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Anisian Strelovec Formation in the Robanov kot, Savinja Alps (Northern Slovenia)

Anizijska Strelovška formacija v Robanovem kotu, Savinjske Alpe (Severna Slovenija)

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Ključne besede: srednji trias, ilirij, anoksični bazen, drobnozrnati turbiditi, zdrsi, progradacija

Abstract

A detailed sedimentological features of the Slatinski plaz section with a transition from the deep-water Anisian (Illyrian) Strelovec Formation to the Ladinian shallow-water Contrin Formation have been presented. The Strelovec Formation is divided into five different lithostratigraphic units that are characterised by dark hemipelagic and pelagic thin-bedded limestones and dolomitic mudstones that are frequently intercalated with deposits of gravity-mass flows, slump and slide to fine-grained low-density turbidity origin. The Strelovec Formation was deposited in a hydrodynamically quiet, pelagic deeper-water anoxic environment, most probably on a gentle platform slope. In the upper part of the formation, the presence of olistolith blocks of shallow-water limestones indicates the closing of the prograding shallow-water platform wedge. Massive dolostones of Unit 6 mark the complete filling of the basin and the beginning of the shallow-water sedimentation of the Contrin Formation in the Early Ladinian.

Izvleček

V članku predstavljamo detajlni sedimentološki profil Slatinski plaz, v katerem lahko opazujemo prehod iz anizijske (ilirske) globljevodne Strelovške formacije v ladinijsko plitvomorsko Contrinsko formacijo. Strelovško formacijo smo razdelili na pet litostratigrafskih enot, za katere je značilno menjavanje temnih hemipelagičnih tankoplastnatih apnencev in dolomitov (mudstone), med katerimi so pogosti sedimenti gravitacijskih tokov (od zdrsov do zdrobnozrnatih turbiditov). Strelovška formacija se je odlagala v hidrodinamsko mirnem, pelagičnem, globljevodnem anoksičnem okolju, najverjetneje na blagem pobočju. V zgornjem delu formacije se pojavijo olistolitni bloki plitvovodnih apnencev, ki nakazujejo približevanje progradacijskega klina napredujoče platforme. Šesta litostratigrafska enota vsebuje plivovodne kamnine zgodnjeladinijske Contrinske formacije, ki kažejo, da se je globljevodni bazen v tem času že popolnoma zasul.

Introduction

The Strelovec Formation is represented by Anisian bituminous thin-bedded limestone and dolomite deposits with intercalation of marls and clays that can be traced across the entire Kamik-Savinja Alps (Celarc, 2004a, Vičič, 2014). It was first defined by Celarc (2004a) and later investigated due to the rich macrofossil biota (Hitij et al. 2010; Hitij 2012; Žalohar & Hitij 2013). However, compared to younger Triassic rocks (Celarc, 2004a, 2004b; Celarc & Goričan, 2007; Celarc & Kolar Jurkovšek, 2008; Celarc et al., 2013, 2014; Rožič 2008, Rožič et al., 2009, 2013; Gale, 2010, 2012; Gale et al., 2013, 2014, 2015) it still remained insufficiently investigated.

In order to fill this gap, we present a first detailed sedimentological investigation of the Strelovec Formation from the almost perfectly exposed section (Slatinski plaz) in the Robanov kot valley (Kamnik-Savinja Alps, northern Slovenia). The aim of this study is to describe and determine different microfacies of the Strelovec Formation, to define sedimentation processes and environment and to interpret evolution of the Anisian basin in the studied area.

Geological setting

The investigated succession is located in the Kamnik-Savinja Alps in the SE part of the Robanov kot valley (Fig. 1), and structurally belongs to the eastern part of the Southern Alps (Placer, 2008). During Middle Triassic times, the area was situated on the southwestern Neotethyan embayment /shelf of the opening Meliata-Maliac Ocean (e.g. Stampfli et al., 2002; Schmidt et al., 2008).

From the Late Permian onward, the eastern Southern Alps belonged to the Slovenian Carbonate Platform (Buser, 1989). During the rifting phase in the middle Triassic, this platform was dissected into numerous small platforms bounded by relatively shallow basins, most of which were completely infilled in the early Late Triassic time (Winterer & Bosellini, 1981; Doglioni, 1987; Buser, 1989; Bertotti et al., 1993; Ogorelec & Rothe, 1993). In the Robanov kot valley, Lower Triassic to

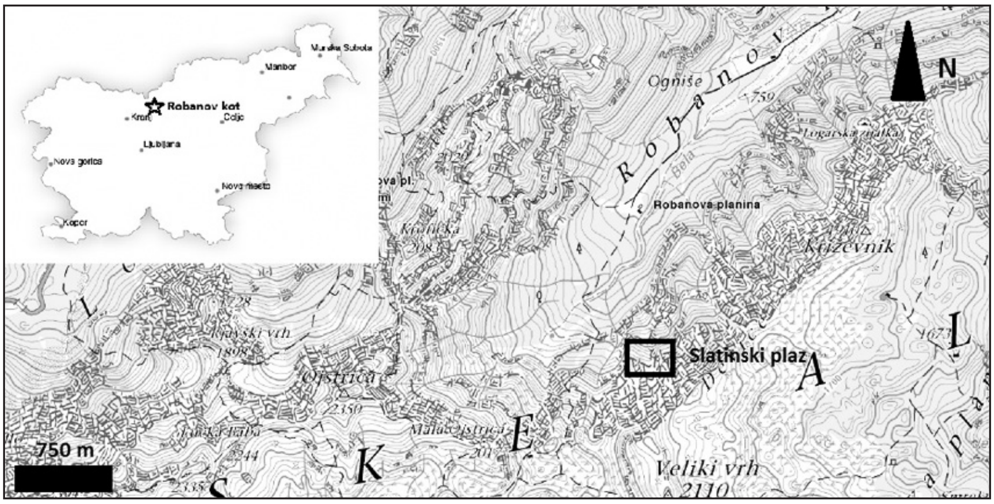


Fig. 1. Location of the studied section. A) Position of the Robanov kot valley. B) Position of the section (square).

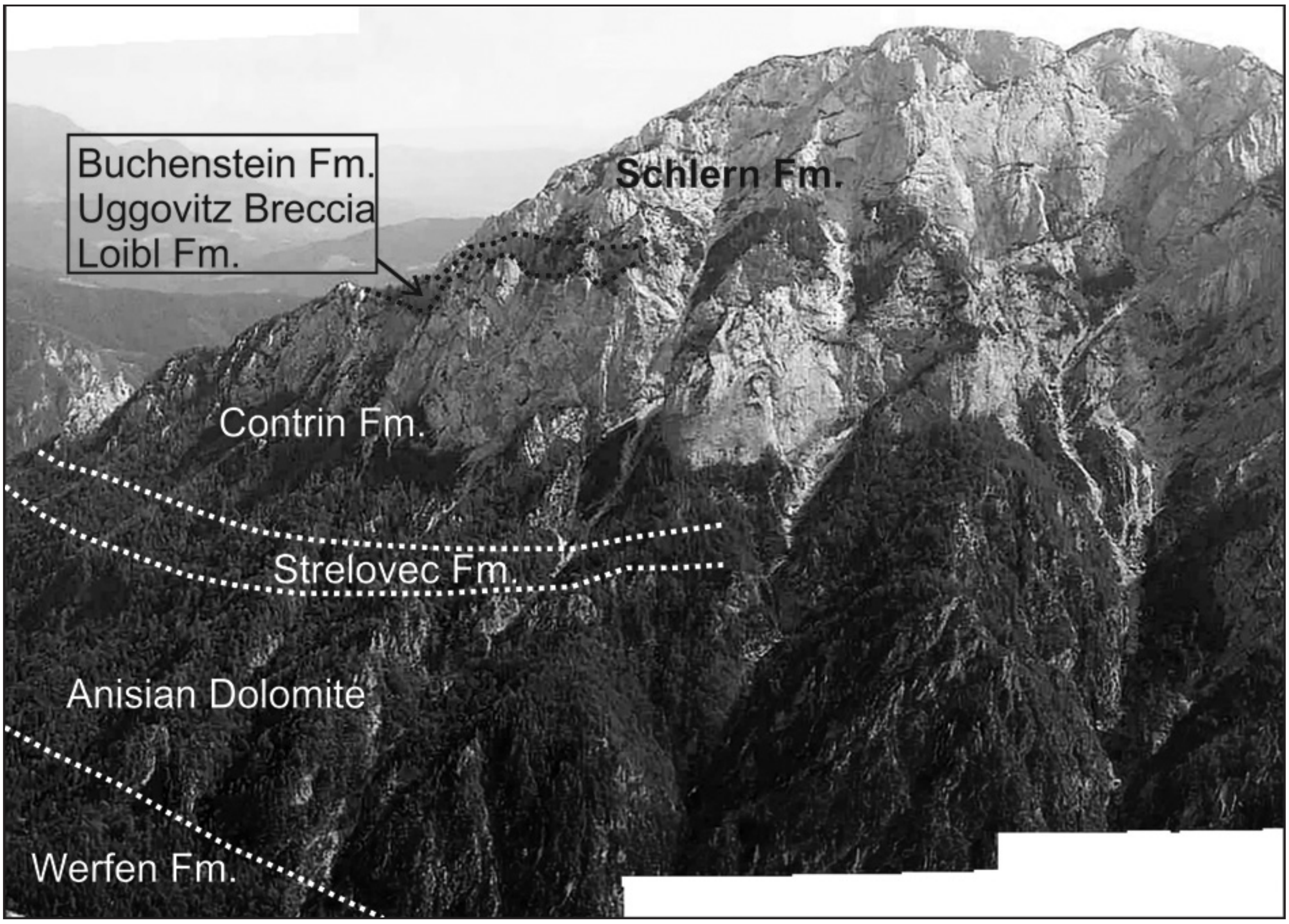


Fig. 2. Triassic formations cropping out in the Robanov kot Valley, below Križevnik Hill (modified after Celarc, 2004a).

lowermost Upper Triassic rocks crop out (Celarc, 2004a, Celarc et al., 2013, Fig. 2). The succession commence with a deposition of the Lower Triassic marls, and sandstones intercalated with of oolitic limestones and dolostone beds (Werfen Formation) continues with a deposition of Anisian bedded and massive dolostone. These rocks belong to the Slovenian Carbonate Platform (cf. Buser, 1987, 1989) that are conformably overlain by the deeper-water upper Anisian (Pelsonian to Illyrian) Strelovec Formation, composed of dark-coloured thin-bedded limestone. The Strelovec Formation is concordantly overlain with the shallow-water Anisian (Illyrian) Contrin Formation, characterised by bedded and massive limestones with rare intercalations of dolostones (Celarc et al., 2013). Middle Anisian to lower Ladinian strata are represented by the Loibl Formation, Uggowitz Breccia and Buchenstein Formation composed of thin-bedded limestones with cherts, tuffs, conglomerates, breccias, calcarenites and bedded and massive limestones representing renewed extensional tectonic activity and the formation of small basins. The youngest formation in the Robanov kot valley is Upper Anisian and Ladinian massive limestone and dolomite of the Schlern Formation, recording a progradation of the shallow-water platform over deposits of the deeper basin (Celarc et al., 2013).

The first workers to investigate Triassic strata in the Robanov kot area were Teller (1898) and Seidl (1907, 1908). The area was later mapped for the Basic Geological Map of Yugoslavia, at a scale of 1: 100 000 by Mioč et al., (1983). The Strelovec Formation was first defined and described by

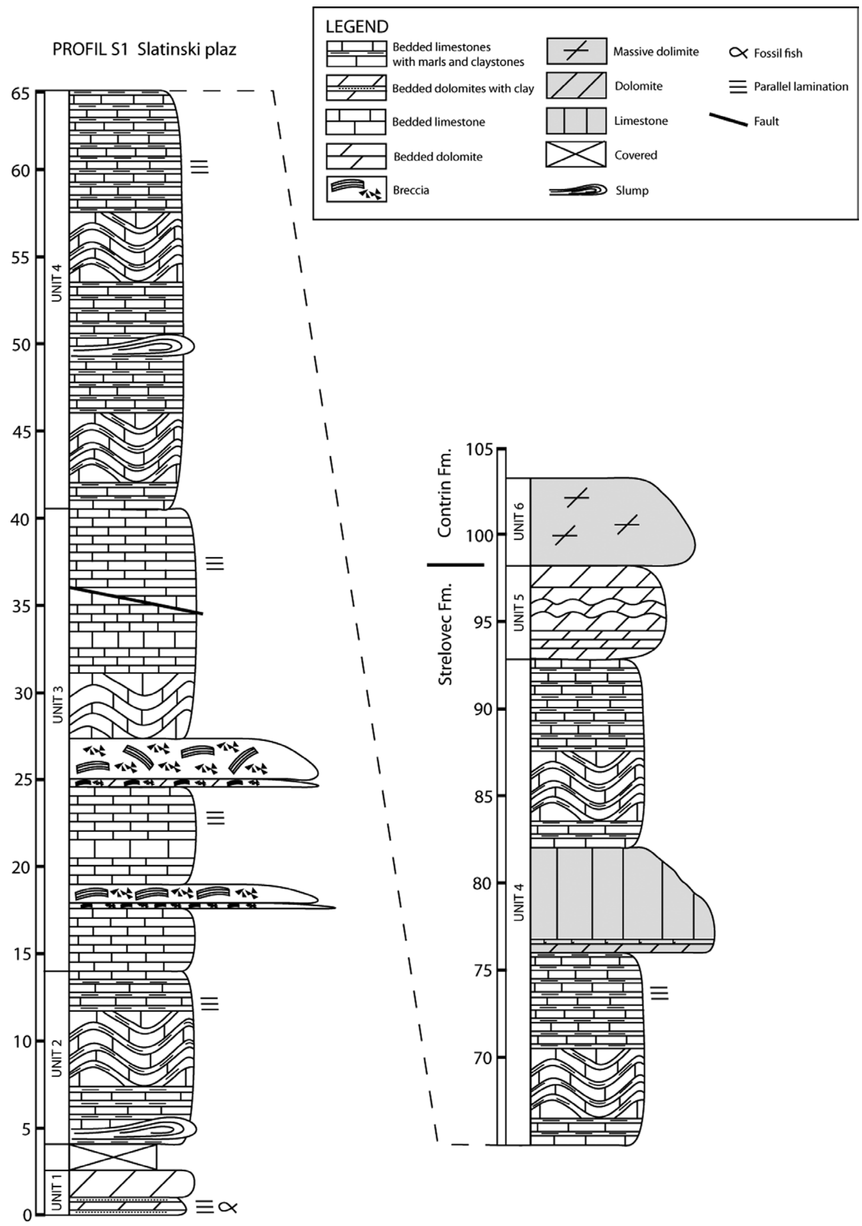


Fig. 3. Slatnikov Plaz section.

Celarc (2004a) who, on the basis of stratigraphic position, ascribed it to the upper Anisian to lower Ladinian age. The rich fossil fauna of the Strelovec Formation was described by Hitij et al. (2010), Hitij (2012), and Žalohar & Hitij (2013).

Materials and methods

The Anisian succession was recorded in the Slatnikov plaz section (lat. 46°21'55.76", lon. 14°39'29.23") by a standard sedimentological procedure (logging in scale 1:50). Total of twenty five thin sections were made for petrographical and sedimentological analysis that were conducted on a Zeiss Axioplan 2 microscope using plane and polarised light. The thin sections were photographed with a Zeiss AxioCam HRc camera. Limestones were classified according to Dunham's (1962) classification. The mineral composition of marls was determined for two samples by X-ray powder diffraction (XRD), using a Philips PW3710 X-ray diffractometer equipped with Cu–Kα radiation and a secondary graphite monochromator. Data were collected at 40 kV and a current of 30 mA in the range from 2–70° 2θ at a rate of 3° 2θ min^{-1}.

Additionally, composite conodont samples of 2.5–3 kg weight were collected aiming to determine the exact biostratigraphic position of the Strelovec Fm. The samples were crushed and treated with diluted acetic acid following standard procedures. Unfortunately, all analysed samples proved to be negative.

Slatinski plaz section

The Slatinski plaz section is 102 m long and exhibits a transition from the Strelovec to Contrin Formations (Fig. 3). The section is divided into six distinct lithostratigraphic units.

Lithostratigraphic Unit 1: *dark grey laminated thin-bedded dolostones with intercalated beds of greyish clays*

Unit 1 represents the base of the Slatinski plaz section and is composed of a 2.5 m-thick package of alternating dark grey, thin to thick bedded and horizontally laminated dolostones and thin beds of dark grey clays (Fig. 4). The contact with the underlying Anisian dolostones is not visible in the section.

Dolostones are thin-bedded or laminated (with the exception of one 1.5 m-thick bed in the middle of the unit). Lamination occur due to alternation of 180–1100 µm thick laminae of dark dolomicrite light crystalline dolomite with

Fig. 4. Grey thin-bedded dolostones of Lithostratigraphic Unit 1.

Fig. 5. Fish fossil (*Eosemionotus sp.*,-) discovered in Unit 1. Fish is 5 cm long.

Fig. 6. Alternation of black thin-bedded and laminated limestones with marls and claystones of lithostratigraphic Unit 2.

350–2800 µm thick laminae of light crystalline dolomite. Horizontal laminae predominate; wavy laminae occur rarely (Pl. 1, fig. 1). In the dolostones mud rich types predominate with a grain to matrix ratio of 15:85. Grains are represented mainly by poorly sorted peloids, whereas grains of unknown origin occur rarely. Up to 20 µm large pyrite grains are also present. The microfacies also contains amorphous organic streaks and seams that occur parallel to lamination. The finest, muddy component is represented by homogenous dolomicrosparite and dolomicrite. The dolostones in rare cases contain extremely well preserved macrofossils of fish (*Eosemionotus* sp., Fig. 5), coprolites and brachiopods.

Lithostratigraphic Unit 2: *black laminated thin-bedded limestones with intercalated beds of dark grey marls and claystones*

Unit 2 conformably overlies Unit 1, however the contact is covered in the section. Unit 2 is 10 m thick and is represented by an alternation of black laminated and thin-bedded limestones and dark grey marls (Fig. 6).

Limestones are thin-bedded and horizontally laminated mudstones (Pl. 1, fig. 2) with a grain to matrix ratio of 10:90. Lamination are expressed as an alternation of thicker (up to 3 mm) micrite laminae with up to 0.5mm thick laminae of microsparite (Pl. 1, fig. 3). Grains are represented by recrystallised bioclasts, small pyrite grains and rare glauconite grains. The microfacies also contains amorphous organic matter disseminated in the matrix and /or streaks and seams parallel to the lamination.

The marl intercalations are up to 1 cm thick and are composed of illite/chlorite, dolomite, calcite, quartz and rare micas.

Lithostratigraphic Unit 3: *black laminated thin- to medium-bedded limestones with rare interbeds of breccias*

Unit 3 conformably overlies Unit 2. The contact is gradual but over a short distance. Unit 3 is 27 m thick and is characterised by black limestones (Fig. 7) with rare interbeds of breccias.

Fig. 7. Black, thin-bedded and laminated limestones of lithostratigraphic Unit 3.

Limestones are mainly thin- to medium-bedded; only a few thicker beds (up to 1 m) are present. Laminations are expressed as an alternation of 0.5–1 mm thick horizontal laminae of microsparite and micrite. In rare cases normal grading from micrite to microsparite occur (Pl. 1, fig. 4). Wispy and wavy discontinuous laminae are also present (Pl. 1, fig. 4). Mudstone lime types predominate while carbonate grains represented mainly by poorly sorted peloids, and recrystallised bioclasts are subordinate. Pyrite crystals are rare. Similar to the previously described microfacies, also amorphous organic component is common.

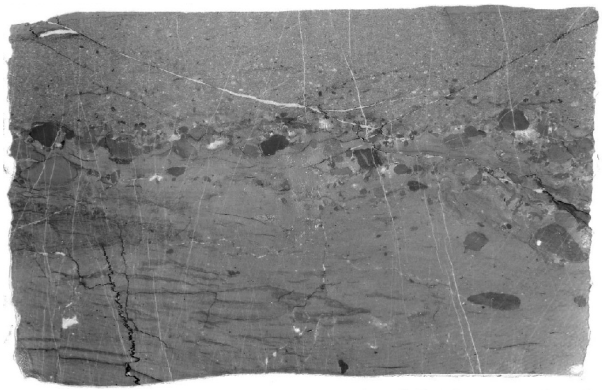


Fig. 8. Polished slab of intraclastic limestone. Lithostratigraphic Unit 3. Longer side of photo is 4 cm long.

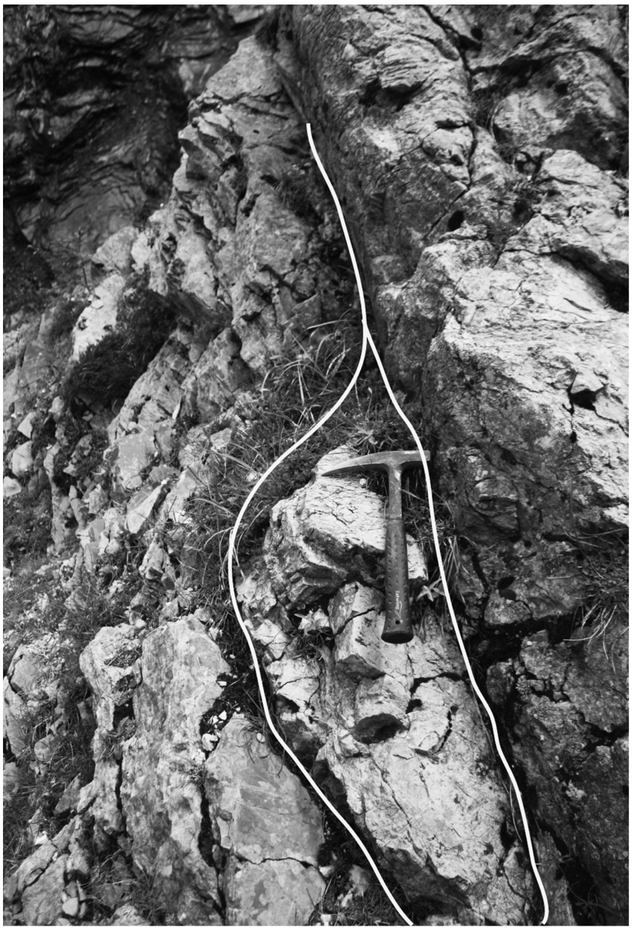


Fig. 9. Intercalated laterally discontinuous breccia bed. Lithostratigraphic Unit 3.

Rare thin-bedded intraclastic limestones are also present (Fig. 8). They are wackestones to packstones composed almost exclusively of small elongated, sub-rounded and rounded intraclasts of micritic limestones. Fragments of echinoderms are extremely rare. The matrix is micrite and rarely microsparite.

Matrix-supported breccias occur occasionally in the Unit 3. The beds are up to 2.6 m thick and in places represent laterally discontinuous beds (Fig. 9) perched into underlying lithologies. Clasts are up to 9 cm in diameter and are composed of microsparite. Occassionaly rip up clasts composed of laminated black limestone occurr (Fig. 10). Matrix of breccia is composed of rare peloids and some pyrite crystals embedded in microsparite and micrite.

Lithostratigraphic Unit 4: *black laminated and thin-bedded limestones with intercalated beds dark grey marls and claystones and large blocks of light grey limestone*

Unit 4 is 52 m thick and is composed of limestones and marls identical to those of Unit 2. In the upper part of the unit large megablocks of light grey limestone occur (Fig. 11). The most characteristic feature of the Unit 4 is numerous

Fig. 10. Intraformational breccia with large clasts, composed of ripped-up and deformed beds of underlying limestones. Lithostratigraphic Unit 4.

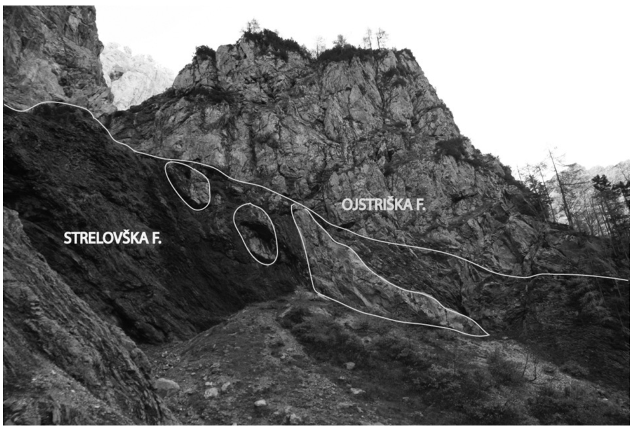


Fig. 11. Large olistolith blocks of shallow-water limestones in the upper part of lithostratigraphic Unit 4.

Fig. 12. Brown laminated, thin- to medium-bedded dolomites with erosional channels. Lithostratigraphic Unit 5.

Fig. 13. Conformable contact between Strelovec Formation (lower part of the photo) and Contrin Formation (upper right part of the photo).

channels eroded into underlying beds, slumps and synsedimentary folds.

Limestones are thin-bedded and horizontally laminated mudstones with only rare occurrence of wackestones (Pl. 1, fig. 5). Laminations are expressed as an alternation of micrite with microsparite laminae (Pl. 1, fig. 3). The grains are represented by recrystallised bioclasts, small pyrite grains and rare glauconite grains. Amorphous organic matter impregnates the matrix and also forms streaks and seams parallel to the lamination. The matrix in wackestones is microsparite and micrite.

Large blocks of light grey limestone are up 6.3 m in size and are composed of dolomitised medium to thick-bedded and massive limestones. Beds of black limestone underlying blocks are strongly deformed as slumps.

The dolomitised limestones from the lower part of the blocks are dark grey mudstones. The grain to matrix ratio is 10:90. The grains are rare echinoderm fragments and pyrite grains. Limestones from the upper part of the blocks are light grey wackestones to packstones. The grain to matrix ratio is 45:55. The grains are represented by bioclasts of echinoderms, shell fragments, fragmented microbialites, intraclasts and peloids (Pl. 1, fig. 6). Glauconite and small pyrite grains are rare. The matrix is mainly micrite, rarely microsparite.

Lithostratigraphic Unit 5: *brown laminated, thin- to medium-bedded dolostones*

Unit 5 represents the 5.5 m thick uppermost part of the Strelovec Formation. It is represented by thin- to medium -bedded laminated dolostones that contain clearly visible small channels eroded into underlying beds (Fig. 12).

Dolostones in the lower part of Unit 5 are laminated mudstones with micrite matrix and rare small pyrite grains. The matrix is micrite.

Lithostratigraphic Unit 6: *Contrin Formation: thick-bedded bioclastic dolostones*

Unit 6 conformably overlies Unit 5. The deposition started with one 60 cm thick bed of dolostone, followed by massive dolostone (Fig. 13).

The lowermost bed of Unit 6 is bindstone composed exclusively of microbialites with microsparite infill (Pl. 1, fig. 7).

Massive dolostones of Unit 6 are wackestones with a grain to matrix ratio of 30:70. The grains are represented by echinoderm fragments, foraminifera, and algal fragments, fragments of microbialites, intraclasts and peloids (Pl. 1, fig. 8). The grains are embedded in micrite and rarely sparite.

Age of Strelovec Formation

Based on stratigraphic position, Celarc et al. (2013) assigned the Strelovec Formation ranging from Pelsonian to Illyrian. Unfortunately, during our study, no age-relevant fossils were found in the Strelovec Formation.

Depositional environment of the Strelovec Formation

Microfacies in units differentiated in the Strelovec Formation share similar features. The predominance of fine-grained textures (mudstone), presence of organic matter, presence of horizontal lamination, thin bedding and absence of shallow-water elements (with the exception of rare peloids) suggest to hemipelagic and pelagic sedimentation in a hydrodynamically quiet deeper-water environment. According to Stow's (1986) classification of pelagic facies, these rocks correspond to the well-laminated and well-bedded organic rich facies.

Additionally, some beds exhibit normal grading and wispy and wavy discontinuous laminations and are also channelized into underlying beds (these features are especially evident in units 4 and 5, but not exclusive in Units 2 and 3). These features indicate deposition from low-density, fine-grained muddy turbidites (Piper & Stow, 1991).

Within hemipelagic limestones and fine-grained muddy turbidites slumps, synsedimentary folds and intraformational breccias were recognised as well. The nature of the clasts in breccias indicates redeposition within the sedimentary basin. In our opinion, these mass movement deposits represent a continuum of facies that evolved along slope environment. Facies include slides slumps that in some cases evolved into debris to mudflows and turbidites (cf. Coniglio & Dix, 1992; Whitham, 1993; Stow et al., 1998; Chough, 2001; Flügel, 2010). This interpretation is further proved by the fact that in some breccias, we could follow the deformation of indivudual beds: from initial folding, to breaking, and disintegration, resulting in the formation of the clasts that finally form breccias.

Common features of the Strelovec Formation are also fine lamination of limestones, a relatively high content of amorphous organic matter, the presence of pyrite and almost perfectly preserved fish skeletons (Hitij et al., 2010). All these features are indicative of sedimentation in a dysoxic or anoxic deeper-water environment with poor water circulation which allowed the preservation of organic matter, fish skeletons and also lack of bioturbation due to apparent absence of infounal biota. (e.g. Wignall, 1994).

In the lower (Units 1 and 2) and middle (Unit 4) part of the succession thin beds of marls and claystones are intercalated within limestones and dolostones. These beds indicate periods of intensified input of fine-grained clastic material into the basin.

In the upper part of the succession, large blocks of light grey shallow-water dolomitised limestones are embedded within pelagic deeper-water rocks. We interpret them as resedimented olistoliths transported from the edges of a prograding shallow-water platform (cf. Gale et al., 2015). Additionally they could represent the clasts from collapse of the platform edge. The emplacement of these large blocks caused the deformation of semilithified deeper-water sediments, as is clearly evident from the deformed and folded structures in the thin-bedded dolostones lying immediately below the blocks.

In the uppermost part of the succession, brown dolomitic bindstones and bioclastic wackestones are present. The presence of numerous shallow-water clasts and the absence of any indication of resedimentation processes indicate that these limestones were formed in a moderate to high-energy subtidal environment, most probably as a sand belt in a marginal part of a shallow-water carbonate platform (e.g. Flügel, 2010).

Sedimentary evolution of the present-day Robanov kot

In the Anisian, the shallow-water carbonate platform existed in the present-day area of Robanov kot, as evidenced by the Anisian Dolomite Formation (Celarc, 2004a). In the late Anisian (Illyrian), the platform drowned as a consequence of the rifting processes (e.g., Winterer & Bosellini, 1981; Doglioni, 1987; Buser, 1989; Bertotti et al. 1993; Ogorelec & Rothe, 1993; Celarc, 2004b). In the newly formed dysoxic basin in the distal part of the gentle platform slope below the storm wave base, the hemipelagic thin-bedded and laminated limestones of Lithostratigraphic Unit 1 deposited. During this time, there was also a significant input of clastic material into the basin. Lithostratigraphic Unit 2 represents a continuation of the hemipelagic sedimentation in the anoxic hemipelagic conditions. However, the increased occurrence of slides, slumps and fine-grained turbidites suggest sedimentation on the steeper slope compared to Unit 1 and/or increased tectonic activity that possibly triggered mass movements. Lithostratigraphic Unit 3 is similar to Unit 2; however it marks a decrease of the clastic input into the basin. A reduced input of clastics could be related to a drier climate or to Anisian-Ladinian sea-level fluctuations or formation of several dee-basins due to rifting (e.g., Razin et al., 1996). Clastic input was reestablished in Unit 4, while the olistolith blocks found in the upper part of Unit 4 indicating a shallowing of the environment and the reestablishing of the platform prograding wedge. The shallowing of the basin caused the oxygenation of the environment, as evidenced by the light colour and the absence of preserved organic matter in Unit 5. However, the sedimentation was still characterised by fine-grained turbidites and hemipelagites. Deposition of lithostratigraphic Unit 6 designate the complete infilling of the basin and beginning of shallow-water sedimentation of the Contrin Formation in the early Ladinian time.

Correlation with neighbouring areas

The Strelovec Formation was correlated with the Anisian deeper-water successions cropping out in the Dolomites, Julian Alps and Southern Karavanke areas (e.g. Krainer & Mostler, 1991, De Zanche et al., 1993; Gianolla et al., 1998). The Strelovec Formation is time equivalent of the Bivera (Pelsonian) and Ambata (Illyrian) Formations. The Bivera Formation is divided into five lithofacies, with predominant wavy-bedded limestones and clayey limestones and marls with frequent pyroclastic beds. Other facies include mass movement deposits, intra and extraformational breccias, condensed facies and hardgrounds (Metzeltin, 1973; Pisa, 1974; Assereto & Pisa, 1978; Jadoul & Nicora, 1979). The formation was deposited in the basin with complex sea-bottom topography. The Ambata Formation was also deposited in a deeper-water basin, and is divided into two lithofacies units. The first is characterised by bedded black limestones with intercalated marls and clayey limestones. The deposits are interpreted as fine-grained turbidites. The second facies are represented by thin-bedded and laminated marls with intercalation of nodular limestones, and some rare intercalated fine-grained turbidites. In the Southern Karavanke, the Kosiak Formation (Schafhauser, 1997) is also composed of the black, bituminous, platy limestones. Rihthofen Conglomerates in the Dolomites, and the Ugovizza Breccia 1 in the Italian part of the Julian Alps (Gianolla et al., 1998), could also reflect tectonism, related to the formation of the Pelsonian-Lower Illyrian basins.

PLATE 1

1 Lithostratigraphic Unit 1: In the microphotograph of laminated mudstone alternation of thinner micritic and thicker microsparitic laminae is visible. A clast composed of organic matter is present in the centre of the photograph (Sample S2 2, 3).

2 Lithostratigraphic Unit 2: mudstone composed of microsparite and a glauconite grain (centre) (sample S1 89, 25).

3 Lithostratigraphic Unit 2: Microphotograph of the laminated mudstone. In the darker laminae, the recrystallised grains show orientation parallel to the lamination. Organic matter is visible as dark streaks and seams in the middle and lowermost parts of the photograph (Sample 58, 63).

4 Lithostratigraphic Unit 3: laminated mudstone with visible wispy and wavy discontinuous laminae of mudstone in the microsparitic matrix (sample S1 64, 39).

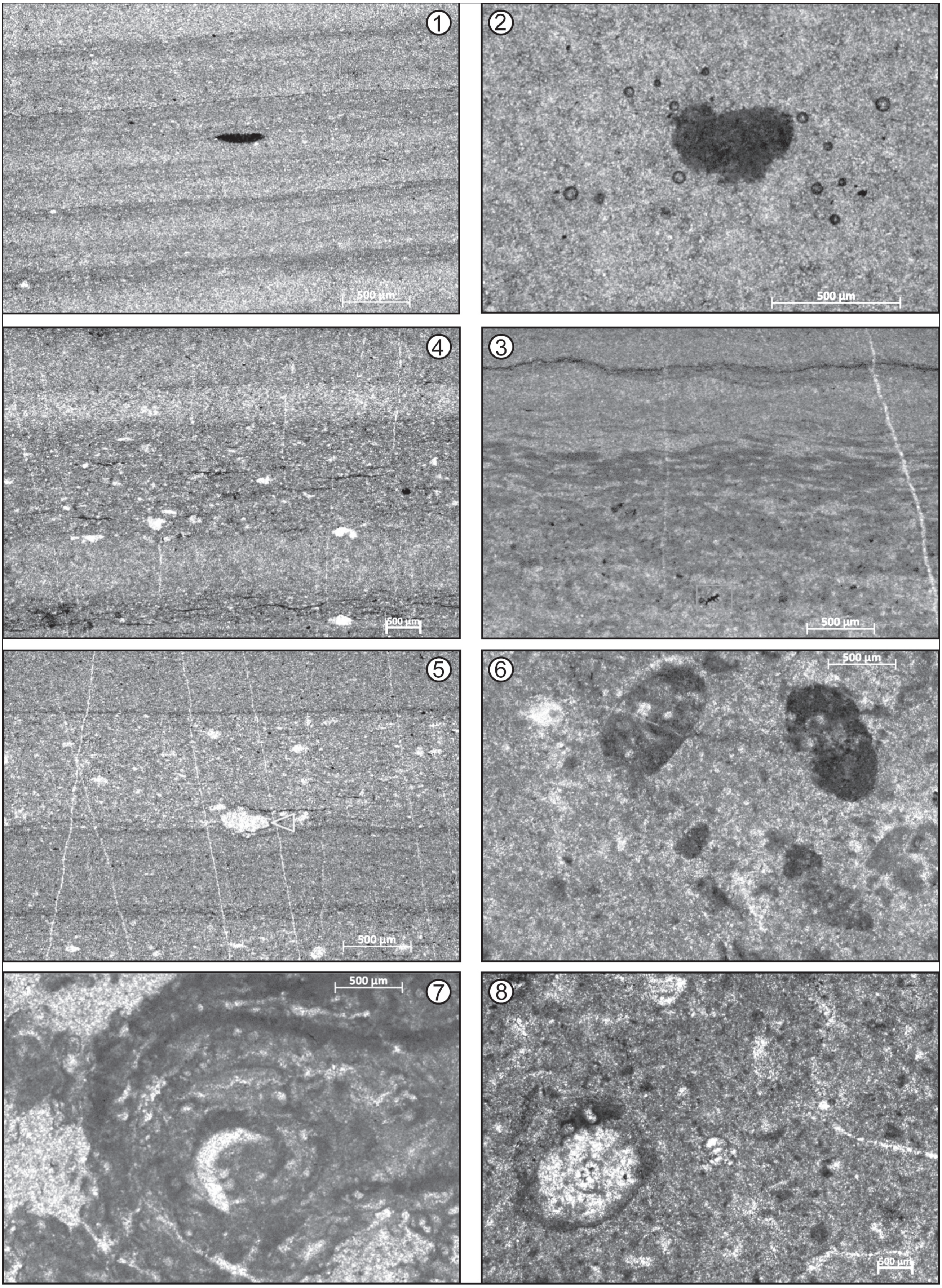
5 Lithostratigraphic Unit 4: Microphotograph of the laminated mudstones with recrystallised grains in the middle part of the photo. The larger grain (marked with the arrow) is impressed into the lower lamina (sample S1 58, 63).

6 Lithostratigraphic Unit 4, sample from megablock: wackestone with intraclastic sand-sized peloids (sample S1 22, 45).

7 Lithostratigraphic Unit 6. Microphotograph of the brown dolomitic, bindstone of microbial origin and some microsparitic infill (sample S1 5, 1).

8 Lithostratigraphic Unit 6: Microphotograph of homogenous dolomitic wackestone texture with small foraminifers and algae (sample S1 4, 7)

PLATE 1



Conclusions

The Anisian (Illirian) Strelovec Formation can be traced across the entire Kamik-Savinja Alps and is characterised by dark thin-bedded limestones and dolostones with intercalated marls and clays. Here, the 102 m-thick Slatnikov plaz section in the Robanov kot area was investigated. The section exhibits a transition from the Strelovec to the Contrin Formations and is divided into six different lithostratigraphic units. Laminated limestone and dolostones with clay-marl interbeds predominates. Intraclastic breccias are common in the lower half of the section. Slumps and synsedimentary folds are also common. Massive dolomite is the uppermost exposed unit. Sedimentary features of the Strelovec Formation indicate hemipelagic and pelagic sedimentation in a hydrodynamically quiet, deeper-water anoxic environment. Pelagic and hemipelagic sedimentation was frequently interrupted by various gravity mass movements ranging from slumps and slides to fine-grained low-density turbidites. Presence of the gravity flow deposits indicate deposition on the slope. In the upper part of the succession, large olistolith blocks of shallow-water limestones embedded within pelagic deeper-water rocks, indicate steepening of the platform wedge and transport of megablocks/ olistolith or possibly a collapse of platform edges. Massive bioclastic dolostone marks complete infilling of the basin and the reestablishing of shallow-water sedimentation of the Contrin Formation in the early Ladinian.

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