A sedimentological description of the Middle Triassic vertebrate-bearing limestone from Velika planina, the Kamnik-Savinja Alps, Slovenia

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Abstract

In the Kamnik-Savinja Alps (Slovenia), the Lower Serla Dolomite laterally passes into a succession of thin- to medium-bedded bituminous limestones of the Velika planina member. The finely laminated lower part of this member contains well-preserved actinopterygian fish and sauropterygian remains. The research aimed to determine the sedimentological and palaeoenvironmental characteristics of the depositional basin on the basis of three detailed sedimentological sections logged atop the Velika planina plateau. The Velika planina member is underlain by a whitish to light grey, thick bedded to massive dolomite with oncoids, stromatolites, and lumachelas deposited under peritidal to shallow subtidal conditions. The lower part of the Velika planina member consists of thin, often platy, finely laminated beds of bituminous mudstone. The Chondrites ichnofossil is very common; however, in some beds numerous lingulid brachiopods, bivalves, and crinoids were observed. Fossil vertebrates and crustaceans are relatively rare and confined to a few levels. Ammonoids are very rare. Subordinate beds of intraclastic-peloidal wackestone to packstone, intraclastic-bioclastic grainstone, and bivalve floatstone occur. Slumps are common. Upwards, bedding gradually becomes thicker and bioturbation more common. Finally, stromatolites, birdseye fenestrae, and oncoids reappear. The entire succession is confined to the early to middle Anisian by the foraminifer Citaella dinarica (Koachsansky-Devide & Pantić). The absence of breccias at the base of the Velika planina member, the gradual transition upwards into shallow marine carbonates, as well as the presence of sauropterygians of the order Nothosauridae suggest deposition in a relatively shallow basin. The finely laminated facies of the lower part of the member indicates a stratified water column, with oxygenated near-surface waters and hypoxic to anoxic conditions near the sea floor.

Keywords: Southern Alps, intraplatform basin, Anisian, sedimentology, vertebrates, Sauropterygia

1. INTRODUCTION

The Triassic was an important period for the recovery of life on Earth after the end-Permian extinction. Not only were new ecosystems established, but new animal lineages came to play key roles in the emerging Modern Evolutionary Fauna (Payne & Van de Schootbrugge, 2007; Benton, 2016; Buatois et al., 2016). Among such groups were also the actinopterygian fishes (Tintorì et al., 2014a, b) and marine reptiles (Motani, 2009; Stubbs & Benton, 2016; Brayard et al., 2017). The most famous finds of the latter come from the classic deposits of the Germanic Basin (Rieppel, 1999; Hagedorn & Rieppel, 1999; Diedrich, 2012), and the Southern Alps of the Monte San Giorgio area (Furrer, 1995a; Röhl et al., 2001; Stockar, 2010; Hugi et al., 2011; Furrer & Vandelli, 2004; Renesto et al., 2014; Beadmore & Furrer, 2016, 2019), as well as from more recently discovered sites in southern China (Liu et al., 2011; Benton et al., 2013).

As recently as 20 years ago, reports of sauropterygians from the Triassic beds of Slovenia were scarce. Deecke (1886) mentioned remains of a marine reptile collected from the scree below Mt. Storžič in the Kamnik-Savinja Alps. The fossil was later described as a pachypleurosaur of the Serpianosaurus – Neusticosaurus clade (Rieppel, 1997). More than two centuries later, new discoveries started to emerge: a placodont dentary bone from the upper Carnian or lower Carnian beds of Toško Celo near Ljubljana (Buffetaut & Novak, 2008), isolated bones and teeth of sauropterygians from the Carnian shallow marine deposits in the Poljane Valley (Križnar, 2009), pachypleurosaur, placodont, and ichthyosaur bones from the Anisian Strelowe Formation (Hitij & Renesto, 2010), and sauropterygian bones from the Ladinian Buchenstein Formation in the Kamnik-Savinja Alps and the Southern Karavanke Mountains (Hitij et al., 2010b). However, most of the new finds of sauropterygians came from the Anisian beds of the Velika planina member on the Velika planina mountain plateau (Fig. 1), where they occur together with a number of actinopterygian fish genera of the so-called “Early Anisian Fish Fauna” (Hitij et al., 2010a; Tintorì et al., 2014a). Despite the importance of these finds and the large potential for future palaeontological research, the stratigraphic position of the Velika planina member remains poorly constrained, with no information on its lower and upper boundaries. Moreover, the sedimentological composition of the member as a whole and its microfacies association have not been previously described.
The aim of this paper is to fill this gap by presenting several key sections of the Velika planina member. We provide direct evidence for the early to middle Anisian age of the member on the basis of determinations of foraminifers. Based on the detailed description of microfacies associations and currently known fossils from this member, we try to provide some answers about the relative depth of the depositional area, the type of sedimentation, and the palaeoenvironmental conditions on the sea floor.

2. STRUCTURAL SETTING OF THE KAMNIK-SAVINJA ALPS

Velika planina is a karstified mountain plateau with an average altitude of 1500 m, located in the southern part of the Kamnik-Savinja Alps (Fig. 1). In terms of regional tectonic structure, the Kamnik-Savinja Alps belong to the eastern Southern Alps, shaped during the Cretaceous to Cenozoic Alpine orogeny (PLACER, 1999; SCHMID et al., 2008). Together with the Southern Karavanke Mountains, they represent a mega shear lens between two major dextral strike-slip faults in the Periadriatic Fault Zone: the Periadriatic Fault to the north and the Sava Fault to the south. While the main, northern branch of the Periadriatic Fault formed during the Oligocene and was later reactivated several times, the main movements along the Sava Fault took place after the latest Miocene (VRABEC & FODOR, 2006). The two dextral strike-slip faults are connected by left strike-slip faults running in NE-SW directions. Palaeomagnetic directions from Oligocene to Neogene sediments indicate domino-like block rotations along these faults (FODOR et al., 1998; VRABEC & FODOR, 2006; VRABEC et al., 2006). Prior to the formation of the shear zone, the area experienced two major phases of thrusting: the NE – SW directed Eocene – Oligocene thrusts preceded the N – S directed Miocene – recent thrusts (PLACER, 1999; PONTON, 2014). In the central part of the Kamnik-Savinja Alps, MIOC et al. (1983) distinguished the so-called Savinja Thrust overlying the Southern Karavanke Thrust. CELARC (2004) later found no evidence of a thrust in the northern part of the Kamnik-Savinja Alps, which called into question the existence of the Savinja Thrust in that area. DOLŽAN (2017) recently confirmed the existence of a detachment surface (named the Kočna Detachment Surface, KDS) in the central Kamnik-Savinja Alps, dipping 8° to the E. However, no evidence for thrusting was found, and the KDS was interpreted as a low-angle normal fault, that is towards the NW successively lowered along normal faults until it is no longer exposed.

3. TRIASSIC STRATIGRAPHY OF THE KAMNIK-SAVINJA ALPS

Systematic geological research of the Kamnik-Savinja Alps started in the second half of the 19th century (LIPOLD, 1856; Rolle, 1857; Teller, 1885, 1898 a, b). Modern geological maps were produced by BUSER and CAJHEN (1977), MIOC et al. (1983), PREMRU (1983a), and CELARC (2004). Accompanying explanatory books were written by BUSER (1980), MIOC (1983), and PREMRU (1983b). Stratigraphic research, focused on Triassic deposits, was carried out by RAMOVŠ (1973), JURKOVIČ (1984), GORIČAN & BUSER (1990), RAMOVŠ & JAMNIK (1991), CELARC (2004), CELARC & GORIČAN (2007), CELARC et al. (2013, 2014). The Triassic succession preserved in the Kamnik-Savinja Alps first reflects the existence of a mixed siliciclastic – carbonate ramp in the Early Triassic and then the gradual establishment of a flat and uniform carbonate platform, the formation of various smaller intraplatform basins with accompanying volcanism from the Anisian until the Late Ladinian, regional drowning in the Late Carnian, and progradation of the platform in the Norian (BUSER, 1989, 1996). The development took place at the western passive margin of equatorial Pangea, close to the Palaeotethys and from the Middle Triassic onwards also next to the Neotethys Ocean (HAAS et al., 1995; STAMPFLI & BOREL, 2002; STAMPFLI & KOZUR, 2006). In the Kamnik-Savinja Alps the Lower Triassic is represented by sandstones, marly limestone, and oolitic limestone belonging to the so-called Velika planina member. The unit locally contains isolated bones and partial to complete vertebrate skeletons. On the Velika planina plateau, the Velika planina member gradually passes upwards into medium-bedded and then massive limestone and dolomite still belonging to the Lower Seria Dolomite. The Lower Seria Dolomite laterally and vertically passes into a succession of thin- to medium-bedded, locally finely laminated bituminous limestone several tens of metres thick, here referred to as the Velika planina member. The unit locally contains isolated bones and partial to complete vertebrate skeletons. On the Velika planina plateau, the Velika planina member gradually passes upwards into medium-bedded and then massive limestone and dolomite still belonging to the Lower Seria Dolomite. On the Velika planina plateau, this dolomite is in a faulted contact with the limestone and dolomite of the Schlenz Formation. Elsewhere in the Kamnik-Savinja Alps (as well as in parts of the Julian Alps), where the contact is not disturbed by younger faults, the Lower Seria Dolomite passes upwards into a unit of
marlstone, mudstone, thin- to medium-thick bedded limestone and dolomite of the middle to upper Anisian (Pelsonian – early Illyrian) Strelovec Formation which is up to 60 m thick (CE-LARC et al., 2013; MIKLAVC et al., 2016; PRIMOŽIČ, 2020). The Strelovec Formation is concordantly overlain by the upper Anisian Contrin Formation, comprising shallow marine bedded and massive limestone, or locally dolomite (CELARC et al., 2013). The Contrin Formation is locally dissected by palaeo-faults. Small half-grabens are filled with red radiolarian-bearing limestones of the Illyrian Ljubelj (Ljubelj) Formation, volcanic and volcaniclastic rocks, polymict breccias, and conglomerates (equivalent to the Ugovizza/Uggowitz Breccia), marls, and hemipelagic limestones (equivalent to the Buchenstein/Livinallongo Formation). Upwards follow several hundred metres of massive limestone of the LadinianSchlern Formation (CELARC et al., 2013). The growth of the Schlern platform was interrupted during the late Ladinian (Longobardian). Volcaniclastics, platy limestone with chert, and calcarenites of the Korošica Formation were locally deposited (JURKOVŠEK, 1984; CELARC, 2004; ŽALOHAR & CELARC, 2010). Elsewhere, the top of the Schlern Formation is marked by breccias, indicating a stratigraphic gap between the Schlern Formation and the lower Carnian peritidal Razor Limestone. During the late Carnian, approximately 25 m of hemipelagic Martuljek Platy Limestone was deposited. In distal positions relative to the prograding Dachstein platform approximately 150 m of lower Norian limestone with chert follows. Finally, after a narrow prograding reef margin, a thick succession of peritidal limestones of the Dachstein Formation deposited over the wider area (CELARC et al., 2013).

4. GEOLOGICAL MAP AND SETTING OF THE VELIKA PLANINA PLATEAU

Geological maps of the Velika planina mountain plateau were produced by TELLER (1898a, b), and PREMRU (1983a, b). Reambulation of the geological map covering the research area was performed by one of the authors of the paper (B.V.) in 2014. The southern part of the Velika planina plateau is dominated by Middle Triassic carbonates, i.e. the Anisian Lower Serla Dolomite and the Velika planina member (Fig. 3). To the north, these two Anisian units are in faulted contact with the younger shallow marine dolomites and subordinate limestones of the Ladinian Schlern Formation. To the south, the Lower Seria Dolomite is in normal stratigraphic contact with the Lower Triassic Werfen Formation. The latter is thrust over the Middle Triassic dolomite. Lineation on the thrust plane indicates initial thrusting to the SW, overprinted by younger thrusting to the S. The area is additionally transected by steep faults of SSW-NNE, NE-SW, NEE-SWW, and NW-SE strikes, respectively. We were unable to determine whether some of these are reactivated synsedimentary faults.

Figure 2. Stratigraphic column of the Triassic in the Kamnik-Savinja Alps. Modified after ŽALOHAR & CELARC (2010).

Figure 3. Geological map of part of the Velika planina plateau. a) Position of the studied area. b) Geological map and position of the sections.
5. MATERIALS AND METHODS

The Velika planina member was logged and sampled in three sections on top of the Velika planina plateau (Figs. 3–4). In addition, samples from the Lower Serla Dolomite below the Velika planina member were collected from outcrops at the “Jarški dom” hut (samples Jar 1–17 on Fig. 4), and an additional sample from a massive limestone overlying the Velika planina member was taken at “Dovja raven” (sample DR-K). Altogether, 71 thin-sections 28 × 47 mm in size were made. Selected thin-sections were stained with Alizarin Red. Textures were defined according to classifications by DUNHAM (1962), and EMBRY & KLOVAN (1971). In determining floatstone, we follow the criteria of WRIGHT (1992), considering matrix as mud to silt-sized grains. Textures were also determined by WRIGHT (1992), with Alizarin Red. Textures were defined according to classification.

47 mm in size were made. Selected thin-sections were stained with Alizarin Red. Textures were defined according to classifications by DUNHAM (1962), and EMBRY & KLOVAN (1971). In determining floatstone, we follow the criteria of WRIGHT (1992), considering matrix as mud to silt-sized grains. Textures were also defined based on a comparison with examples in FLÜGEL (2010). When adding the constituents to the name of the carbonate, we follow the reverse ranking order, putting the dominant component first (e.g. packstone dominated by bioclasts and with subordinate intraclasts was named bio-intraclastic packstone), as suggested by WRIGHT (1992). The fossil material was collected from several outcrops of the Velika planina member. All specimens are housed within the Hišitj & Žalohar Palaeontological Collection, curated, and registered according to Slovenian legislation in the Slovenian Museum of Natural History, Ljubljana, Slovenia.

6. LITHOLOGICAL COMPOSITION OF THE STUDIED SECTIONS

Lower Serla Dolomite

The Velika planina member is underlain by whitish to light grey thick bedded to massive dolomite some 100 m thick, sampled at the locality “Jar” (see Fig. 3). The dolomite macroscopically contains numerous oncoids, stromatolites, bivalve and gastropod lumachellas. Several foraminifers, including Citaella dinarica (Kochansky-Devíd & Pantić) have been found in several microfacies types. Microfacies types comprise mudstone, partly washed bioclastic wackestone, partly washed intraclastic-bioclastic wackestone to packstone, dolomitized dasycladacean grainstone, microbial intraclastic rudstone, dolomitized bivalve rudstone, microbialite boundstone, and microbialite wackestone or bafflestone (Table 1; Fig. 5).

Velika planina member – section VP1

The transition from light grey Lower Serla Dolomite into darker, thinner, and finely laminated limestone beds of the Velika planina member appears to be gradual. The basal part of the Velika planina member was logged in the 26 m long section VP1 (Fig. 6). Platy to thin-bedded dark bituminous and finely laminated micritic limestone predominates. Slumps are common. Subordinate are

| Table 1. Microfacies types of the Lower Serla Dolomite (locality Jar on Fig. 3, and samples Jar 1–17 on Fig. 4). |
|---------------------------------------------------------------|
| Microfacies | Description | Figures |
|-------------|-------------|---------|
| Mudstone | Micrite containing very rare ostracods, micritic tubular fossils and echinoderms. Some dissolution voids are present. Gradually passes into bioclastic wackestone. | / |
| Partly washed bioclastic wackestone | Clasts represent approximately 30% of the area. Most are probably bioclasts, replaced by drusy mosaical cement. Bivalve shells can be recognised besides smaller oval bioclasts. Shells are encrusted by microbialite. Echinoderms, rimmed with syntactical cement, are very rare, as well as ostracods. Approximately 30% of the grains are microbialite intraclasts. The intergranular space is filled with brown dolomicrospar, locally containing small pellets (microbial in origin?). Dissolution voids are filled with large elongated crystals of carbonate. | 5a |
| Partly washed intraclastic-bioclastic wackestone to packstone (?) | Texture is heterogeneous. Grains occupy 20–50% of the thin section area. Predominant are microbialite intraclasts (estimated 75% of the grains). Bioclasts are casts of shell fragments and geniculi of dasycladaceae algae, filled by sparry calcite, echinoderm plates, and foraminifers (Endotribolites kocaetensii (Dager), ?Earlandinita sp., ?Citaella dinarica (Kochansky-Devíd & Pantić), Nodosaria ordinata Trifonova, ?Dustominae). The intergranular space is filled with mesosparite, which is partly washed out and/or corroded. Echinoderm plates are overgrown by syntactical cement. | 5b |
| Dolomitized dasycladacean (?) grainstone | Rounded recrystallized grains represent 40–50% of the total thin section area. They are in point contacts and often stuck together in bundles. Individual grains are 0.5–1.3 mm in diameter. The majority of them could belong to dasycladaceae algae. Alternatively, some smaller grains could also be interpreted as ooids. The intergranular space is filled by dolomicrosparite and anhedral to subhedral dolomite. | 5c |
| Microbial intraclastic rudstone | Intraclasts larger than 2 mm represent up to 20% of the thin section area. Most belong to microbialite (thrombolite and leiolite). Large grains are supported by the grainstone in which smaller microbialite intraclasts and peloids predominate. Very rare are ostracods (2.5%), foraminifers (Endotribolites kocaetensii (Dager), ?Earlandinita sp., ?Citaella dinarica (Kochansky-Devíd & Pantić), Nodosaria ordinata Trifonova, ?Dustominae). The intergranular space is filled by anhedral to subhedral carbonate. Echinoderm plates are overgrown by syntactical cement. Cockade textures are locally common. They are filled with zoned euhehedral dolomite crystals. | 5d-e |
| Dolomitized bivalve rudstone | Bivalve shells larger than 1 cm represent 40% of the area. Shells are replaced by dolomite cement. The supporting grainstone is nearly identical in composition to the intraclastic grainstone described above. Citaella dinarica (Kochansky-Devíd & Pantić), Earlandinita sp. and sessile foraminifers were determined among microfossils. Small gastropods are also present. Fibrous to accicular rim cement prevades drusy mosaical spar. | 5f |
| Microbialite boundstone | The sample is interpreted as microbialite boundstone with intragranular wackestone matrix. Microbial carbonate forms irregular clusters. The intergranular space is filled by mesospar, whereas some fenestrae are filled with true spar. Besides the larger microbialite clumps/clasts, it contains smaller echinoderms, foraminifers (Trochamina altemensis Koehn-Zaninetti, Earlandinita sp.), and bivalve shells. | 5g |
| Microbialite wackestone or bafflestone | Branching clasts of microbialite are surrounded by mesospar. The microsparitic matrix locally contains larger irregular cavities filled with elongated calcite, followed by subhedral drusy mosaical cement. Complete bivalves and calcimicrobes are rarely preserved. The microbialite embeds an unknown organism, which either had no skeleton or had a skeleton that later dissolved and was replaced by spar. The remaining shape reveals a tubular shape, a smooth inner side, and an irregular outer surface. | 5h |
Figure 5. Microfacies of the Lower Serla Dolomite. a) Partly washed bioclastic wackestone. Thin section 1490. b) Partly washed intraclastic-bioclastic wackestone to packstone. Thin section 1496. c) Dolomitized dasycladacean (?) grainstone. Thin section 1486. d) Large microbialite intraclast within a microbial intraclastic rudstone. Thin section 1495. e) Intraclastic grainstone matrix of a microbial intraclastic rudstone. Thin section 1497. f) Dolomitized bivalve rudstone. Thin section 1493. g) Microbialite boundstone. Thin section 1501. h) Microbialite wackestone or bafflestone. Thin section 1488.
Beds of calcarenite up to 15 cm thick, which are lighter in colour and without lamination. Seven microfacies types are determined, namely mudstone, finely laminated mudstone, *Earlandia* mudstone, peloid wackestone with ostracods, partly washed intraclastic-peloid wackestone to packstone, intraclastic-bioclastic grainstone, and bivalve floatstone (Table 2; Fig. 7). Small-scale bioturbations are locally present.

**Velika planina member – section VP2**

Section VP2 comprises dark brown to almost black micritic limestone 10.5 m thick in total. Most beds are thicker than in section VP1 from the lowermost part of the member, measuring between 15 cm and 1 m in thickness. Lamination is commonly present, but the laminae are also much thicker (approximately 1 cm). Subordinate are platy to thin-bedded beds with finer lamination, which no

![Figure 6. Sections of the Velika planina member.](image-url)
Table 2. Microfacies types of the lower Velika planina member (section VP1). *The number in brackets refers to the microfacies type number in Fig. 6.

| Microfacies Description | Figures |
|-------------------------|---------|
| Micritic matrix recrystallised into microsparite. Ostracods and bioturbations are very rarely present. | / |
| Finely laminated mudstone (*) | 7a |
| The microporosity is finely laminated. Laminae are mostly horizontal and parallel to each other, between 0.05 mm and 2.51 mm thick. In some samples, they are deformed as a result of slumping. The grey-coloured laminae are separated by thinner, 0.04–0.48 mm thick laminae of darker micrite or microporite. Besides laminae of mudstone, some rare sparse wackestone laminae up to 1 cm thick with very small peloids, foraminifers (Earlandia sp., Nodosaria ordonata Trifonova, Milliolidia), ostracods or thin-shelled bivalves are present. Microporite locally contains rhomboidal crystals of calcite. They are more common in the darker laminae. Lamination follows the outlines of the crystals. One sample contained ellipsoidal horizontal and vertical burrows filled with pellets and cutting through the laminae. Small-scale synsedimentary faults are locally present. Some samples are stylolitised concordant or oblique to the bedding planes. | |
| Earlandia mudstone (*) | 7b |
| Micritic matrix is laminated. Laminae are slightly wrinkled. They are wider and more uniformly dark than in MF 1. The presence of Earlandia tinniniformis (Mišák) is characteristic, especially in slightly darker laminae. Other foraminifers (Nodosaria ordonata Trifonova) and ostracods are rarely present. | |
| Peloid wackestone with ostracods (*) | 7c |
| Grains represent 25–40% of the area. Peloids and intracrystals represent 15–20% of the area. Ostracods with complete carapaces or separated valves are always present (8–15% of the area). Filaments, echinoderm plates, and foraminifers (Earlandia tinniniformis (Mišák), Nodosaria ordonata Trifonova, Glomospira sp., Endotriada sp., Trochammina sp.) are rare. Micritic matrix is locally recrystallised into microspar. | |
| Partly washed intracrystal-peloid wackestone to packstone (*) | 7d |
| Grains represent 30–50% of the area. They are moderately to poorly sorted; the mean grain size is 0.15 mm, while the largest reach sizes up to 5.3 mm. Peloids and micritic intracrystals strongly predominate. Ostracods, echinoderm, foraminifers (Endotriada sp., Earlandia sp., fragments of brachiopods and bivalve shells (casts filled with sparry calcite) are very rare. Micritic matrix is partly washed out, and part of the intergranular space is filled with drusy mosaic calcite. Echinoderm plates are overgrown by syntaxial calcite cement. Note: Similar microfacies was sampled in section VP3. | |
| Intraclastic-bioclastic grainstone (?) (*) | 7e |
| Grains are moderately well sorted. They represent 50% of the area and are in point contacts. Their mean size is approximately 0.15–0.2 mm. Small micritic intracrystals and peletoiods predominate (35% of area). Rare coated grains built by sessile foraminifers and microbials are also recognizable. Particles with micritised margins and filled with sparry calcite occupy approximately 7% of the area. Foraminifers (3%), echinoderms (3%) and ostracods are less common. The foraminifers are Glomospira sp., Endotriada spheninca Vachard et al., Endotriada bithynica Vachard et al., Earlandia gracilis (Pantić). The cement is subhedral, probably drusy mosaic calcite. | |
| Bivalve floatstone (*) | 7f |
| The dominant bioclasts are bivalve shells. They are in point or long contacts. Bivalves are mostly disarticulated, but the valves are not fragmented, up to 2 cm long. Gastropods are rarely present. The intergranular space is filled with micritic matrix. | |

Table 3. Microfacies types of the middle Velika planina member (section VP2). *The number in brackets refers to the microfacies type number in Fig. 6.

| Microfacies Description | Figures |
|-------------------------|---------|
| Micritic matrix predominates. Elongated lenses of microspar suggest bioturbation. Rare bivalves and unidentified shells are present. | 8a |
| Bioturbated mudstone with sparse bioclasts (*) | 8b |
| Micritic limestone exhibit light and dark brown sub-millimeter thick laminae. The darkest laminae have wavy or even more irregular upper surfaces and consist of dense micrite. The wider and lighter laminae are mudstone or pellet packstone. Pellet grainstone is locally present, as well as fenestrae. | |
| Microbially-bound grainstone with fenestral fabric (stromatolite) (*) | 8c |
| Microbialite laminae are dense, structureless, or made of clots of dark micrite. Desiccation cracks and fenestrae are locally present. Microbialite binds grainstone with peloids and/or particles of dissolved and neomorphically replaced bioclasts. Foraminifers (Glomospirella irregularis (Moeller)) are locally present. | |
| Partly washed intraclastic-peloidal wackestone to packstone (*) | / |
| See description in Table 2. Foraminifers in this part are: Glomospira sp., Palaeolituonella meridionalis (Luperto), Endotriada sp., Trochammina sp., Earlandia sp., and Nodosariidae. | |
| Peloidal wackestone (*) | / |
| Micritic matrix predominates. Angular to subangular peloids represent 15% of the thin section area. Subrounded to rounded spartic grains are also present. Foraminifers (Glomospira sp., Earlandia sp.) are very rare. | |
| Bioclastic-peloidal grainstone (*) | 8d |
| Grains occupy 65% of the total area. They are in point contacts. The prevailing grain size is around 0.15 mm (ranges between 0.03 mm and 0.7 mm). The most common grains are subrounded to rounded spartic bioclasts (45% of the area), which may have been leached-out and replaced by spar. The rest of the grains are peloids (20% of the area), which are subangular to angular. Foraminifers (*Glomospira sp., Earlandia sp.) are very rare. Intergranular space is filled with drusy mosaic spar. | |
| Oncoid floatstone (*) | 8e |
| Oncoids form 10–40% of the area. They are up to 1.5 cm large. Cortices consist of dark micrite and sessile foraminifers. Vagile foraminifers were occasionally trapped in oncoids. While most cores cannot be determined, some oncoids formed around bivalve shells and genula of dasycladacean algae. The space between oncoids is filled by grainstone. In thin section 1525 it is made of peloids and small oncoids. Foraminifers (Glomospira sp., Glomospirella irregularis (Moeller)) are also common, while gastropods and casts of small particles filled with sparry calcite are rare. In contrast the grainstone in thin section 1529b consists mostly of well-rounded particles preserved as casts filled with sparry calcite and micritic intracrystals. Rare gastropods, dasycladacean algae, echinoderms, and bivalve shells are less common than in thin section 1525. Foraminifers are less represented by the same taxa. The cement is drusy mosaic, in thin section 1529b proceeded by accicular rim cement. Some larger vugs are filled with euhedral crystals of zoned (banded) carbonate and crystal silt. Echinoderm plates are overgrown by syntaxial cement. | |
| Peloid-bioclastic grainstone (*) | 8f |
| Grains represent 50% of the area. They are in point contacts. Except for some large (up to 2.5 mm) gastropod shells, the rest of the grains are moderately sorted. Bioclasts and peloids are present in approximately equal amounts. Subangular to subrounded spartic particles with microparticulate outlines represent the majority of the former. Among the recognisable bioclasts are foraminifers (Glomospira or Huyenella sp.) and some bivalve fragments. Cockade structures are rimmed by bladed spar and filled partly with crystal silt and partly by subhedral dolomite. Subhedral dolomite also fills the intergranular space. | |
| Mud-supported breccia (*) | / |
| Mudstone clasts are very poorly sorted and angular, floating in micrite. Remarks: Breccia appears in pockets within micritic limestone. | |
longer form thicker bundles. Slumping of the sediment is evident, and intraclastic rudstone (“flat-pebble breccia”) is locally present. Mudstone and mudstone with filaments and sessile foraminifers (Table 3) are the only microfacies types in this section.

**Velika planina member – section VP3**

The uppermost part of the Velika planina member was logged in section VP3. The total length of the section is approximately 72 m, but large parts of it are poorly exposed. The bedding, however, remains constant. Platy to thin-bedded dark brown mudstone predominates in the first 16 m of the section. Subordinate are densely bioturbated beds of micritic limestone 70 – 100 cm thick. Above, thin to medium-thick beds of light grey limestone follow. Possible neptunian dykes were observed in one bed. Above the 30-metre mark of the section the limestone becomes light grey in colour. Wavy lamination and birdseye fenestrae are commonly present. Calcarenite is present along with micritic limestone, and oncoids are present in the uppermost part of the section. Microfacies types from the VP3 section are bioturbated mudstone with sparse bioclasts, microbial laminated mudstone (stromatolite),
microbially-bound grainstone with fenestral fabric (stromatolite), partly washed intraclastic-peloid wackestone to packstone, peloid wackestone, bioclastic-peloid grainstone, oncoid floatstone, peloid-bioclastic grainstone, and mud-supported breccia (Table 4; Fig. 8). *Citaella dinarica* (KOCHANSKY-DEVIDÉ & PANTIĆ) was found approximately 20 m higher in a seemingly massive limestone (sample DR-K in Fig. 4).

**Macrofossils of the Velika planina member**

Macrofossils can be found throughout the entire Velika planina member; however, they are most frequent in its lower part (section VP1). The trace fossil *Chondrites* is relatively commonly present in the laminated bituminous limestone of the Velika planina member (Fig. 9c,d). In the lower part of the member there are several beds with accumulated imprints of the bivalves of the genus *Modiolus*. The shells are only rarely preserved. *Bakevellia costata* (Fig. 9a) is rarer, as well as some well-preserved crinoid specimens (Fig. 9b). The latter belong to the genera *Dadocrinus* and *Holocrinus*. One complete, fully articulated crinoid specimen probably belongs to a new yet undescribed crinoid family. Small ammonoids are extremely rare. The organisms with predominantly chitinous shells are generally well preserved. In some beds we find numerous lingulid inarticulate brachiopods. The inarticulate brachiopods of the genus *Discinisca* are rarer and occur only as single specimens. Other brachiopods are also present, but are not sufficiently preserved for a determination. Crustacean fossils are very rare (Fig. 9d), e.g. mass mortality beds with lobsters in their larval stage. Vertebrate fossils are more common in the...
lower part of the member. Some specimens are completely articulated and can even bear impressions of soft tissues. Others show partial disarticulation (Fig. 9f). Several remains of sauropterygian reptiles of the order Nothosauroidea were discovered, among them also a complete, fully articulated specimen more than 1 m long. Several genera of actinopterygian fish are also present (see TINTORI et al., 2014a). These include at least two different species of the genus Saurichthys, together with Eosemi- onotus, Placopleurus, Furo (Fig. 9e), at least one other neopterygian fish, probably closely related to the basal semionotiform Sangiorgioichthys, and the isolated remains of a coelacanth. Coprolites are quite abundant (Fig. 9g).

7. DISCUSSION ON CHARACTERISTICS AND EVOLUTION OF THE BASIN

Triassic rocks, which today form the majority of the Kamnik-Savinja Alps, were deposited on the continental shelf offshore from the eastern equatorial Pangea (HAAS et al., 1995; STAMPFLI & BOREL, 2002; STAMPFLI & KOZUR, 2006). No signs of tectonic activity during the Early Triassic have been reported from this region so far, and a shallow marine mixed carbonate-siliciclastic shelf developed. With the rising sea level, carbonate sedimentation prevailed, giving rise to the Anisian carbonate platforms (BUSER, 1989, 1996). The Velika planina member, under- and overlain by light-coloured peritidal carbonates, testifies

Figure 9. Fossils of the Velika planina member. a) A bivalve Bakevellia costata; length 7 mm. b) An undescribed crinoid; length of the crown 9 mm. c) Chondrites ichnogenus; width of the photo is 4 mm. d) A mass mortality bed with arthropod remains and the trace fossil Chondrites; length of the arthropod on the right is 5 mm. e) A fish of the genus Furo coated by ammonium chloride sublimate; length of the fish is 5 cm. f) A sacral region of a sauropterygian reptile of the order Nothosauroidea exposed on the site, length of the specimen is 9 cm. g) A coprolite; length is 5 cm. Image credit: (A, B, E): Jure Žalohar Tomaž Hitij; (C, D, F): Tomaž Hitij.
to a relative deepening of part of the Anisian platform, probably due to local tectonic subsidence. The finding of the foraminifer *Citelloa dinarica*, both in the underlying rocks and in the transitional interval to the overlying peritidal limestones, confines the deposition of the Velika planina member to the early to middle Anisian (REETORI, 1995; UENO et al., 2018). This age estimation is consistent with the previously estimated pre-Pelcosinian age of the Velika planina member based on the biostratigraphy of fossil fishes (TINTORI et al., 2014a).

The diversity of bioclasts, which include echinoderms and dasyycladacean algae, and the light grey colour of the underlying massive or poorly bedded Lower Serla Dolomite suggests initial deposition in an oxygenated shallow marine environment of a carbonate platform. The platform was microbially-dominated, as evidenced by the abundance of microbialites. Bivalve and gastropod lumachellas represent local accumulations of shells.

The absence of breccia at the base of the Velika planina member and a gradual shift from light grey intertidal dolomites to dark bituminous limestone suggest a gradual deepening and the subsequent establishment of a shallow restricted basin. Due to the limited areal extent of the basin, the deepening was probably caused by subsidence along normal faults. Slumping is especially common in the lower and middle part of the Velika planina member (sections VP1, VP2), but was not observed in the uppermost part (section VP3). This could suggest the basin was deeper in its early evolution, or (more likely) initially a more active tectonic subsidence, with a quiescence of tectonic activity later on. The relatively shallow nature of the basin, or at least the lack of connection with an open sea, is supported by the near-absence or even lack of open-marine plankton and nektan, such as radiolarians and ammonoids, within the Velika planina member and a subsequent gradual transition into oxygenated shallow marine facies within section VP3.

The lower part of the Velika planina member (section VP1) is recognised by the predominance of finely laminated mudstone. The facies association here is similar to the lower Ladinian Me-ride Limestone of Monte San Giorgio in southern Switzerland/northern Italy (FURRER, 1995a; STOCKAR, 2010: “laminite lithofacies”), the upper Anisian to lower Ladinian Posanto Formation in eastern Switzerland (BURGÉN et al., 1995; FURRER, 1995b, 2019), and the Cretaceous Komen limestone in Slovenia (PALCI et al., 2008). At this stage, the water column was likely stratified, with oxygenated near-surface layers and hypoxic to anoxic conditions at the bottom. This is suggested by the preservation of coprolites, as well as articulated vertebrate skeletons. Mudstone, finely laminated mudstone, and *Earlandia* mudstone all represent background sedimentation. The darker laminae are richer in organic matter and could represent microbial mats on the basin floor. The general absence of larger benthos, the bituminous nature of the limestone, and the fine lamination of the sediment suggest poorly ventilated bottom conditions. This is supported by the profuse presence of *Chondrites* and the near exclusion of all other trace fossils (BROMLEY & EKDALE, 1984). However, the local presence of bioturbations, small and rare bi- valves, rare crinoids, and even the presence of small benthic foraminifers, such as *Earlandia* and thin-shelled lagenids, suggest an occasional presence of free oxygen in the uppermost sediment. *Earlandia* is considered a benthic opportunist (KRAINER & VACHARD, 2009), and thin-shelled lagenids were tolerant of oxygen-poor conditions (STOCKAR, 2010). Partly washed intraclastic-peloid wackestone to packstone and intraclastic-bioclastic grainstone, on the other hand, indicate deposition in a more energetic setting. Size-sorting of particles indicates transport, and at least some of the bioclasts (e.g., foraminifers *Glomospira* sp., Endothyracea, and mollusc fragments) probably originated from a better aerated shallow marine environment. We suggest deposition from diluted turbidity currents. Parautochthonous or allochthonous origin is also suggested for peloidal wackestone with ostracods, and bivalve floatstone.

Higher up in the succession (sections VP2, VP3), beds are thicker and lamination is less pronounced. More sediment was perhaps shed from the surrounding shallow carbonate platform, or perhaps the conditions on the sea floor became more stable and less restricted. In the last of the logged sections (VP3), the intra-platform basin’s deposits gradually give way to the well oxygenated shallow platform carbonates of the platform top. Bioturbation is common in the lower part of the VP3 section, and from the 30-metre mark upwards there are several indicators of peritidal conditions: wavy stromatolites, fenestrae, even a foraminiferal assemblage, dominated by glomospiral forms. Grainstones with various bioclasts, especially fragments of molluscs, again suggests an environment densely populated by benthic invertebrates. Finally, oncoids from the top of the section indicate the presence of waves and/or currents.

Even though the Velika planina member was initially considered to represent a deeper marine basin (HITJU et al., 2010a), the evidence presented above tends to support the idea of a rather shallow intraplate basin. This is also supported by the vertebrate remains found in the lower part of the Velika planina member. Among the groups of marine reptiles, only nothosauroids have been identified so far, and these were limited to shallow intraplate basins and shallow epicontinental seas (RIEPPEL, 1999; ČERNANSKY et al., 2018).

8. CONCLUSIONS

The Velika planina member was deposited within a relatively shallow and restricted intraplate basin during the early to middle Anisian. The basal part of the member is dominated by finely laminated mudstone deposited in a stratified basin with mainly hypoxic to anoxic bottom conditions. Actinopterygian fishes and marine reptiles are well preserved in this facies due to limited bioturbation and scavenging on the sea floor. Moving upwards, restricted facies gradually gives way to well-oxygenated shallow platform carbonates of the Lower Serla Dolomite.

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REFERENCES

BEARDMORE, S.R. & FURRER, H. (2016): Taphonomic analysis of *Saurichthys* from two stratigraphic horizons in the Middle Triassic of Monte San Giorgio, Switzerland:− Swiss J. Geosci., 109, 1–16. doi: 10.1007/s00015-015-0194-z

BEARDMORE, S.R. & FURRER, H. (2016): Taphonomic variation within a Middle Triassic fossil lagerstätte (Cassina beds, Meride Limestone) at Monte San Giorgio:− Paläontol. Zeitschrift, 53, 49–67. doi: 10.1007/s12542-016-0415-7

BENTON, M.J. (2010): The Triassic:− Current Biology, 26/23, R1205–R1225. doi: 10.1016/j.cub.2016.10.060
