerial exposure. Mudstone seems to correspond to residual clay in Durn et al.[68]. The breccia can be thus interpreted as emersion breccia[69, 70], or as dissolution breccia accumulated on subaerially exposed surface[68]. The repeated occurrence of emersion levels (residual clay) on upper bedding planes, as well as rare intercalations of micritic and calcarenitic beds, however, point at oscillating, rather than a single drop of sea level, and the lack of bauxite deposits similarly discredit a longer-lasting emergence. Foraminifera, found in calcarenite, thus point at intervals of re-flooding of the surface.

An example of megabreccia, formed concordantly on platform top, has been reported by Gianolla et al.[71]. According to Spence and Tucker[72], megabreccia may form on the platform-top during subaerial emergence due to the increase in stress on the sediment as the interstitial pore-water drains from the system. However, this example was set for the unlithified sediment, while clasts composing breccias in Medvedica show marks of complete lithification of limestone before brecciation. An explanation for this may be found in very early lithification of Ladinian – earliest Carnian platform carbonates, largely governed by microbes[47, 50, 73, 74]. The third model for formation of megabreccias may be cliff erosion[75]. This model, however, requires tectonic activity, which would create steep relief.

The importance of emersion surfaces for correlations

Emergence horizons are a valuable marker as they allow precise subdivision and dating of similarly looking dolomitized platform carbonates which would otherwise prove to be impossible to distinguish[71, 76]. Moreover, as emergence often results from eustatic sea-level drop, it may become possible to correlate lithostratigraphic units on at least regional scale[71]. Despite the lack of relative sea level curves in the northern External Dinarides, to which the Medvedica area belongs, we may resort to the sequence stratigraphy set for the Southern Alps area. According to Gianolla et al.[71] and De Zanche et al.[76], the time frame from Late Ladinian to end-of-Julian in the Southern Alps comprises four sequence stratigraphic cycles, with systems boundaries marked on the platforms by emersions. The Car1 depositional sequence (Late Langobardian to Early Julian) represents a time-frame for deposition of the Cassian Dolomite 1 platform carbonates. Its upper sequence boundary separates the Cassian Dolomite 1 from the Cassian Dolomite 2[76]. The next sequence, Car2, comprises the entire Cassian Dolomite 2 platform, ranging in age from Early Julian to the latest Julian. At the end of this sequence, the intraplatform basins were partly levelled-out due to a high export of carbonate from the platform. The following sequence, Car3, lasting until the Early Tuvalian, saw the final filling of the remaining intrabasinal space. During this time, shallow-water siliciclastic-carbonate sediments of the Dürrenstein Formation (sensu De Zanche et al.[76]) deposited. The lower system boundary is marked by erosion and carstification of the Cassian Dolomite 2 platform, while the upper one represents an erosional surface separating peritidal dolomite of the uppermost Dürrenstein Formation from the overlying clastics of the Raibl Formation (Car4) sensu De Zanche et al.[76].

Within the given time frame, the observed breccia level most likely correlates with the upper sequence boundary of the Car1 depositional sequence. This interpretation would be supported by the overlying CDLF in the same tectonic block. In should be mentioned, however, that the changes in relative sea level depend not only on the eustasy, but are also under the influence of local tectonics[77]. Emergence of shallow platform may thus also result from the interplay of factors operating on a much more narrow area.

Towards the sequence stratigraphic framework

Breccias of similar composition to the one described in this paper, but located on top of the CDLF, were described by Dozet and Godec[5], Ramovš[8], Buser[9], Dozet[11, 23, 79], Pleničar[78], and Jelen[80]. Like the Medvedica breccia, these consist of angular, often very large clasts of CDLF in reddish matrix, but they differ in lacking intermediate autochthonous carbonates and are overlain by fine-grained clastics. They are often described as being positioned above the erosional surface on top of the CDLF and associated with bauxite, so they too represent emergence horizons (see[23]). Despite the lack of fossil evidence form the breccia matrix itself, they are considered as lowermost Julian 2 to Tuvalian in age[5, 9].

In our opinion, this breccia on top of the CDLF marks the second and final emergence of the CDLF platform and correlates with the upper sequence boundary of the Car2 (the lower boundary of the Car3) depositional sequence of the uppermost Julian. Alternatively, it could be positioned at the lower sequence boundary of the Car4 depositional sequence[71, 76]. In the first case, the emergence lasted through the entire Car3 sequence, which is thus completely missing, through the lowstand systems tract of the Car4 depositional sequence, and perhaps also through part of its transgressive systems tract. This emergence phase is thus sufficiently long to allow for the formation of bauxite (see[13]). Alternatively, considering option of correlation with the lower boundary of the Car4 sequence, part of the older sequences may be eroded. However, the latter option does not allow for a time gap necessary for formation of bauxite, formation of which also requires humid and warm climate conditions[81], which became established soon or at the platform demise[82, 83].

Correlation of the emergence level on top of the CDLF platform in the northern External Dolomites with the Southern Alps is much more reliable as the Car1 sequence boundary, as it marks the sea-level drop of the second order, a regionally much more widespread event[84, 85]. For example, the cessation of platform growth and karstification in Julian is correlatable in the Northern Calcareous Alps, in the Carpathians and also in Serbia[52].

Concluding remarks

In the area of Medvedica (central Slovenia, External Dinarides), a succession of breccia beds separated by medium-thick limestone or dolomite and mudstone beds was investigated. Breccia consists of clasts belonging to Cassian Dolomite and Limestone Formation. Its lower boundary is presumably faulted, while it continues upwards into the Cassian Dolomite and Limestone Formation. Mudstone beds and weathered bed surfaces point at subaerial exposure. The breccia is thus interpreted as emersion breccia[69, 70], or as dissolution breccia accumulated on subaerially exposed surface[68]. The emergence of platform top is correlated with the upper sequence boundary of the Southern Alps' Car1 depositional sequence of Late Ladinian age[71, 76]. The emergence, however, could also result from local tectonics[77].

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