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The Carnian-Norian basin-platform system of the Martuljek Mountain Group (Julian Alps, Slovenia): progradation of the Dachstein carbonate platform

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Abstract: In the Martuljek Mountain Group (MMG), positioned in the northern part of the Julian Alps (NW Slovenia), a widespread drowning of the middle Carnian carbonate platform is marked by the onset of a thin (approximately 25 m) horizon of reddish pelagic platy basinal limestones (Martuljek platy limestone). According to conodont data, different ages of the upper part of the Martuljek platy limestone are documented, namely late Carnian in the SW and early Norian in the NE part of the MMG. The rimmed Dachstein carbonate platform progrades into the basin with typically developed facies zones: slope and reef margin (approximately 300 m thick) with abundant coral fauna with other framebuilders and the Lofer cyclic Dachstein Limestone in the backreef peritidal area. In the NW face of the Mt Škrlatica, platform to the basin transition is spectacularly exposed. The interfingering of slope to basin sediments and the dip of the clinostratification, indicate SW to NE progradation of the Dachstein platform (in recent orientation), which is also in accordance with conodont data estimation of the underlying Martuljek platy limestones. The margin of the Dachstein platform in the MMG is thus progressively younger from the SW direction to the NE. After (and during) the filling of the basin, the peritidal carbonate platform, with a more than 1 km thick succession of the Dachstein Limestone prevailed until the end of the Triassic Period in the central part of the Julian Alps. The Carnian drowning event in the Julian Alps and also in the Kamnik–Savinja Alps is not just a locally limited phenomenon, as described so far, but a widespread event, triggering the growth of the Tuvalian–Norian reefs, facing more open marine areas.

Key words: Late Triassic, Slovenia, Julian Alps, carbonate platform progradation, facies analysis, conodonts.

Introduction

According to paleogeographical studies, the Slovenian part of the Julian Alps formed an isolated platform between the Slovenian Basin and the Hallstatt-Meliata Ocean (e.g. Haas et al. 1995; Ziegler & Stampfli 2001; Stampfli & Borel 2002). A distinct transgression pulse, recognized above the former Ladinian–Carnian platforms or Raibl Group, deepening, formation of the basin(s) and progradation of the rimmed Main Dolomite or Dachstein Limestone platforms, was recognized in the Julian Alps (Lieberman 1978; Ramovš 1986a,b, 1987; Jurkovšek 1987a,b; Schlaf et al. 1997a,b; De Zanche et al. 2000; Gianolla et al. 2003). In the Slovenian Basin and in the western part of the Pokljuka Plateau, basinal sedimentation persisted through the Norian and Rhaetian (Kolar-Jurkovšek et al. 1983; Buser 1989; Buser et al. 2007) with coeval reef development (Turnšek & Buser 1989). In the nearby Karavanke Mountains, however, the stratigraphic development of the Norian strata differs strongly. In the Košuta Unit, Dachstein Limestone is developed in the Norian (Kolar-Jurkovšek et al. 2005), while basinal sedimentation persisted through the Liassic in the Hahnkogel area (Krystyn et al. 1994; Schlaf 1996). The Tuvalian deepening event and stratigraphically very similar developments are also recognized in the Kamnik–Savinja Alps around 50 km to the east (Ramovš 1989; Jamnik & Ramovš 1993).

The progradation geometry of the Upper Triassic Carnian–Norian carbonate platform in the Julian Alps (Slovenia) is often difficult to study because of the strong Alpine tectonics and hence rarely preserved stratigraphic successions (in the direction of the platform progradation, that is perpendicular to the clinostratification). Transitions from basinal to platform sediments often coincide with important detachment horizons. An excellent seismic scale section was described by Gianolla et al. (2003) in the Portella (near Cave del Predil) close to the Italian-Slovenian border with the progradation of the Main Dolomite platform in the SSW–NNE direction. In the Martuljek Mountain Group (MMG), another tectonically relatively undisturbed basin to platform transition (also considerably laterally extended) is discussed in this paper.

Before the pioneering study of Ramovš (1986a), little was known about the upper Carnian–lower Norian basinal sediments in the northern part of the Julian Alps. The Tuvalian pelagic, red, platy, ammonoid rich limestones of the Hallstatt facies were described in the Mt Razor and Mt Planja area, as part of the Kriški podi Plateau, SW of the MMG (Ramovš 1987; Sattler 1998) and on top of the Mt Kukova špica (Ramovš 1986a) in the NE part of the MMG. These studies were spatially confined, and the extension of the basinal sediments between the aforementioned areas (the central part of the MMG) was unknown until recently (Celarc 2006; Celarc & Ogorelec 2006). The Norian-Rhaetian reef limestones are much better studied (Turnšek & Ramovš 1987; Ramovš & Turnšek 1991).

The main goal of the present paper is to describe the architecture of the facies belts of the prograding platform, based on

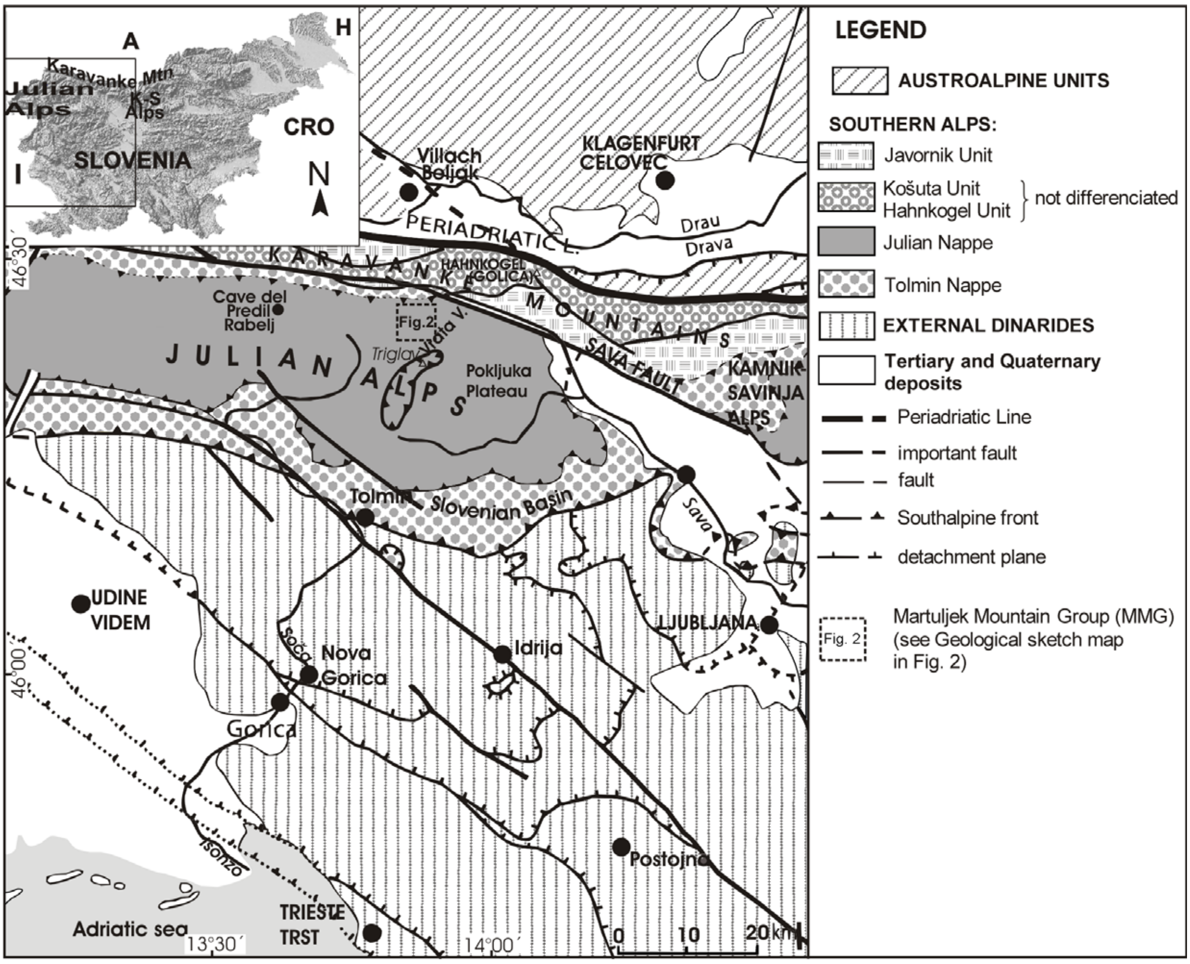

Fig. 1. Location (rectangle) of the research area (Martuljek Mountain Group, Julian Alps, Slovenia). Tectonic units after Placer (1999).

the detailed mapping and conodont analysis of the basinal platy limestones. We introduced a new (informal) name for this lithological unit as the Martuljek platy limestone. Besides determining the direction of progradation, we estimated sedimentation rates (filling of the basin) and the dynamics of the platform's growth.

Geological background and location

The study area belongs to the Julian Alps (NW Slovenia) (Fig. 1), which along with the eastern lying Kamnik–Savinja Alps, forms the so-called Julian Nappe. Along with the southerly positioned Tolmin Nappe it represents the easternmost continuation of the Southern Alps (Placer 1999; Haas et al. 2000) extended from NE Italy. On their north side part the Julian Alps are separated from the South Karavanke Mountains by the dextral strike slip Sava fault. Paleogeographically, the Julian Nappe in the Upper Triassic belonged to the relatively uniform Julian Carbonate Platform, bound to the south with the deeper Slovenian Basin (Buser 1989). In the Norian, the Julian Alps were located on the passive margin of the southern shelf of the Hallstatt-Meliata branch of the Neo-Tethys (Haas et al. 1995; Ziegler & Stampfli 2001). During the Late Triassic, a different paleogeographical environments were formed. In the western (Italian part), the terrigenous influenced Raibl Group filled previous basins in the Julian and early Tuvalian (Gianolla et al. 2003; Preto et al. 2005). In the eastern (Slovenian) part of the Julian Alps, reefs and platform sedimentation persisted continuously from the late Ladinian to the beginning of the Tuvalian periods (Ramovš & Turnšek 1984; Jurkovšek 1987b).

The MMG is geographically positioned in the Northern Julian Alps, bordered to the north by the Upper Sava Valley, to the east by the Vrata Valley, to the south by the Kriški podi Plateau and to the west by the Pišnica and Krnica Valleys. The researched area is bounded by the north vergent Tamar backthrust, and NE–SW directed strike-slip faults in the west and east, respectively. The studied area thus belongs to a relatively subsided tectonic block, internally slightly deformed, with strata generally dipping gently to the south (Fig. 2).

Stratigraphy

Since there are no officially accepted names for formations, we use informal names taken from various works of previous

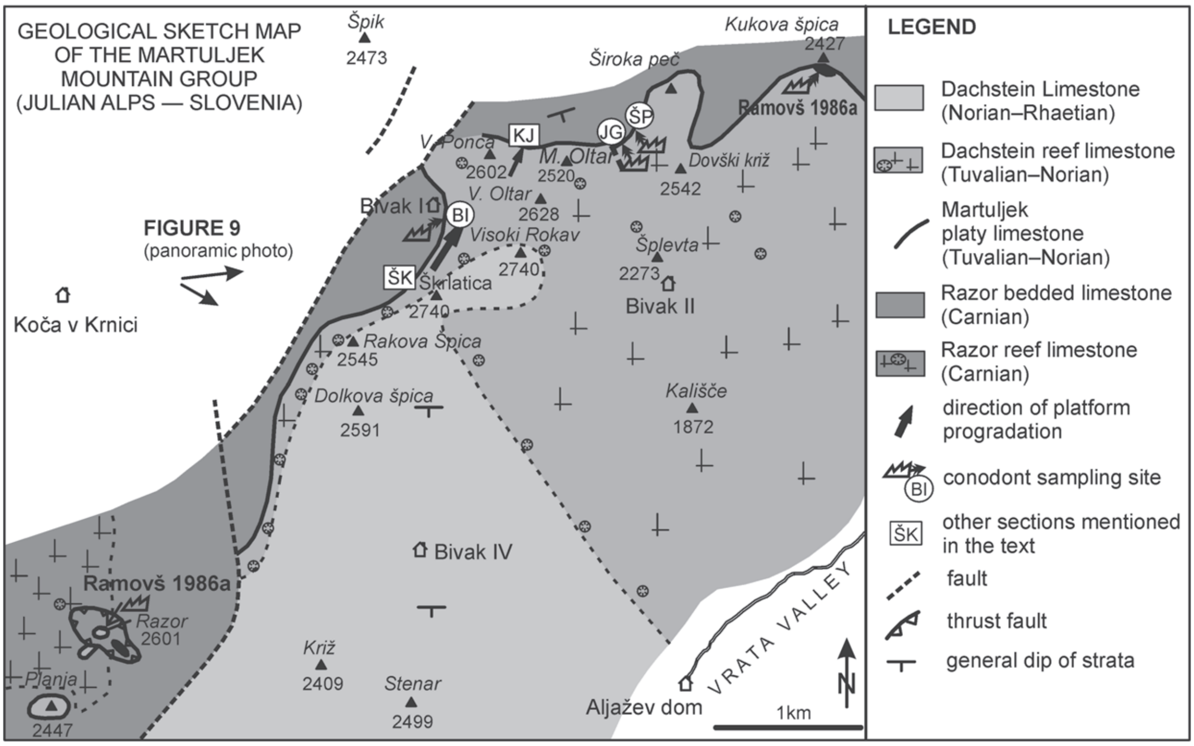

Fig. 2. Geological sketch map of the Martuljek Mountain Group. For location see Fig. 1.

authors. The geological succession is composed from bottom to top as (Fig. 3):

1) Razor limestone (lower Carnian) as proposed by Ramovš (1987), consisting of cyclic bedded limestones and massive reef limestones;

2) Martuljek platy limestone (upper Tuvalian — Ramovš (1986a); upper Tuvalian–lower Norian in this paper), consisting of reddish, platy pelagic limestones;

3) Dachstein reef limestone (upper Tuvalian–lower Norian), consisting of hard-to-distinguish slope and reef margin facies;

4) Dachstein Limestone (Norian–Rhaetian), consisting of cyclic bedded limestones (Jurkovšek 1987a,b).

Razor limestone (lower Carnian)

Ramovš (1987) described a new calcareous formation and named it Razor (after Mt Razor) limestone, forming a footwall below the thin horizon of the Hallstatt type Tuvalian platy limestone (Martuljek platy limestone in this article). He distinguished between two lithologic types of Razor limestone:

— Thick-bedded grey to brownish micritic limestone with transition to trombolitic, oncoidic and pseudooncoidic limestones (bedded peritidal Razor limestone);

— Biolithic reef limestone, with small patch reefs. Corallites are overgrown with spongiostromata crusts. *Margarosmilia* sp. is abundant, together with sponge *Ceotinella mirunae* and *Uvanella* sp. There are many patch reefs with corals of Retiophyllia type and bioclastic reef detritus between mounds (Razor reef limestone).

The age of the limestones is not entirely clear. According to Ramovš (1987) the reef limestone is similar to the Carnian Tisovec Limestone from the Western Carpathians (Kollarova-Andrusova 1960) and is probably early Carnian.

In the MMG only bedded peritidal Razor limestone is present. The maximum thickness is around 400 m (Mt Široka peč). Under Mt Mali Oltar and Mt Velika Ponca it reaches around 100–200 m and passes downwards into massive dolomites. The bedded Razor limestone is in tectonic contact with Middle Triassic limestones west of Mt Škrlatica, Mt Rakova špica and Mt Rogljica.

The bedded peritidal Razor limestone is organized into 1–1.5 m thick, predominantly shallowing upward asymmetric cycles (Fig. 4.1).

Subtidal deposits are characterized by thick-bedded packstone and grainstone with variable amounts of pellets, peloids, oncoids and intraclasts. Skeletal grains are composed of green algae and foraminifers. Shallower subtidal facies are represented by abundant oncoidal horizons with a maximum thickness of 20 cm (Fig. 4.2). The origin of oncoids is probably associated with a slightly more agitated environment, with tidal channels in which tidal currents enabled constant movement and their concentric growth.

Intertidal-supratidal facies are recognizable by laminated grainstones, which are often dolomitized, and with horizontal microbial laminites. Fenestral pores (loferites) are very common in these horizons. They are often developed as microbial boundstones, forming typical bedding parallel cracks and birdseye pores (Fig. 4.3) Desiccation structures could also be found in the wackestone–packstone facies (Fig. 4.4) and in the upper parts of the oncoidal horizons (Fig. 4.5). Tepee stuctures are also abundant, represented as low relief antiforms (Fig. 4.6). Cavities of the tepee walls are filled with laminated,

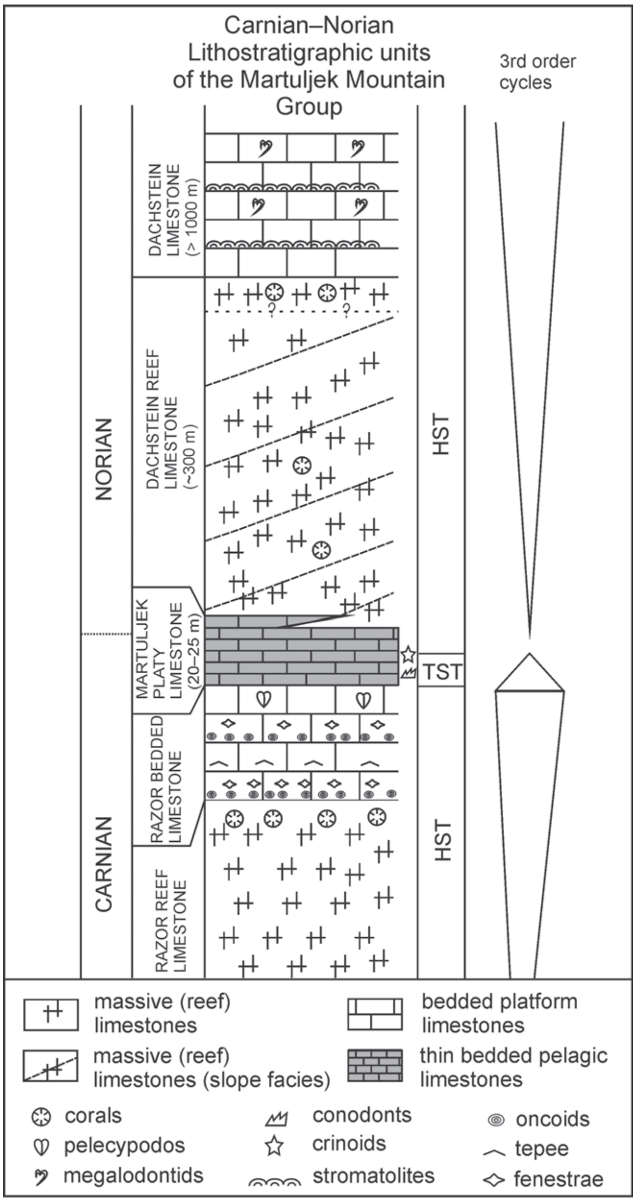

Fig. 3. Schematic late Julian–early Norian stratigraphy in the Martuljek Mountain Group.

often reddish calcite crusts. Flat lying rip up clasts up to 20 cm long and 5 cm thick occur in distinct horizons. They are interpreted as tempestites. The groundmass consists of the carbonate matrix.

Exposure surfaces are found at the top of some (rare) subtidal and intertidal–supratidal deposits. These intervals are usually very thin (up to 10 cm) with an uneven disconformity surface, overlain with matrix supported breccia with clasts eroded from underlying shallow-subtidal and intertidal supratidal limestones. These breccias suggest a short lived interruption in deposition. The matrix is usually yellow silt and residual carbonate clay. Angular to subangular black pebbles are common constituents in the breccia horizons and they are also scattered in the lower part of the subsequent subtidal horizon.

Martuljek platy limestone (upper Tuvalian–lower Norian)

The reddish, platy, pelagic upper Tuvalian limestones were described by Ramovš (1986a, 1987) in the areas of Mt Razor, Mt Planja (Kriški podi Plateau), Mt Kukova špica (MMG), Kozja Dnina, Mlinarica and Macesnovec (Mt Triglav area). Tuvalian platy limestones from the latter three locations are shown in the Basic Geological Map of Slovenia (Jurkovšek 1987a), and biostratigraphic study of these strata documented the conodont faunas of the *polygnathiformis* and *nodosa* Zones (Jurkovšek et al. 1984; Kolar-Jurkovšek 1991). Based on findings of the ammonites *Projuvavites jaworskii*, *Discotropites plinii*, and conodonts *Epigondolella nodosa* and *Neogondolella polygnathiformis* on Mt Razor, Ramovš (1986a) assigned this horizon to the upper Tuvalian, *Anatropites* Zone — the *plinii* subzone, and according to their lithological similarity compared these limestones to the Hallstatt Limestones of the Northern Calcareous Alps.

In the MMG, except on Mt Kukova špica, the red pelagic platy limestones of the Hallstatt type were mapped and described for the first time. On the summit of Mt Kukova špica only their lower part is preserved as an erosional remnant. On the basis of conodonts and ammonites, Ramovš (1986a) assigned the limestones from Mt Kukova špica to the upper Tuvalian, *Anatropites* Zone.

As this horizon does not have any formation name, we refer to it as the Martuljek platy limestone. The Martuljek platy limestone extends from the northeastern face of Mt Rogljica, Mt Rakova špica and Mt Škrlatica, the northeastern and eastern faces of Mt Velika Ponca and the northern face of Mt Mali Oltar, Mt Široka peč and Mt Škrnatnarica (Fig. 2). From the top of Mt Kukova špica, it continues in a southern direction towards the Vrata Valley. The strata dip predominantly in a southern direction with a moderate inclination of 10–20° and attain a maximum thickness of 25 m.

Two members are distinguished in the Martuljek platy limestone (Fig. 5).

The Lower Member is composed of reddish (rarely greyish) sometimes indistinctly bedded (Fig. 4.7), pelagic limestone (bioclastic wackestone to packstone). It is organized in 10–20 cm thick beds with wavy to planar bedding. Thin (up to 5 mm) intercalations of reddish to green silt frequently occur on the bedding planes and are also randomly scattered in the beds. Stilolitic seams parallel to the bedding planes are often developed, indicating chemical compaction. Some beds in the lower part of succession are rich in ammonoids, gastropods and brachiopods. Green glauconite grains are also present in some samples, testifying to the slow rate of the sedimentation. The main facies type is bio-intra clastic packstone rich in foraminifers, brachiopod shells, calcified spicula, pellets, crinoids, ostracodes (Fig. 6.1) and is often dolomitized (Fig. 6.2). The Lower Member overlies sharply, without paleorelief, peritidal bedded Razor limestone (Fig. 6.3), that is occasionally also reddish around the contact and sometimes some meters below. The succession of pelagic Martuljek platy limestone on the shallow water Razor limestone represents a major drowning unconformity and is identical to the Mt Razor area (Sattler 1998). The reason for the drowning is not entirely clear, but this event is widespread over a broad area (Lieberman 1978;

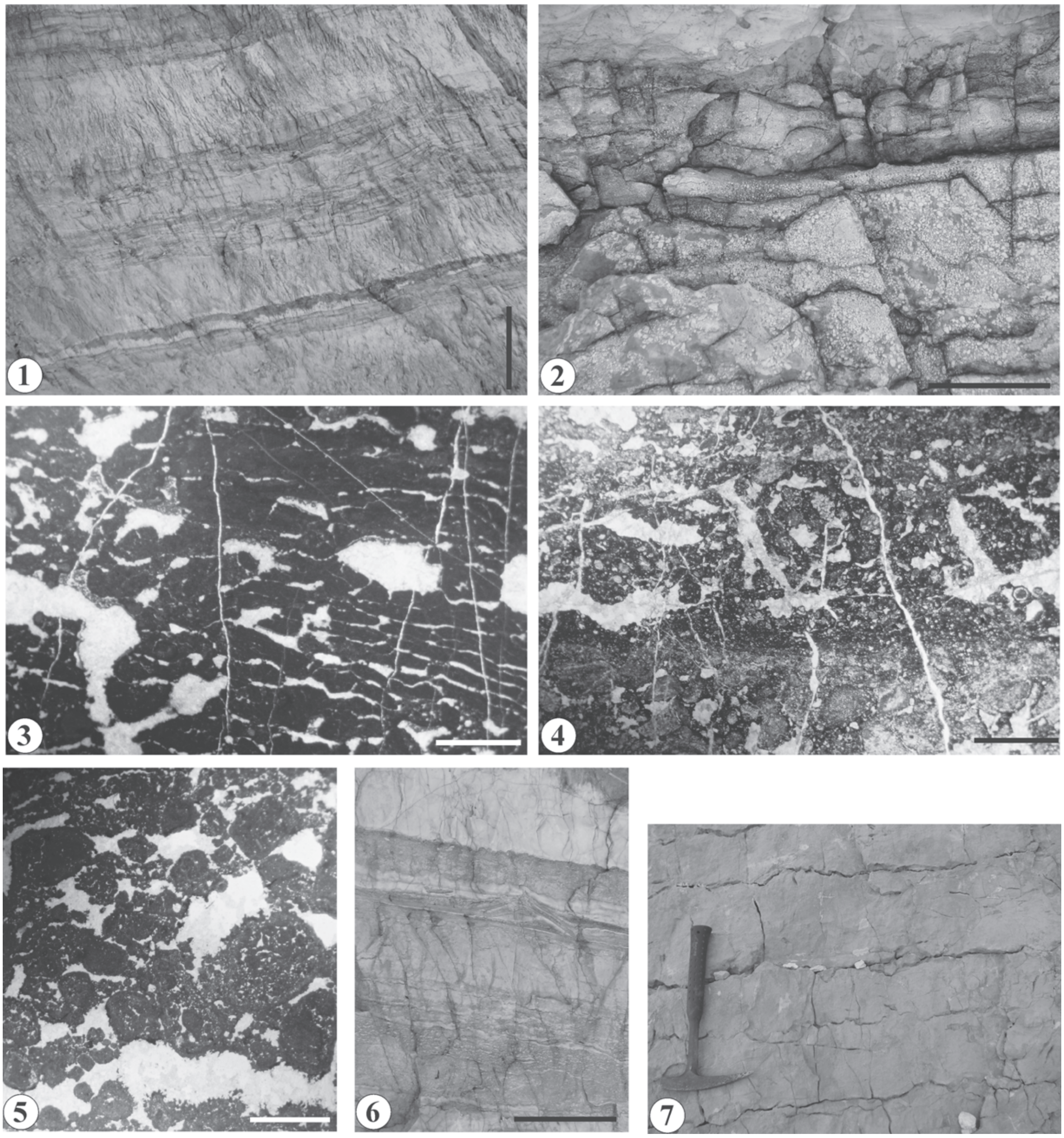

Fig. 4. Facies of the Razor limestone (1–6) and Martuljek platy limestone, Lover Member (7). **1** — Bedded peritidal Razor limestone. Cyclic alternation of subtidal and intertidal oncoidal–loferitic limestone. Kačji jezik (KJ) section, scale bar 1 m. **2** — Oncoid horizon, Kačji jezik (KJ) section, scale bar 4 cm. **3** — Microbial boundstone with loferitic shrinkage cracks and some birds eyes pores, filled with stalactite and blocky cement. Skrlatica (ŠK) section, sample ŠK20, scale bar 2 mm. **4** — Wackestone–packstone with loferitic pores. Kačji jezik (KJ) section, sample KJ16, scale bar 2 mm. **5** — Pisoid rudstone–oncoid grainstone with shrinkage pores. Pisoid–oncoid nuclei consist of pellets and intraclasts. Kačji jezik (KJ) section, sample KJ16, scale bar 2 mm. **6** — Tepee in the laminated loferitic limestone. Kačji jezik (KJ) section, scale bar 10 cm. **7** — Indistinctly bedded red micritic Martuljek platy limestone, Lower Member, Kačji jezik (KJ) section, hammer (32 cm long) for the scale.

Krystyn et al. 1994; Schlaf 1996; De Zanche et al. 2000; Gianolla et al. 2003). It is probably connected with rapid relative sea-level rise caused by strong extensional tectonic pulse at the beginning of the 3rd-order, No. 1 depositional sequence in the Southern Alps, which also corresponds to the lower boundary of a 2nd-order cycle (Gianolla et al. 1998). A similar situation is reported from the Northern Calcareous Alps (Mandl 2000).

The Upper Member is composed of light grey to white platy and thin-bedded, often dolomitized limestones (coral and crinoid grainstones and rudstones), showing a tendency towards upward bed thickening (in the lower part 20 cm, in the upper part 45 cm). The bedding is more clearly pronounced than in the Lower Member. In the detritic limestone (rudstone), normal gradation is evident, expressed with the reef detritus in the horizons with a sharp planar or irregular

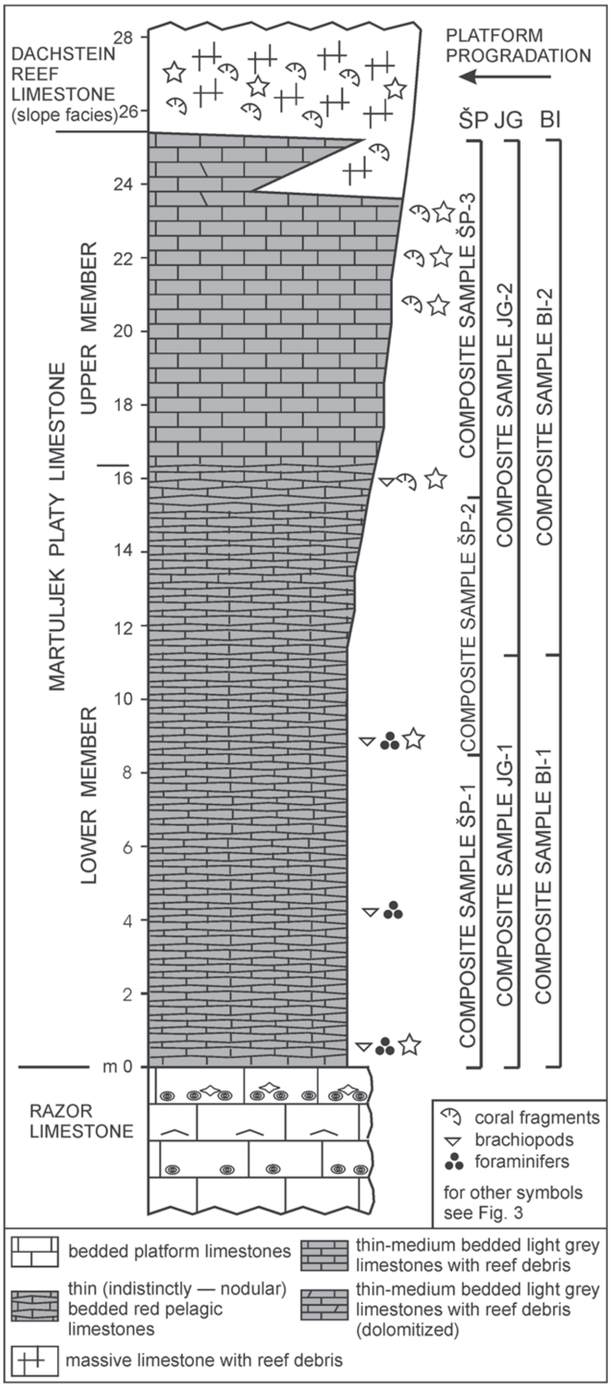

Fig. 5. Stratigraphical column of the Martuljek platy limestone (Mt Škrlatica (ŠK) section), and results of conodont analysis from other sections (see text and Fig. 2 for the location).

erosional lower boundary and gradual upper boundary with overlying grainstone (Fig. 6.4). Reef debris is frequently dolomitized and the primary structure is strongly obliterated (Fig. 6.5). Beds of the red pelagic limestone are often found between reef detritus, indicating a temporary break in the shedding of material from the platform. As the Upper Member passes upward into the slope limestones, we interpret these deposits as the toe of the slope facies. Graded grainstones and rudstones near the toe of the slope are redeposited shallow water sediments (reef margin with abundant corals, sponge and other biota) during sea-level highstands in the form of turbiditic flows. Similar graded grainstones are reported from the Ladinian Latemar buildup in the Dolomites (Goldhammer & Harris 1989). Slight lateral thinning of individual strata in a seaward direction, namely in the direction of the progradation of the platform, can be noted in some places.

The Martuljek platy limestone shows a shallowing upwards trend with an increasing amount of platform derived clasts (reef debris, algal remnants) and abundant stems and plates of crinoids from the slope environment.

Conodont fauna from the Martuljek platy limestone

Seven conodont samples were collected from three sections (B1, JG and ŠP) (Table 1, Fig. 2, Fig. 5), where the Martuljek platy limestone is exposed, between Razor limestone in the footwall and the slope of the Dachstein reef limestone in the hangingwall. Their WGS 84 coordinates in fractional degrees and elevations are: B1: lat = 46.438509, lon = 13.819957, elevation = 2140 m; JG: lat = 46.441170, lon = 13.83905, elevation = 2220 m; ŠP: lat = 46.44134, lon = 13.83993, elevation = 2220 m.

Sections were chosen according to positions relative to the direction of the Dachstein platform progradation in order to test the age of the uppermost part of the Martuljek platy limestone. Due to difficult access and very steep mountain terrain, composite (and not bed-by-bed) test sampling was carried out in order to document conodont fauna in the investigated section and in order to ascertain the potential for future establishment of conodont biozonation intervals. Therefore, only an estimated age assessment can be made based on the obtained results. For detailed paleontological study that would enable the introduction of precise conodont biozonation, bed-by-bed sampling would be required. For this study we collected composite samples, with most three samples and at least one sample per section, with a weight of 1–1.5 kg.

Conodonts are white with CAI = 1 (Epstein et al. 1977) indicating an average thermal overprint of 65 °C.

The determined conodont taxa are shown in Table 1. Ammonoid and conodont biostratigraphic zonations for the upper Carnian and lower Norian (Gradstein et al. 2004) are shown in Table 2.

Faunas are marked by the *Carnepigondolella, Epigondolella* and *Metapolygnathus* species (Fig. 7). In this report a taxonomic differentiation of Orchard (1991a) and Kozur (2003) is adopted: *Metapolygnathus* ranges throughout the Carnian and into the basal Norian, but *Epigondolella* is restricted only to the Norian, while the recently established *Carnepigondolella* is a marker of the upper Carnian.

Metapolygnathus is characterized by reduced platforms that may have ornamented (nodes) platform margins. A basal pit is usually situated in the posterior part of the platform. On the contrary, the genus *Epigondolella* has a more reduced platform with lateral platform denticles of considerable height. A well marked free blade is developed. A basal pit is usually situated beneath the centre of the platform (Orchard 1991a). *Carnepigondolella* is regarded as the forerunner of *Epigon-*

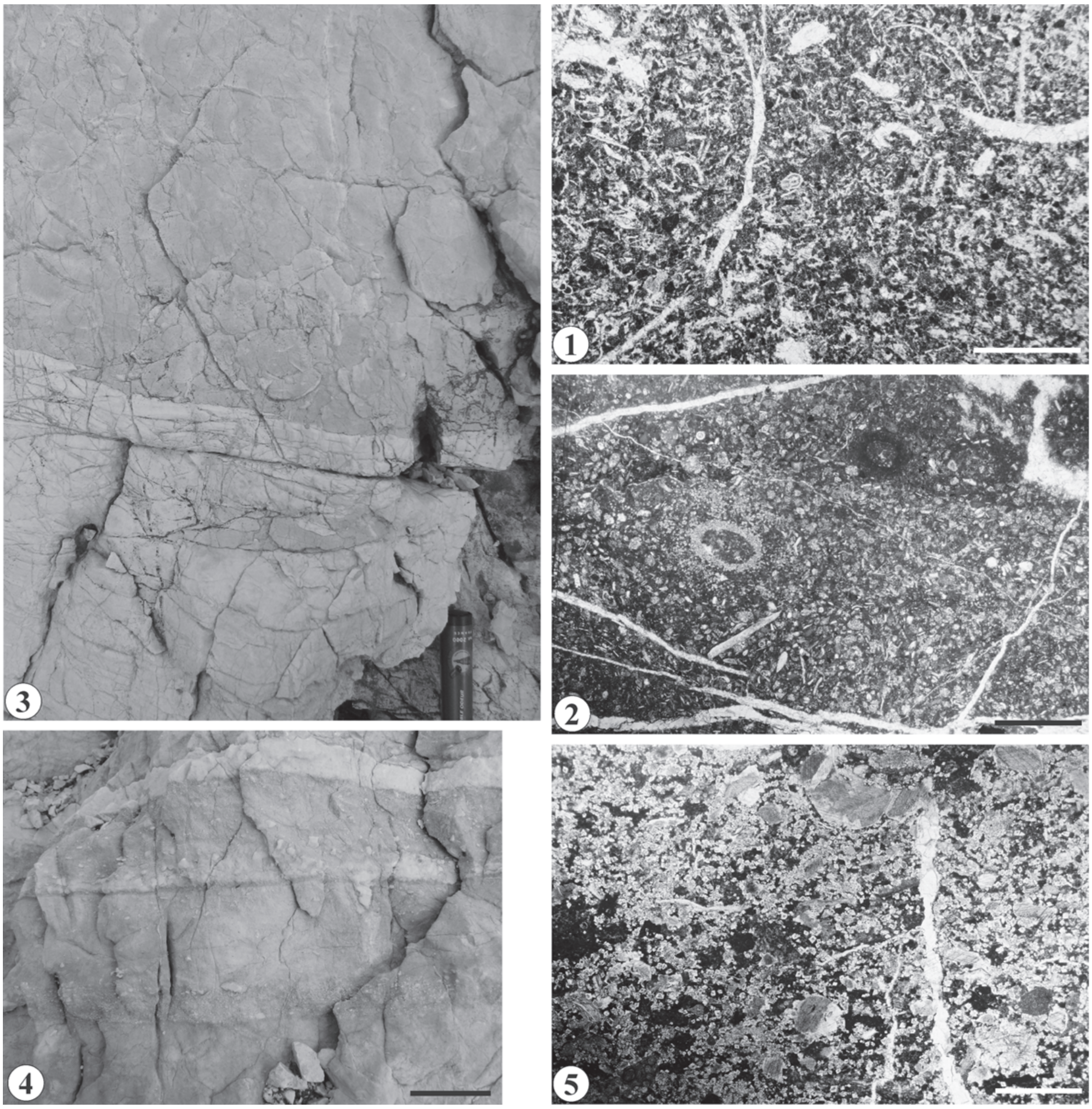

Fig. 6. Facies of the Martuljek platy limestone, Lower Member (1–3), Upper Member (4, 5). **1** — Bio-intra clastic packstone. Škrlatica (ŠK) section, sample ŠK19, scale bar 1 mm. **2** — Bio-intra clastic slightly dolomitized packstone, Škrlatica (ŠK) section, sample ŠK20, scale bar 2 mm. **3** — Contact between Razor limestone (lower part of the photo) and Martuljek platy limestone (upper part of the photo) is sharp and shows no relief. Jugova grapa (JG) section, marker pencil (8 cm long) for the scale. **4** — Graded reef debris with sharp lower boundary. Jugova grapa (JG) section, scale bar 4 cm. **5** — Strongly dolomitized reef debris with crinoid plates. Jugova grapa (JG) section, sample JG2, scale bar 2 mm.

dolella and is characterized by the presence of nodes or broad and short denticles on the platform margins and by a subterminal basal pit (Kozur 2003).

In the studied material ornate gondolellid forms predominate, but the presence of unornamented forms (*M. communisti*, *M. polygnathiformis*) have been recorded in two samples only.

The conodont faunas of the collected samples markedly characterize the Carnian-Norian boundary interval. During the last period of investigations in many countries, several suggestions to define the Carnian–Norian boundary (CNB) have been made (Orchard et al. 2000; Krystyn & Gallet 2002). In some older proposals the FAD of *Norigondolella navicula* have been utilized to mark the base of the Norian (Krystyn 1980; Orchard 1991a). Yet the species is ecologically controlled and thus its entry is not reliable for comparison (Orchard et al. 2000; Krystyn & Gallet 2002; Kozur 2003).

Upper Triassic conodont zonation has been considerably refined based on data from British Columbia (Orchard 1991b). Well documented faunas of the CNB interval have just recently been demonstrated by Orchard (2007). In a short succession at Black Bear Ridge in British Columbia, spanning the Welleri 2 through Kerri ammonoid zones, seven conodont datums defining eight faunal intervals can be identified. They are based on a detailed study of progressive evolutionary changes that enable recognition of several morphogenetic lineages (Orchard 2007).

Table 1: Conodont taxa determined from sections B1, JG and ŠP. For the geographical position of the sections see Fig. 2, for composite sample position in lithological column see Fig. 5. Selected conodont taxa are shown in Fig. 7.

Conodont taxa / Inventory number	**4065**	**4066**	**4070**	**4071**	**4067**	**4068**	**4069**
Sample number	**BI-1**	**BI-2**	**JG-1**	**JG-2**	**ŠP-1**	**ŠP-2**	**ŠP-3**
Carnepigondolella samueli	x						
Carnepigondolella ex gr. *samueli*					x		
Carnepigondolella sp.				x		x	x
Epigondolella quadrata				x			x
Epigondolella ex. gr. *quadrata*					x		
Epigondolella aff. *spatulata*							x
Epigondolella triangularis							x
Epigondolella ex. gr. *triangularis*				x	x		
Epigondolella sp.						x	
Metapolygnathus carpathicus	x						
Metapolygnathus communisti					x		
Metapolygnathus polygnathiformis	x		x			x	
Metapolygnathus n. sp. G	x		x	x		x	
Metapolygnathus sp.		x					

Table 2: Ammonoid and conodont biostratigraphic zonations for the upper Carnian and lower Norian (Gradstein et al. 2004).

<table>
<tr><th rowspan="2"></th><th colspan="2">Ammonoid zones</th><th rowspan="2">Conodonts zones</th></tr>
<tr><th>Alpine</th><th>B. Columbia</th></tr>
<tr><td rowspan="5">L. Norian (Lacian)</td><td>Juvavies magnus</td><td>Juvavites magnus</td><td rowspan="2">Epigondolella triangularis</td></tr>
<tr><td rowspan="2">Malayites paulckei</td><td rowspan="2">Malayites dawsoni</td></tr>
<tr><td rowspan="2">Epigondolella quadrata</td></tr>
<tr><td rowspan="2">Guembelites jandianus</td><td rowspan="2">Stikinoceras kerri</td></tr>
<tr><td>Metapolygnathus primitius</td></tr>
<tr><td rowspan="5">U. Car. (Tuvalian)</td><td rowspan="2">Anatropites spinosus</td><td>Klamathites macrolobatus</td><td>Metapolygnathus communisti</td></tr>
<tr><td rowspan="2">Tropites welleri</td><td rowspan="3">Metapolygnathus nodosus</td></tr>
<tr><td>Tropites subbulatus</td></tr>
<tr><td rowspan="2">Tropites dilleri</td><td rowspan="2">Tropites dilleri</td></tr>
<tr><td>Metapolygnathus polygnathiformis</td></tr>
</table>

A recent suggestion to define the CNB based on the FAD of *Epigondolella quadrata* has been put forward among conodont workers and members of the Subcommission on Triassic Stratigraphy (personal communication). It should be mentioned that in Kozur's (2003) integrated ammonoid, conodont and radiolarian zonation of the Triassic *Epigondolella quadrata* Zone is equivalent to the upper Kerri and lower Paulckei (= Dawsoni) zones. As this proposal has not been formally accepted by international geological institutions, this datum can currently be considered only as a potential candidate.

On the basis of the composition of the examined faunules and taking into account above mentioned data, the following conclusions can be made:

1) samples BI-1 and JG-1 are marked by *M. polygnathiformis*. This element is accompanied by *Metapolygnathus* n. sp. G Orchard (forerunner of *M. primitius*) or *M. carpathica* and *Carnepigondolella samueli*. The absence of epigondolellids is evident. Age: late Carnian.

2) samples ŠP-1, ŠP-2 and JG-2 are mixed late Carnian–early Norian in age due to the co-occurrence of *Carnepigondolella, Epigondolella* and *Metapolygnathus* forms.

3) sample ŠP-3 is characterized by the exclusive presence of *Epigondolella* species, including *E. quadrata*. Age: early Norian.

Dachstein reef limestone (upper Tuvalian–lower Norian)

Dachstein reef limestones in the MMG are represented with obviously a very narrow reef crest (margin) and up to 300 m thick slope toward the basin (fore-reef area) as evident from the natural cross-sections of the MMG. Because it is macroscopically almost impossible to distinguish between the reef margin, positioned immediately below the bedded Dachstein Limestone, and the slope, we named the entire lithological unit of predominantly massive unbedded limestones as the Dachstein reef limestone. Corals are the most important and prevailing reef builders; sponges and hydrozoans are subordinate (Turnšek & Ramovš 1987).

On Mt Planja and Mt Razor (Ramovš & Turnšek 1991) the Dachstein reef limestone complex is up to 150 m thick, but the actual thickness is unknown because the upper parts are eroded. Coral genera present in the Dachstein reef limestone are *Cyclophyllia*, *Pokljukosmilia*, *Protoheterastraea* and *Rhopalodendron*. Three of them are also known from the Tuvalian of the Pokljuka Plateau (Turnšek & Buser 1989). According to Sattler (1998), the reef complex on Mt Razor is upper Tuvalian, based on the upper Carnian pelagic micrite filling of the fissures in the Dachstein reef limestone. On Mt Dovški križ, Mt Šplevta and Mt Kopica, the reef complex is up to 1000 m thick (Turnšek & Ramovš 1987). The main framebuilders in the MMG are corals and subordinately sponges, which are also significant for the Norian–Rhaetian reefs in other areas (Riedel 1991; Flügel & Senowbari-Daryan 1996; Turnšek 1997). The most abundant corals are the branching forms *Gillastraea*, *Retiophyllia*, *Elysastraea* and *Parathecosmilia* and massive *Astraeomorpha* and *Toechastraea*. According to the geological mapping and observations in the NW face of Mt Škrlatica, the thickness of the reef complex between the underlying basinal Martuljek platy limestone and the overly-

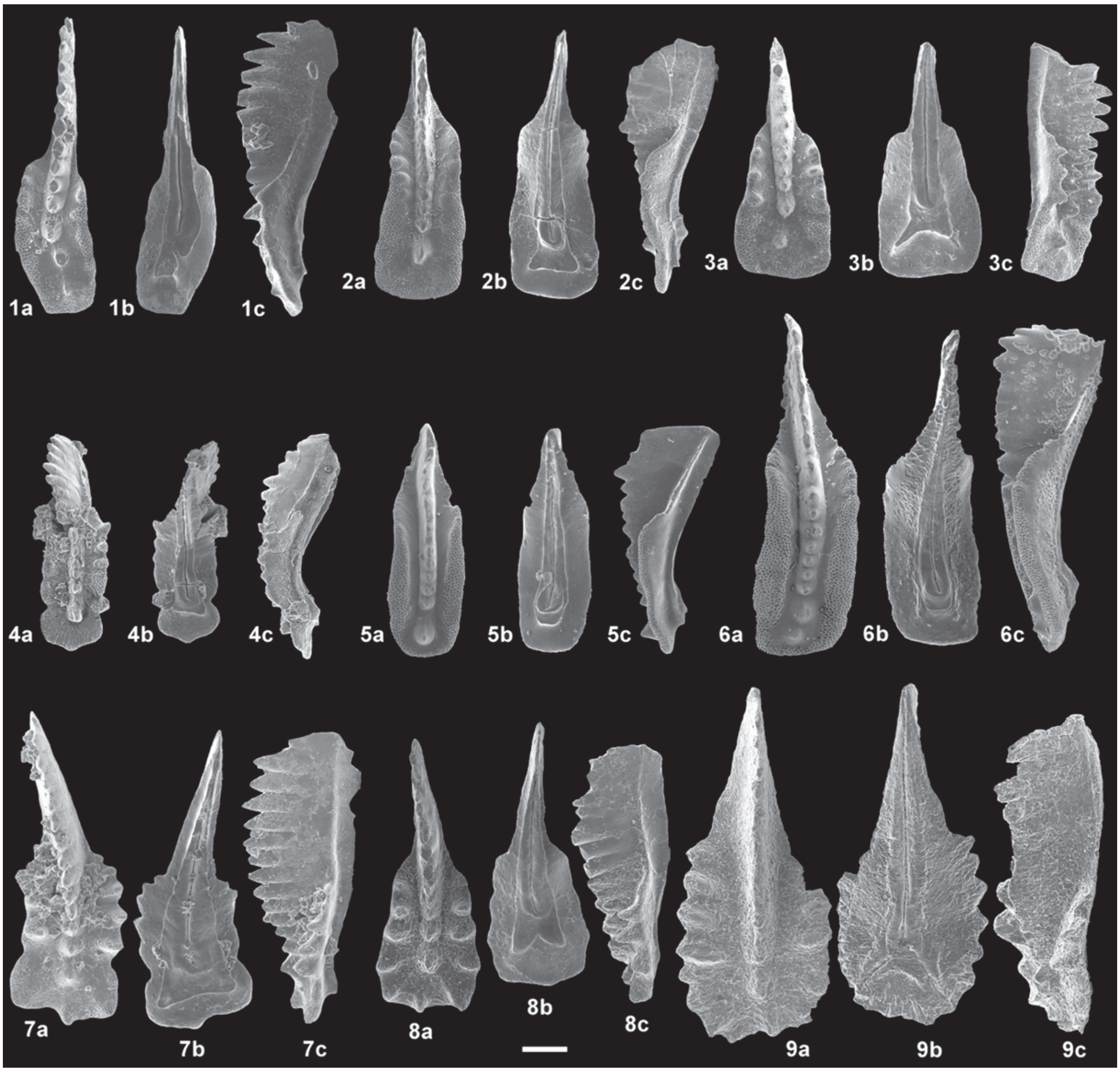

Fig. 7. Conodonts from the Martuljek platy limestone. **1–3** — Mixed upper Carnian-lower Norian faunas. 1a–c — *Metapolygnathus communisti* (Hayashi), sample ŠP-1 (GeoZS 4067). 2a–c — *Metapolygnathus* n. sp. G (Orchard), sample JG-1 (GeoZS 4070). 3a–c — *Epigondolella quadrata* (Orchard), sample JG-2 (GeoZS 4071). **4–6** — Upper Carnian, sample BI-1 (GeoZS 4065). 4a–c — *Carnepigondolla samueli* (Orchard). 5a–c — *Metapolygnathus polygnathiformis* (Budurov & Stefanov). 6a–c — *Metapolygnathus carpathicus* (Mock). **7–9** — Lower Norian: sample ŠP-3 (GeoZS 4069). 7a–c — *Epigondolella quadrata* (Orchard). 8a–c — *Epigondolella* aff. *spatulata* (Hayashi). 9a–c — *Epigondolella triangularis* (Budurov). Scale bar = 100 μm.

ing bedded Dachstein Limestone of the interior platform is around 300 m. This is opposed to finding of Ramovš (1986a, Fig. 2) and Turnšek & Ramovš (1987) for the Dovški križ area, where it is estimated to be greater than 1000 m. In our opinion, this is just an apparent thickness, because dipping of the strata is directed along the mountain slopes and the reef occupies a relatively extensive area (Fig. 2). Perhaps the most prominent mountain built of Dachstein reef limestone in the MMG is Mt Mali Oltar (Fig. 8.1). During our fieldwork, we also collected some samples with corals from the top of Mt Velika Ponca. D. Turnšek determined the Norian species *Retiophyllia norica* (Fig. 8.2). Coarse-grained breccia or boulders derived from the top of the platform are completely missing at the toe of the slope and only rudstone with reworked reef particles and plates of crinoids is present (Fig. 8.3,4).

Piller (1981) explains the absence of breccias as the result of water agitation generally being too weak to produce large boulders from the reef framework.

Dachstein Limestone (?upper Tuvalian, Norian, Rhaetian)

Peritidal bedded Dachstein Limestone rests with a sharp boundary above the massive Dachstein reef limestone and was deposited on the broad area behind the prograding reef rim. It extends between Mt Visoki Rokav on the north and Mt Stenar in the south (Fig. 2), where it is overlain by Jurassic oolitic limestone and attains a thickness of around 1000 m with char-

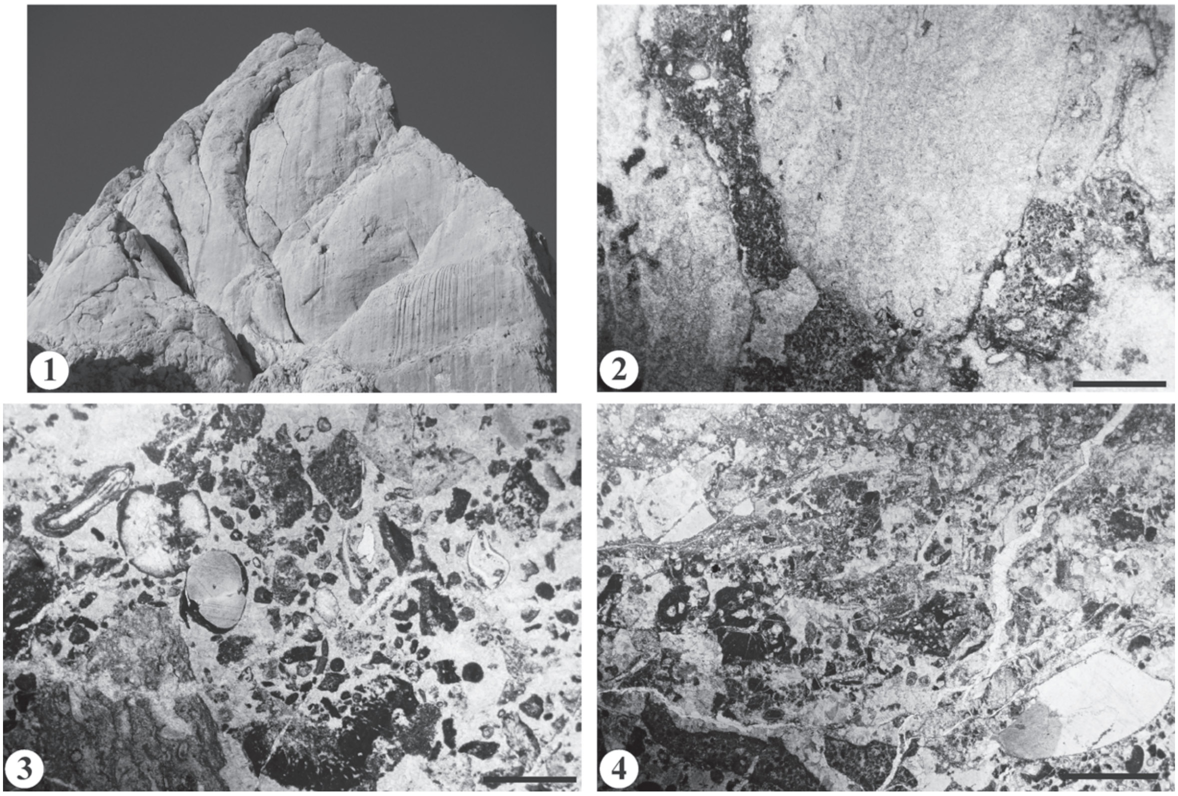

Fig. 8. Facies of the Dachstein reef limestone. **1** — Mt Mali Oltar is built of autochthonous Dachstein reef limestone and allochthonous reef debris (slope) limestones (height of the face app. 200 m). For location, see Fig. 2. **2** — Coral *Retiophyllia norica* (det. D. Turnšek). Reef crest of the Mt Velika Ponca. For location, see Fig. 2. **3** — Coral-crinoid rudstone, slope facies, Kačji jezik (KJ) section, sample KJ5, scale bar 2 mm. **4** — Coral-crinoid rudstone, Škrlatica (ŠK) section, sample ŠK14, scale bar 2 mm.

acteristic cyclic Lofer (sensu Fisher 1964) development. Subtidal member C consists of 1–3 m thick beds, predominately wackestone and packstone, subordinately bioclastic rudstone. Megalodontids and gastropods are abundant in distinct horizons. Solution carstic vugs, filled with reddish silt or isopachous cement, are often present in the upper part of the subtidal unit, indicating sudden emersions and subsequent carstification. Black pebbles are common. Often basal member A is not developed and laminated fenestral limestone of intertidal member B directly overlies subtidal unit C (cf. Enos & Samankassou 1998). Fenestrae are filled with white cement. In the eastern part of the Julian Alps Dachstein Limestone extends through the entire Norian and Rhaetian stages, while further west, the lower part consists of Main Dolomite (Jurkovšek 1987a; Cozzi & Hardie 2003; Gianolla et al. 2003; Cozzi et al. 2005).

Progradation of the Dachstein platform

The progradation geometry of the Dachstein platform passing into the basin is exposed in the northwest face of Mt Škrlatica parallel to the direction of the platform advance (Fig. 9a–c). Interfingering of thin-bedded reef-debris limestones (Martuljek platy limestone — Upper Member) and clinostratificated reef-debris limestones of the slope facies (Dachstein reef limestone) is clearly visible. The lithological boundary in Mt Škrlatica can be interpreted as a climbing progradadion in the sense of Bosellini (1984), yet generally, the boundary is horizontal. The thin-bedded limestones exhibit low angle onlap against the upper boundary of the intermediary wedge of the slope limestone intercalated in the Martuljek platy limestone (Fig. 9c, detail). The Upper Member of the Martuljek platy limestone slightly thickens basinward, while individual beds thin in the same direction.

We consider interfingering to be just a local phenomenon. Namely, elsewhere, it is not expressed and its boundary is sharp, although clinoforms are still visible. Clinoforms are expressed as discontinuities in the slope limestones with an inclination of around 15–25° and dip in the NE direction (Fig. 9b,c). Their configuration is oblique-parallel. We assume that underlying Martuljek platy limestone and overlying Dachstein Limestone were deposited horizontally and their tectonic dip in the northwest face of Mt Škrlatica is now slightly (5–10°) to the SSW. If we remove the later tectonic dip, the true depositional dip of the clinoforms shows only minor change. In other localities, the contact between the slope limestones and thin-bedded reef debris is sharp and shows no interfingering. The clinoform surfaces seem to be absent or are poorly exposed. We interpret this pattern as the horizontal downlap plane (Bosellini & Stefani 1991; Maurer 2000) which indicates rapid progradation of the platform.

The upper boundary of the slope and the margin with the Dachstein Limestone is almost horizontal in Mt Oltar (toplap

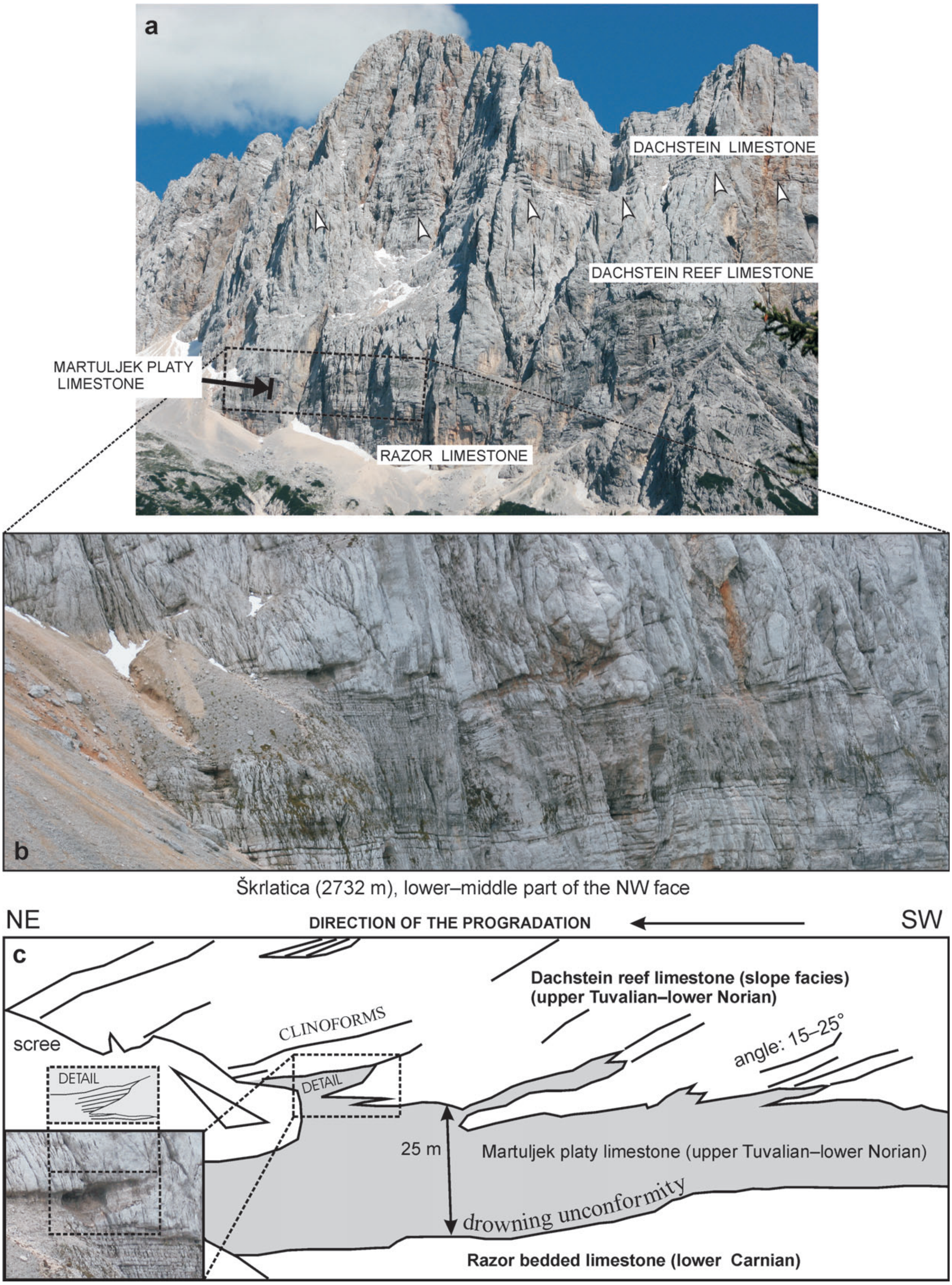

Fig. 9. Facies interpretation and progradational geometry in the NW face of Mt Škrlatica (Martuljek Mountain Group). **a** — Small scale facies interpretation. Arrows indicate contact between Dachstein reef limestone (slope and margin facies) and bedded Dachstein Limestone (inner platform facies). For location see also Fig. 2. **b** — Photo of area indicated by rectangle in a. **c** — Interpretation of facies relationship with detail of toe of slope interfingering between Martuljek platy limestone (Upper Member) and Dachstein reef limestone. For detail explanation see text.

sensu Bosellini 1984) and perhaps a slightly low angle lap off against a massive margin is visible in Mt Škrlatica (Fig. 9a, arrows indicate contact between massive Dachstein reef limestone and bedded Dachstein Limestone). This relationship points to the stillstand in the sea level during the early Norian and progradational dominated highstand systems tract (Wright & Burchette 1996).

The coral reef margin in the upper part is macroscopically similar to the slope, so its exact thickness is unknown. Based on the clinoform dip, the progradation is in the SW–NE direction, analogous to the trend of the upper Tuvalian Dolomia Principale in the Portella section (Italy), 16 km to the W (Gianolla et al. 2003). The basinal limestones are also progressively younger in this direction. According to the Triassic sequence stratigraphy patterns of the Southern Alps, they represent the beginning of the No. 1 depositional sequence (Gianolla et al. 1998).

Discussion

The Carnian–Norian lithostratigraphic developments exhibit a distinctive heterogeneity in the scale of the Julian Alps. During the late Julian time, in the Cave del Predil area, the pre-existing interplatform basin was completely filled, while the rimmed carbonate platforms (Cassian Dolomite) with framebuilding organisms underwent strong crisis and were replaced by a carbonate-terrigenous ramp (Gianolla et al. 2003; Preto et al. 2005). However, in the MMG shallow platform sedimentation persisted through the early Carnian, when the bedded peritidal and reef Razor limestones were deposited. Terrigenous "Raibl" beds are not present in this area and the same is true for the Kamnik–Savinja Alps (Ramovš 1989). In the Slovenian Basin, positioned further east, basinal Carnian Amphiclina beds and Norian–Rhaetian cherty Bača Dolomite were deposited (Buser 1989). During the Tuvalian, strong subsidence affected the area of the Julian Carbonate Platform, with sedimentation of the basinal Carnitza Formation in the Cave del Predil area (Lieberman 1978; De Zanche et al. 2000; Gianolla et al. 2003). In the Vrata Valley, east of the MMG, Tuvalian and also Lacian basinal limestones are present (Ramovš 1986a; Schlaf et al. 1997a,b). Schlaf et al. (1999) described thick coquina accumulations in the lower Norian carbonate slope of the Vrata Valley. The corals are very rare and the margin of Dolomia Principale in the Cave del Predil is serpulid and microbial dominated (Gianolla et al. 2003). On the other hand, corals are abundant in the rim of the synchronous or slightly younger prograding Dachstein platform in the MMG.

On the basis of conodont age-dating, some rough estimations of the growth mode of the Dachstein platform in the MMG can be made. The platform prograded in the SW-NE direction as shown by the dip of clinoforms in the NW face of Mt Škrlatica. The lateral extent of the basinal Martuljek platy limestones from Mt Razor in the SW, to the Mt Široka peč in the NE is around 5 km which is also the total (visible) progradation. Conodonts of the late Tuvalian age (Macrolobatus Zone) were reported for the Mt Razor area (Ramovš 1986a), but our recent study revealed early Norian age (Kerri–Dawsoni Zone) for the upper part of the Mt Široka peč section (this paper). According to the ICS timescale (Gradstein et al. 2004), the Macrolobatus and Kerri Chron has a duration of about 3.4 Myr and the Dawsoni Chron about 1.8 Myr. The platform prograded at least through the entire Macrolobatus Chron, the whole Kerri Chron, and at least until the middle part of the Dawsoni Chron (Table 2), that is about 4.3 Myr in total. The progradation rate is thus estimated at 1200 m/Myr. Nothing can be said about the aggradation rate of the Dachstein Limestone because of its unfavourable position on the reef margin (it is mainly eroded). In Cave del Predil, the Tuvalian progradation of the Main Dolomite platform is estimated at 4600 m/Myr (Gianolla et al. 2003), based on Gradstein et al. (1994), but this was corrected to around 2700 m/Myr based on new durations of the ammonite zones (Gradstein et al. 2004). This approximates to the Ladinian platforms in the Dolomites. In fact, for better estimation of the rate of platform progradation, a detailed bed-by-bed resampling should be performed. Sequence stratigraphy and paleogeography supported by conodont age-dating of the MMG shows some interesting comparisons between the neighbouring areas, particularly with stratigraphic successions in the Vrata Valley.

In the MMG, the Lower Member of the Martuljek platy limestone (Tuvalian) represents the TST (transgressive systems tract), while the Upper Member, the Dachstein reef limestone and the Dachstein Limestone belong to the HST (highstand systems tract). In the Vrata Valley in a relatively limited area, Schlaf et al. (1997a) recognized another HST and TST around the Carnian-Norian boundary, positioned between the TST and HST of the MMG. This points to the tectonic control of systems tracts within a broader area. Sedimentary succession in the Vrata Valley consists of 80 m thick cherty, bituminous wacke- and mudstones of Tuvalian age (TST) (Kolar-Jurkovšek 1991), followed by 150 m thick lower Norian bedded allodapic limestones (HST), that are overlain by 15–20 m thick bituminous mud- and wackestones (TST) and 500 m thick lower Norian clinoforms of rapidly prograding platform and capped with Dachstein Limestone (HST) (Jurkovšek 1987a).

In the Vrata Valley, an obviously accelerated subsidence along synsedimentary faults (?halfgraben) came into being during the late Tuvalian pelagic episode, manifested with greater thickness and different facies of basinal sediments when compared with the MMG. The Dachstein platform begun to prograde from the SW and filled the relatively elevated basinal areas of the MMG (condensed sedimentation). However, it was not able to completely fill the relatively subsiding area in the Vrata Valley, which led to the development of the small restricted intraplatform basin engraved in the Dachstein platform behind the main prograding rim that is positioned further towards the NE. Finally, the basin was filled with NE–SW prograding bivalve dominating clinoforms, and ultimately the entire area was blanketed by a thick succession of the Dachstein Limestone. The MMG facies architecture is similar to some facies reconstructions in the Northern Calcareous Alps (Mandl 2000), particularly to the Tonion and Hohe Wand facies, where the Dachstein platform progrades over the drowned part of the Wetterstein Platform in the direction of the deep shelf of the Meliata realm.

Conclusions

After widespread Carnian drowning in the Julian Alps (and also in the Kamnik–Savinja Alps more to the E) and the onset of the Hallstatt type limestone sedimentation (Martuljek platy limestone), rimmed prograding Dachstein platforms of the late Tuvalian and early Norian appeared, filling newly-formed basins. The massive margin of the Dachstein platform is predominantly made of corals and sponges. The reef complex in the Julian Alps attains a maximum thickness of 300 m, which means that previous assumptions of the thickness were drastically exaggerated. Slope geometry, dip of clinostratification, and age-dating of the basinal limestones indicate NE progradation of the platform (in the recent orientation).

According to conodont dating, the Martuljek platy limestone is successively younger in the NE direction and indicates platform progradation with an estimated rate of 1200 m/Myr. The conodont samples of the Martuljek platy limestones yield abundant late Carnian–early Norian collections. In the next phase of our study, bed-by-bed resampling is planned in order to introduce precise conodont biozonation that would enable identification of the boundary line. After definition of the Carnian-Norian boundary and its ratification by international geological institutions, the marking of the boundary will also be possible.

There is currently no proof that the basin was connected with true pelagic Hallstatt facies of the deep shelf bordering the Meliata oceanic realm, although progradation indicates the NE direction, which is away from the Slovenian Basin. The Dachstein reef limestone in the Martuljek Mountain Group and also in the Mt Triglav area is, based on the stratigraphy, and on the relationship with well dated basinal limestones, of the late Carnian to Norian age. The more than 1000 m thick succession of the cyclic Dachstein Limestone of the Norian and Rhaetian age sedimented in the broad peritidal area behind the prograding reef.

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