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Upper Triassic–to Lower Cretaceous Slovenian Basin successions in the northern margin of the Sava Folds

Zgornjetriasno do spodnjekredno zaporedje Slovenskega bazena iz severnega roba Posavskih gub

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Abstract

The evolution of the Slovenian Basin southern margin is currently interpreted based on the successions outcropping in the surroundings of Škofja Loka, on the Ponikve Plateau and in the foothills of the Julian Alps in western Slovenia, as well as from the valley of the Mirna River in south-eastern Slovenia. However, no extensive research on this paleogeographic unit has been carried out in the northern part of the Sava Folds region. Recent field observations permitted the recognition of Upper Triassic to lowermost Cretaceous successions of the Slovenian Basin, including the recently described Middle Jurassic Ponikve Breccia Member of the Tolmin Formation. Based on reambulation-type geological mapping, macroscopic facies observations supported by microfacies analysis and biostratigraphy, three stratigraphic columns were constructed showcasing Slovenian Basin formations on the northern flank of the Trojane Anticline (Sava Folds region). These newly described successions encompass Upper Triassic (Bača Dolomite Formation) and Jurassic–lowermost Cretaceous resedimented limestones and pelagic formations, while the attribution of the Pseudozilian Formation is complex. Based on facies characteristics these successions are similar to those preserved in the Podmelec Nappe (lowermost thrust unit of the Tolmin Nappe) in western Slovenia. The connection between the western and the eastern Slovenian Basin during the Late Triassic-Early Cretaceous interval could be thus recognised.

Izvleček

Razvoj južnega obrobja Slovenskega bazena je trenutno poznan na podlagi zaporedij, ki izdanjajo v okolici okrog Škofje Loke, na Ponikvanski planoti in iz predgorja Julijskih Alp v zahodni Sloveniji ter iz doline reke Mirne v jugovzhodni Sloveniji. Nasprotno do sedaj še ni bilo celostne stratigrafske študije globljemorskih zaporedij iz severnega dela Posavskih gub. Tekom nedavnih terenskih raziskav smo na tem območju prepoznali zgornjetriasno do spodnje kredno zaporedje Slovenskega bazena, ki vsebuje tudi nedavno opisan člen Ponikvanske breče Tolminske formacije. Na podlagi reambulacijskega geološkega kartiranja, makroskopskega opazovanja faciesov, katerega smo podprli z mikroskopsko analizo in biostratigrafijo, smo izdelali tri stratigrafske stolpce, ki prikazujejo zaporedje Slovenskega bazena vzdolž severnih obronkov Posavskih gub (Trojanske antiklinale). Novo prepoznano zaporedje vključuje zgornjetriasni Baški dolomit in jurske do spodnjekredne presedimentirane apnence in pelagične sedimente. Faciesne značilnosti kažejo, da ta del Posavskih gub pripada vzhodno nadaljevanje Podmelškega pokrova (spodnje podenote Tolminskega pokrova). S tem je prepoznana povezava med zahodnimi in vzhodnimi zaporedji Slovenskega bazena.

Introduction

The transitional zone between the Dinarides and the Southern Alps is characterized by a deep marine succession of the Slovenian Basin (SB) (Placer, 1998a, 2008). It was a large-scale inter-platform basin between the Dinaric (Adriatic, Friuli) and Julian Carbonate Platforms that opened during the Middle Triassic and lasted until the end of the Cretaceous (e.g., Buser, 1989, 1996; Rožič, 2006). SB is well-studied in western Slovenia and this part is also known as the Tolmin Basin (Cousin, 1981; Rožič, 2009). Today the SB successions compose the Tolmin Nappe between variable Dinaric nappe units and the Julian Nappes (Buser, 1989; Placer, 1998a; Goričan et al., 2012a, 2018).

Despite the long research history of the classic occurrences of the SB in the West, very little research has been done in eastern Slovenia within the Posavje Hills, which is the Sava Folds region in structural term. On the Basic Geological Map of Yugoslavia, Jurassic formations were recognised only in the east but were not subdivided in detail (Buser, 1978). With reambulation of these maps, (Buser, 2010) assigned this succession to the Biancone Limestone Formation. He also recognized the Bača Dolomite Formation in the northern part of the Sava Folds east of Ljubljana. The possibility of evidence for other SB lithostratigraphic units rose when, recently, within the Middle Jurassic Tolmin Formation of the SB succession a new member, known as the Ponikve Breccia Member, has been described (Rožič et al., 2022). This member is typical for the southernmost SB outcrops characterized by stratigraphic gap in successions. The Ponikve Breccia is up to 90 m thick, coarse limestone breccia that documents evidence of Jurassic platform back-stepping and erosion (Rožič et al., 2019, 2022). The Ponikve Breccia was investigated in western Slovenia between Tolmin and Škofja Loka, whereas in the east it was logged solely in the Mirna Valley (Rožič et al., 2019, 2022). The northern part of the Sava Folds represents another potential area for the existence of the SB successions, which would represent the much-needed connection between the eastern and the western outcrops of the SB. Our work aims to fill in these missing gaps by providing new data and successions of SB from three different parts of the northern Sava Folds; from outcrops in the Tuhinj Valley, the Flinskovo Ridge with the eastern slope of the Čemšeniška Planina, and the Mt. Mrzlica northern and northeastern ridges. In this paper, we introduce in detail those locations where the SB succession, including the Krikov Formation and the Ponikve Breccia Member of the Tolmin Formation, has been identified.

Geological setting

The Trojane Anticline in the central Sava Folds is a stratigraphically and structurally complex area. According to Placer (1998b), it consists of three thrust sheets, these were later folded from the Late Miocene to Pliocene. The folding took place as a result of N-S compression between the Idrija and the Mid-Hungarian tectonic zones creating the Sava compressional wedge (Vrabec & Fodor 2006). The research areas (Fig. 1a, b, c/logs 10, 11, 12) are on the southern edge of the Alpine nappe system, which thrust over the Dinarides probably in the Miocene. Locally only klippen contain the SB sediments (Placer, 1998a, 2008). Basic geological maps of Yugoslavia 1:100,000 (Premru, 1983) have marked only the Triassic and Cretaceous formations in the Tuhinj and Čemšeniška Planina areas. Buser (1978) marked merged Jurassic rocks at Mt. Mrzlica within the studied area. Part of the Upper Triassic and Cretaceous rocks were later re-evaluated by Buser (2010) as the Bača Dolomite Formation, Biancone Limestone and Aptian-Cenomanian flysch, i.e. the Lower Flyschoid Formation of Cousin (1981) and Rožič (2005). These formations could be part of the southernmost SB sedimentary succession, which is the most complete at Ponikve Klippe near Tolmin and Škofja Loka (Rožič et al., 2019).

Methods

Classic field mapping was executed in detail with the aid of the digital mapping software of Field Move (Petroleum Experts Ltd.) implemented on iPad. High-resolution pictures were taken by Panasonic DMC-FZ200. Measured data were processed in MOVE (Structural Geology Modelling Software of Petroleum Experts Ltd.) in which cross-sections were also prepared. The basis of the recognition of the formations was the field observation of the rocks involving their tectonic position, structure, composition, texture, and fossil content, their comparison to the explanatory notes of the existing 1:100,000 maps of Yugoslavia and previously described lithostratigraphic units from the SB (e.g., Gale, 2010; Rožič et al., 2019, 2022). Digital terrain data were derived using the dataset of the Ministry of the Environment and Spatial Planning, Slovenian Environment Agency.

Altogether 76 rock samples were collected, cut and polished. For the identification of the formation, detailed microfacies and microfossil analyses was carried out by Ágnes Görög on 15 thin sections 5 × 5 cm in size. For the microfacies analysis, we followed Dunham (1962), Folk (1962) and Lokier and Junaibi (2016). The images with small magnification were made with Zeiss Axioskop 40 micro-

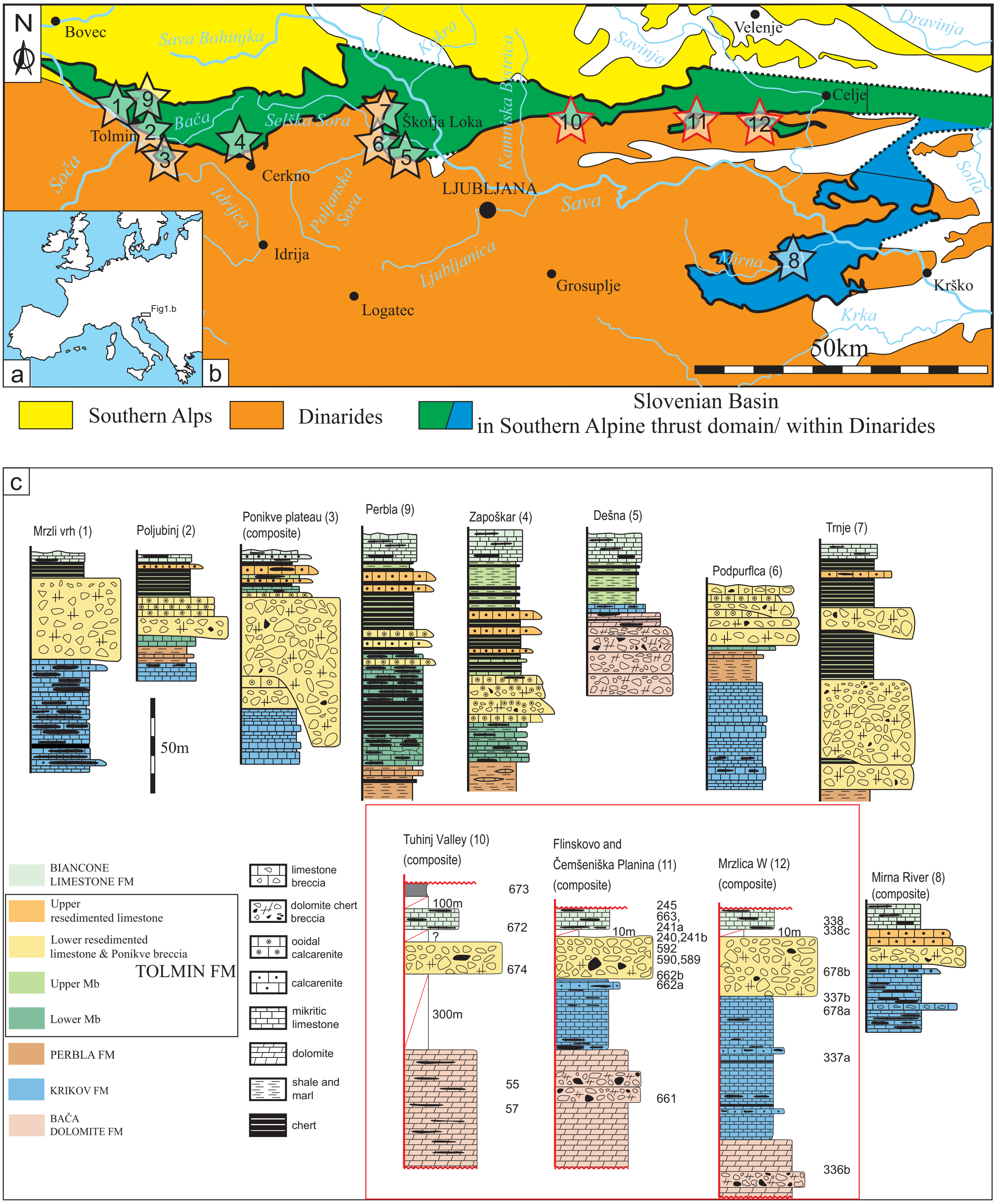

Fig. 1. Location and lithology of studied stratigraphic successions of the Slovenian Basin (SB): a – location of the research area in Europe, b – the black stars mark the sections 1–9 of SB units previously studied by Rožič et al., 2022), while red stars indicate the recently investigated sections; c) Log of the sections, sections 1–9 after (Rožič et al., 2022), sections 10-12 discussed in this work. Thickness of formations was calculated from outcrop distance, elevation differences and bedding dip. In the Tuhinj valley section the formation thicknesses are uncertain due to discontinuous outcrops. The total thickness of the starting and finishing formations could be larger and truncated, indicated by red undulating lines.

scope with AxioCam MRc5 (Zeiss) camera by 1 × zoom at the Department of Geology of Eötvös Loránd University, Budapest. Image composite editor was used to create large composite images. The photomicrographs of the microfacies and the microfossils were taken with a Canon EOS 2000D camera mounted on Olympus BH2 –BHS microscope, at the Hantken Foundation. An abbreviated list of the fossil taxa with their stratigraphic distribution and ecological preferences is given in the Appendix.

Short description of the location of studied successions

Within the studied area three composite geological columns were established from scattered outcrops in the Tuhinj Valley; from the Flinskovo ridge and the eastern slope of the Čemšeniška Planina and from two sections on the Mt. Mrzlica (Fig. 1c). Where the density of the outcrops allowed three detailed geological maps were constructed. The maps were compiled at the eastern side of Čemšeniška Planina, including the Flinskovo ridge (Fig. 1c/log 11, Fig. 2c), while two maps were compiled about the north-western and north-eastern flanks of Mt. Mrzlica (map Fig. 2a, b and Fig. 1c/log 12) and about the north-eastern ridge. Generally, at each area, the bedding is dipping to the north. Previous maps (Premru, 1983; Buser, 1978, 2010) already showed the presence of the Bača Dolomite Formation and the Biancone Formation; however, other members of the SB were unknown.

The observations from the Tuhinj area did not yield a continuous succession (Fig. 1c/log 10). The composite stratigraphic column incorporates outcrops in several north-south directed side valleys and roads near the villages Vaseno and Buč across the Tuhinj Valley. Scarce outcrops were insufficient to create a detailed map. The Bača Dolomite Formation crops out in several road cuts between Vaseno and Velika Lašna (outcrop 057: 46°12’40.0444” N; 14°41’56.3451” E), and observations were also made at a large quarry west of Špitalič (outcrop 055: 46°12’50.7312” N; 14°48’25.4728” E). The Ponikve Breccia can be seen in a road cut on the way from Buč to Vaseno (outcrop 674: 46°13’01.3121” N; 14°42’45.4706” E). The Biancone Limestone was observed at a small agricultural road near Buč twigging to north from the main road (site 672: 46°13’02.7672” N; 14°43’08.3765” E). Finally, the Lower Flyschoid Formation is exposed at the southern boundary of the Hruševka village: (site 673: 46°13’24.8869” N; 14°43’13.8492” E).

The succession Flinskovo is composed from observations along the eastern slope of the Čemšeniška Planina and from the Flinskovo ridge west of Mt. Krvavica (Fig. 1c/log 11). The geological cross section and map (Fig. 2c) were first presented by Scherman et al. (2022).

The succession Mrzlica is located on the northern slope of Mt. Mrzlica (Fig. 1c/log 12). It is compiled from the observations made on the north-western (Fig. 2a) and the north-eastern ridge of Mt. Mrzlica (Fig. 2b).

Lithostratigraphic units oldest than latest Triassic

Although this study is about the Upper Triassic to Lower Cretaceous formations partially newly discovered from the area three other formations were also mapped and are worth briefly mentioning. These are the Werfen Formation, The Schlern Formation and the Pseudozilian Formation.

Werfen Formation

The uppermost Permian – Lower Triassic Werfen Formation consist of limestone or dolomite beds with marl and marly or oolitic limestone intercalations. Based on its relatively rich fossil content it was deposited in a shallow (subtidal – supratidal) marine environment. It is known from the Southern Alps in Italy, the Karavanke Mountains in Austria, the Julian Alps, Kamnik Alps and the Sava Folds in Slovenia (e.g., Broglio Loriga et al., 1983; Ramovš et al., 2001; Krainer & Vachard, 2011; Celarc et al., 2012).

Schlern Formation

The Schlern formation is a Ladinian platform carbonate described from the Southern Alps in Italy. Carbonate platform progradation is characteristic of this formation (Fois, 1982). It is described from the Julian and Kamnik Alps in Slovenia (e.g., Celarc et al., 2012).

Pseudozilian Formation

The Pseudozilian Formation is a Ladinian sedimentary formation. It consists of shale, greywackes, sandstones and resedimented volcanilastics, first described by Teller (1898) from the central Slovenia. According to Dozet and Buser (2009), it marks the opening of the Slovenian Basin during the Ladinian.

Studied lithostratigraphic units of the Slovenian Basin successions

Based on our research, field observation and review of the literature four formations of the SB have been identified with certainty. These are the following the Bača Dolomite Formation, the Krikov Formation, the Ponikve Breccia Member of the Tolmin Formation and the Biancone Formation. In addition to these two other formations are possibly present, namely the Upper Member of the Tolmin Formation and the Lower Flischoid Formation. However, further elaborative research is needed to confirm them for sure.

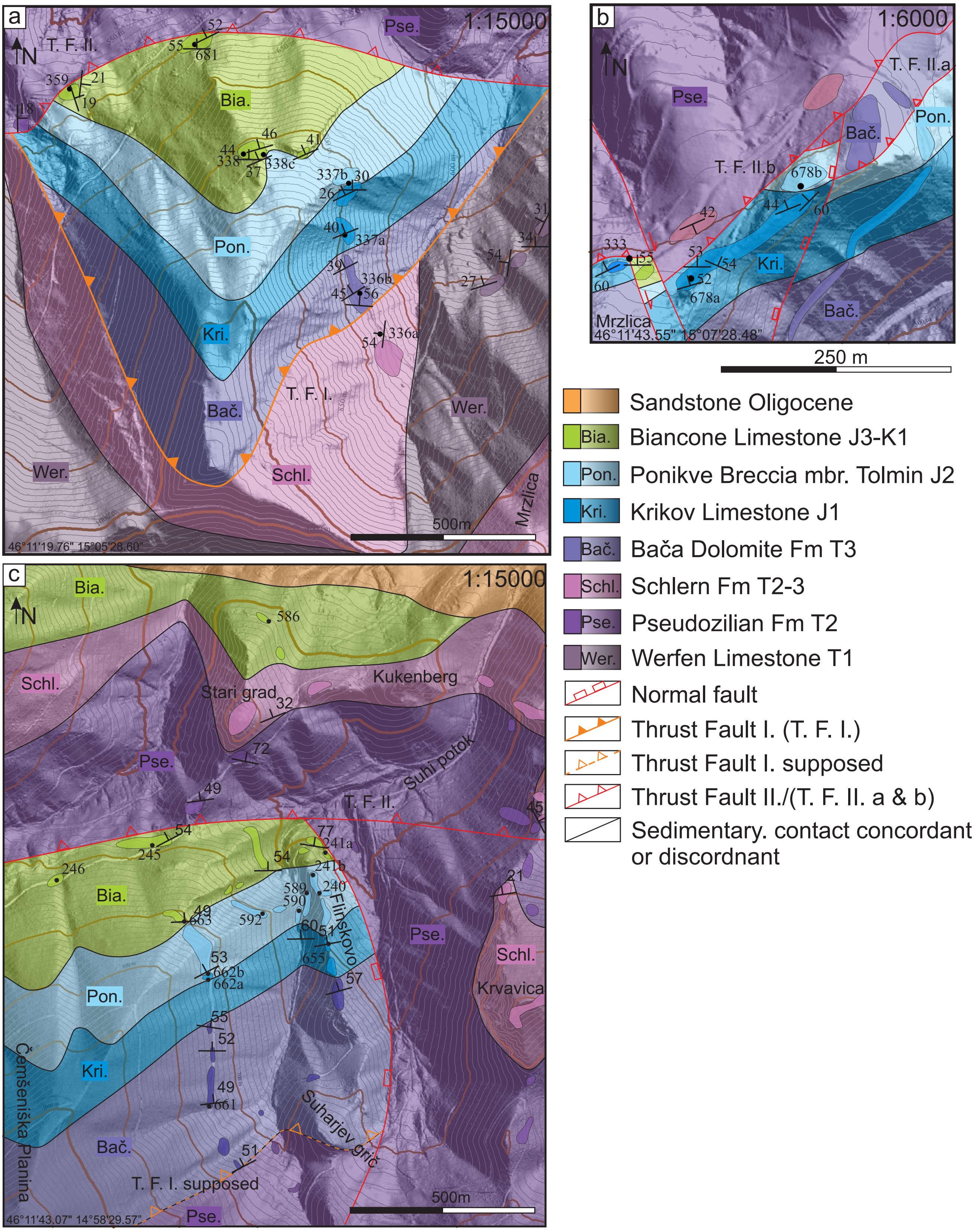

Fig. 2. Detailed new geological maps of the studied sections: a – Mt. Mrzlica NW, b – Mt. Mrzlica NE, c – eastern slope of the Čemšeniška Planina, Flinskovo ridge and Krvavica Mt. Note outcrop numbers that also appear in the stratigraphic logs (Fig. 1c) and on photographs (Figs. 3–7). DEM was produced using the dataset of Ministry of the Environment and Spatial Planning, Slovenian Environment Agency. Outcrops are indicated with opaque colours while postulated extension of formation are marked with transparent colour, note abbreviations for the formations. Thrust Fault I. orange, dashed orange. Thrust Fault II. red continuous line.

Bača Dolomite Formation

Similarly to the classical western development of the SB (e.g., Buser, 1986; Rožič, 2006; Gale, 2010; Goričan et al., 2012b), the Bača Dolomite Formation in the study area mainly consists of black or dark grey dolomite in 20–50 cm thick beds, with chert nodules and even layers. The formation has an estimated thickness of 150–250 m in the Tuhinj Valley area and at the Čemšeniška Planina area (Fig. 1c/log 10; 11) and is approximately 50–150 m thick in the Mrzlica area (Fig. 1c/log 12) but the lower contact is not exposed or truncated. In cases where the bedding is hard to see, chert nodules or layers indicate the bedding as seen in the Tuhinj valley (outcrop 55, Fig. 1c/log 10, Fig. 3d). However, the bedding is mostly clear, for example on the eastern slope of Čemšeniška Planina (outcrop 661, Fig. 4e), where the thick beds alternate with much thinner ones. In some places, such as on the northwest flank of Mt. Mrzlica (outcrop 336b on Fig. 1c/log 12; Fig. 2a, Fig. 3h), the formation contains up to 3–4 m thick breccia layers with a massive appearance. In these, dolomite and chert clasts alternate chaotically. These breccia megabeds were interpreted by Gale (2010) and Oprčkal et al. (2012) as large-scale debris flow deposits related to the middle Norian tectonically-induced subsidence. Since the Bača Dolomite Formation has a distinctive appearance and is therefore easily recognizable in the field, microfacies analysis was not carried out but focused on the overlying limestone layers.

Krikov Formation

The Krikov Formation starts as cherty limestone with a bed thickness of ca. 35 cm. The thickness of the formation is approximately 30 m at the Čemšeniška Planina area (Fig. 1c/log 11) and 70 m at the Mrzlica area (Fig. 1c/log 12). A major part of the formation is composed of a grey to dark grey limestone with chert layers or nodules (e.g., at outcrop 662a on Fig. 2a, Fig. 4d). The limestone is well-bedded (10–30 cm), micritic, with sporadic calcarenite beds. In the Čemšeniška Planina section, calcarenite layers are more common near the top (outcrop 662a, Fig. 1c/log 11; Fig. 2c). However, in the Mt. Mrzlica West sections, calcarenites are more common in the lower and the middle part of the formation (outcrop 337, Fig. 1c/log 12, Fig. 2a). The thin marl interlayers are visible at some places, mostly highlighting the base of a successive layer (Fig. 3g, Fig. 4d). At the top of the formation, the thickness of the layers changes to approximately 15–20 cm; the chert content is much lower, but the marl component increases to almost 20 % (Fig. 3f, Fig. 4c). Different microfacies types, similar to those previously described from the SB (e.g., Rožič, 2006, 2009; Goričan et al., 2012b), were recognised from samples taken from the upper part of the formation in the Čemšeniška Planina section (Fig. 1c/log 11). In the thin section collected from the outcrop (sample 333) on the ridge of Mt. Mrzlica NE (Fig. 2b), the microfacies show dolomitized carbonate mudstone-wackestone texture with “ghosts” of benthic foraminifera (nodosarids, involutinids and textulariids) (Fig. 5a). Scattered rhomboid dolomite crystals could also be observed. The rock was subsequently silicified and the silicification front is clearly visible. In the outcrop on the NW flank of the Mt. Mrzlica section (sample 337; Fig. 1/log 12; Fig. 2a) the formation is represented by bioturbated bioclastic packstone-wackestone limestone that was later silicified and partly dolomitized. Among fossils, it contains mainly fragments of thin-shelled bivalves and sponge spicules. Additionally, a few ostracods, foraminifera and Characeae gyrogonite (Fig. 5b) also occur. The poor foraminiferal fauna consists of textulariids (Fig. 5c), spirillinids (Fig. 5b) and the involutinid *Licispirella* sp. (Fig. 5d). Similar agglutinated forms and spirillinids were figured by Rožič et al. (2022, fig. 14e) from this Lower Jurassic unit of the SB. The genus *Licispirella* appeared in the Norian, but it was common only in the Lower Jurassic (Rigaud et al., 2013). The microfacies and microfossils indicate a distal hemipelagic zone where remnants of Characeae were transported from a freshwater environment.

On the eastern slope of Čemšeniška Planina (sample 662a, Fig. 1c/log 11; Fig. 2c) the characteristic calciturbidite layer of the Krikov Formation could be studied. The original texture of the rock was peloid-ooid-bioclastic wackestone-packstone, with a matrix of micrite and microsparite. Both radial and concentric ooids (sensu Flügel, 2010) occur. Due to the strong silicification, this texture has only been preserved in randomly arranged small fragments (Fig. 5e). In this sample, the majority of the fossils were also silicified and preserved as ghosts. Skeletons of echinoderms are the most frequent, but foraminifers are also common, especially the nodosarianids (*Lenticulina, Marginulina* (Fig. 5f*), Nodosaria, Dentalina*). The agglutinated forms are represented by textulariids, trochamminids, and ?*Siphovavulina* sp. (Fig. 5e). Specimens of the Lower Jurassic involutinids, namely *Involutina farinacciae* (Fig. 5g) and ?*Trocholina* sp. also occur. Among the miliolinids, the evolute *Ophthalmidium* morphogroup (mg.) *kaptarenkoae* (Fig. 5h) and the semiinvolute

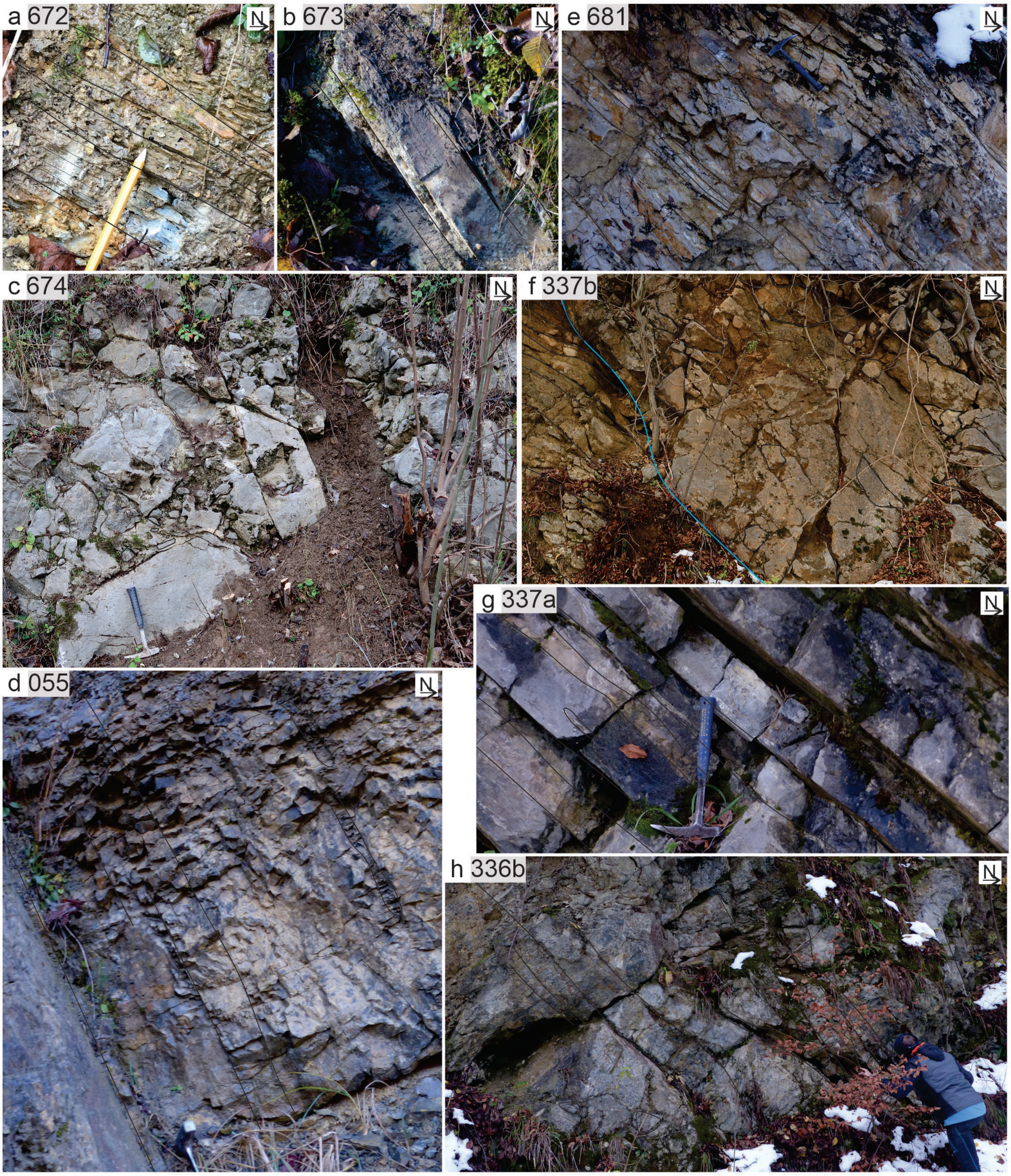

Fig. 3. Interpreted images of the outcrops. The outcrop number is in the top left corner; the north is indicated in the top right corner; a-d) succession of Tuhinj valley area near the villages Vaseno and Buč; e-f) succession on Mt. Mrzlica. Formations: a, e) Biancone Limestone Formation; b) Lower Flyschoid Formation; c, f) Tolmin Formation/Ponikve Breccia Member; f, g) Krikov Formation (the blue line highlights the top of the Krikov Formation and the bottom of the Tolmin Formation/Ponikve Breccia Member); d) Bača Dolomite. Black line highlights the bedding and the contour of the chert.

O. mg. *terquemi* (Fig. 5i) could be tentatively determined. Additionally, a section of an aperture with a bifid tooth could be recognized (Fig. 5j). To our knowledge, this type of aperture is only known from the Lower Cretaceous onwards (e.g., Neagu, 1984; Clerc, 2005), and from the Jurassic only *Sigmoilina moldaviense* has teeth (Danitch, 1971). However, we must note that knowledge about the Jurassic miliolinids, especially the Lower Jurassic ones, is incomplete.

Based on the appearance of *Involutina farinacciae,* the age of the rock can be late Sinemurian – early Toarcian (Fig. 8). This coincides well with the previously determined Early Jurassic, more precisely Hettangian–Pliensbachian age of the Krikov Formation (e.g., Cousin, 1973, 1981; Buser, 1986; Rožič, 2006, 2009; Goričan et al., 2012b).

Tolmin Formation, Ponikve Breccia Member

The Ponikve Breccia member is a massive breccia. It consists of different limestone clasts originating from the erosion of older platform, slope and basinal formations, but in the matrix, contemporaneous grains, such as peloids, ooids, oncoids, intraclasts, and bioclasts are present (Rožič et al., 2022). Based on the occurrence of radiolarians and foraminifera, determined in previous studies (Rožič et al., 2019, 2022) at other localities, the age of the breccia is Middle Jurassic (probably Bajocian – Bathonian), while the age of the clasts ranges from the Late Triassic to Early Jurassic (Rožič et al., 2019, 2022).

Based on the macroscopic and microscopic studies, the Ponikve Breccia appears in each of the investigated areas (Fig. 1c, Fig. 2). The thickness of the formation is approximately 20 m at the Tuhinj area (Fig. 1c/log 10), 25 m at the Čemšeniška Planina area (Fig. 1c/log 11) and 35 m thick at the Mrzlica area (Fig. 1c/log 12). The contact with the Krikov Formation is erosional while the large clasts of the massive Ponikve Breccia truncate the underlying well-bedded Krikov Limestone as seen at outcrops 337b and 662 (Figs. 3f and 4c).

We studied the thin sections of the following samples: sample 338c from Mt. Mrzlica NW, sample 678 from Mt. Mrzlica NE, and samples 240, 241, 589, 590, 592, and 674 from Čemšeniška Planina (Fig. 3c, f; Fig. 4b, c). Macroscopically, many clasts are angular and their size ranges from a few mm to several meters. The clasts are densely packed, thus there is only a minor matrix even further reduced by pressure solution resulting in stylolitic seams. The matrix of the breccia is an ooid-peloid grainstone or packstone. The proportion of peloids, oncoids, and ooids varies greatly, but usually, the latter are the most common. All three major structural types of the ooids (sensu Flügel, 2010) appear. The most frequent are the concentric or tangential ooids, the less frequent are the radial-fibrous ones, and the micritic ones are rare. Fossils occur in the matrix as well as the core of the concentric ooids. In descending order of frequency, the following fossil groups appear: echinoderm fragments, benthic foraminifera, dasycladacean algae, *Rivularia*-type Cyanophyceae, gastropods and incertae sedis (Fig. 5k).

The foraminiferal fauna is relatively poor and shows very low diversity. The characteristic

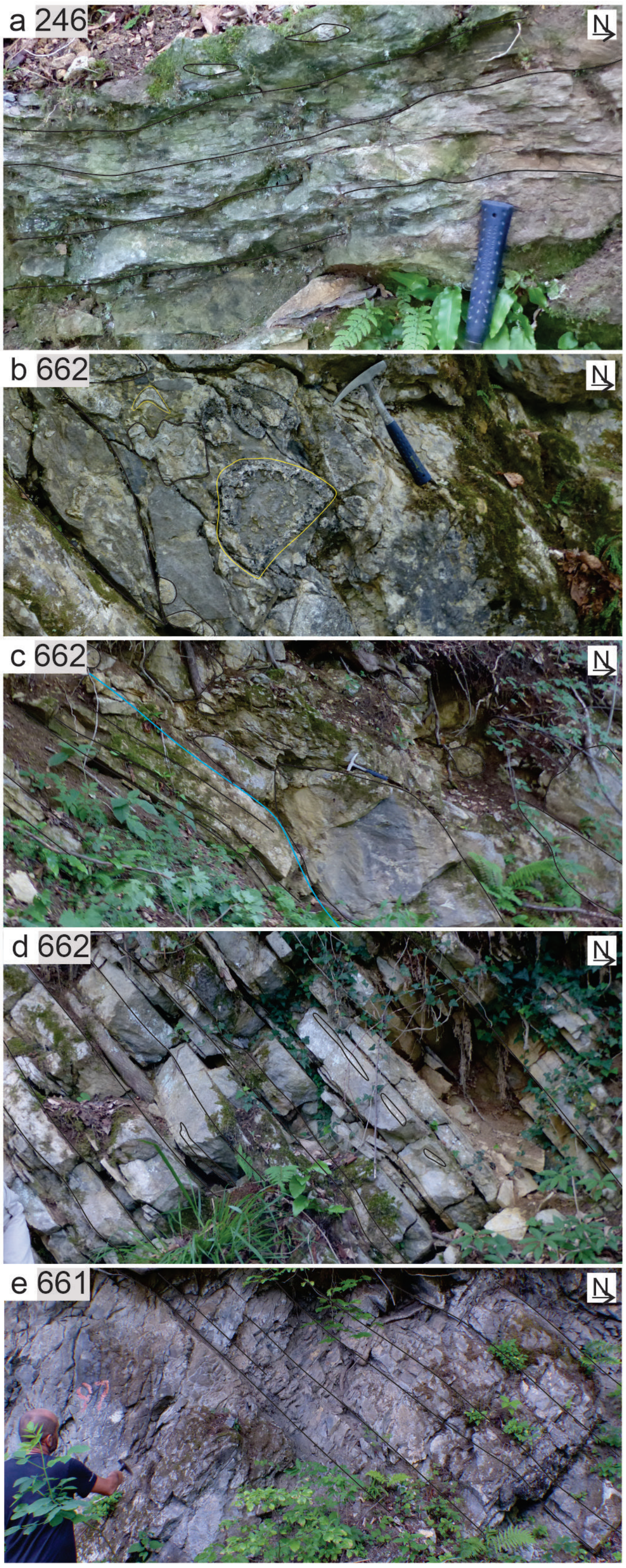

Fig. 4. Images of the outcrops of the succession at Čemšeniška Planina. The number of outcrops is in the top left corner; the North is indicated in the top right corner. Formations: a) Biancone Limestone Formation; b, c) Tolmin Formation/Ponikve Breccia Member (yellow line highlights block with silicified corals); c, d) Krikov Formation (blue line highlights the contact between the Krikov Formation and the Tolmin Formation/Ponikve Breccia Member); e) Bača Dolomite. Black line highlights the bedding and the contour of the cherts.

double-walled *Protopeneroplis striata* and low- and high-spired forms of *Coscinoconus palastiniensis* regularly occur as a core of the ooids or oncoids within clasts, but rarely in the matrix (Fig. 5l, m, n, o). Besides these taxa, agglutinated foraminifera, such as *Glomospira* sp. (Fig. 5q), ?*Siphovalvulina* sp. (Fig. 5p), *Trochammina* sp. (Fig. 5r), several textulariids (Fig. 5s) and a few miliolids, such as *Ophthalmidium* mg. *concentricum* could be recognized (Fig. 5q, t). Nodosarids, mainly *Nodosaria* sp. and Lenticulina sp. (Fig. 6a) are relatively frequent and large, up to 1 mm. The fragile Chlorophyta algae and algal-like bacteria are represented by dasycladales and cyanophytes, such as *Selliporella* mg. *donzellii* (Fig. 6b), *Salpingoporella* sp. (Fig. 6c-d), ?*Megaporella* (Fig. 6e), and algae indet. (Fig. 6g), *Rivularia lissaviensis* (Fig. 6f) and "Cayeuxia" spp. (Fig. 6h). A few specimens of the incertae sedis *Crescentiella morronensis* (Fig. 5u), and other microproblematicum (Fig. 5v) also occur.

The co-occurrence of the early Bajocian – late Bathonian *Selliporella* mg. *donzellii,* Bajocian-Callovian *Coscinoconus palastiniensis,* Aalenian-Tithonian *Protopeneroplis striata* and indicates an early Bajocian – late Bathonian age (Fig. 8).

The effects of the subsequent diagenetic processes on the matrix, such as tectonic deformation and recrystallization could be traced. Due to the pressure solution, peloids and concentric ooids are often deformed, thus becoming elliptic in shape, while the radial fibrous ooids broke (Fig. 5l, Fig. 6a). In most cases, the matrix was dolomitized to varying degrees (e.g., Fig. 5k, o, t, u). Because the micrite or microsparite 'groundmass' of the matrix was affected to a greater extent by late diagenetic dolomitization than for example the ooids or clasts, a rim of dolomite crystals surrounds these grains (Fig. 6h).

Most lithoclasts originate from a carbonate platform. The oldest, the Upper Triassic limestone blocks were the largest and the easiest to recognize macroscopically in the field. Their appearance usually was massive limestone, in some cases, corals, megalodon bivalves or stromatolite layers could be identified in the field (Fig. 4b).

A typical grey, finely laminated platform carbonate clast, showing the features of facies B of the Lofer cycles was found at northern Fliskovo Ridge (outcrop 589, Fig. 1/log 11; Fig. 2c). The laminae consist of packstone, grainstone, dark stromatolites, mudstone with spar-filled shrinkage pores, and spar-filled sheet cracks. The bioclasts occurred only in the pelmicritic packstone and grainstone laminae (Fig. 6i). The foraminifers are the most frequent and diverse, besides them dasycladacean and codiaceaen (Bryopsidales) algae, and *Rivularia*-type calcimicrobes could be recognized. In the foraminiferal fauna, the involutinids dominated. The following taxa could be classified as *Aulotortus communis* (Fig. 6j), *A. sinuosus* (Fig. 6k), *A. tenuis* (Fig. 6l), *A. tumidus* (Fig. 6l), *Parvalamella friedli* (Fig. 6m), *Frentzenella crassa* (Fig. 6i) and *T. ultraspirata* (Fig. 6n). The agglutinated forms are represented mainly by *Gandinella falsofriedli* (Fig. 6o) and "*Trochammina*" *almtalensis* (Fig. 6p, q), additionally a few specimens of ?*Trochammina alpina* (Fig. 6r)*, Textularia* sp., and *Valvulina* sp. occur. The taxa of lagenids (*Austrocolomia* sp., *Nodosaria* sp. and *Lenticulina* sp.) and miliolinids (cf. *Paraophthalmidium* spp.) were represented by one specimen (Fig. 6s, t).

Among the algae the most common were the fragments of ?*Petrascula* sp. (Fig. 6s, u) and *Rivularia lissaviensis* (Fig. 6f). In addition, a few specimens of Norian *Bystrickyella ottii* (Fig. 6w) and *Salpingoporella austriaca* (Fig. 6x), *Arabicodium* sp. (Fig. 6l, y) and dasycladaceaen organs of ?*Acicularia* (Fig. 6i), *Patruliuspora* (Fig. 6z), and dasycladaceans (Fig. 6v) could be identified.

Based on the foraminiferal and algal association the age of this clast is Norian (Fig. 8). These forms indicate a shallow well-lighted low-energy environment.

In the Triassic clast of the previously mentioned sample 241, at Flinskovo Ridge east from Čemšeniška Planina, stromatoporoids, sponges, involutinids as *Aulotortus sinuosus, Semiinvoluta* sp. and *Triasina hantkeni* with an encrusting *Tolypammina gregaria* could be recognized (Fig. 6aa). These fossils indicate the Rhaetian age (Fig. 8) and shallow marine platform environment.

On the east side of the Čemšeniška Planina, close to Flinskovo (outcrop 592, Fig. 1/log 11, Fig. 2c), in the breccia coral-bearing limestone clasts were found. The rock is a framestone, in the cavities between the cylindrical corallites of a phaceloid colony is mudstone. The tiny (up to 6 mm in diameter) corallites have an overall stylophyllid morphology, their septa are composed of isolated or sclerenchyma-embedded spines (Fig. 6bb), which is unique among the Triassic–Jurassic scleractinians (e. g., Stolarski and Russo, 2002). These forms could be classified into the Norian-Lower Jurassic genus *Styllophyllopsis,* which has been found in Slovenia only in the lower Norian of the Julian Carbonate Platform (Turnšek, 1997). In the matrix, there was an ammonite embryo, a fragment of stromatoporoids and only a few specimens of foraminifera, like the

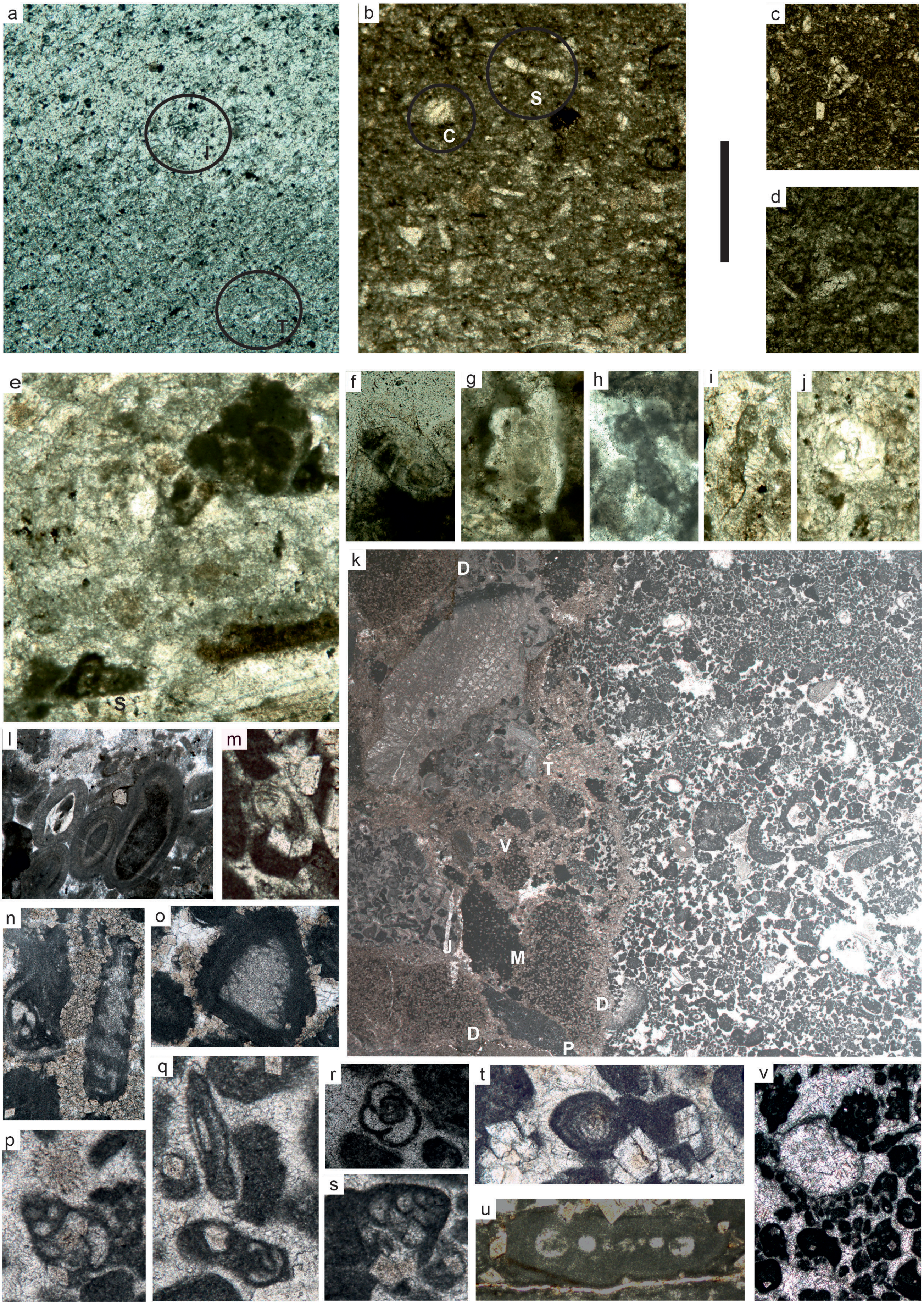

Fig. 5.

involutinid *Coronipora etrusca* (Fig. 6cc) and *Semiinvoluta* sp. (Fig. 6dd) additionally a few agglutinated forms. These foraminifers prefer the oxic and low-energy environment. The *C. etrusca* has an upper Norian—Liassic range, while the genus *Semiinvoluta* is known only from the Rhaetian up to the end of the Pliensbachian (Rigaud et al., 2013). Based on these fossils and the facies, the age of the rock is Rhaetian, but the Early Jurassic (until the end of the Pliensbachian) has not been ruled out (Fig. 8).

A silicified clast with recrystallised radiolarians and sponge spicules occurred in the breccia at the northern Flinskovo Ridge, Čemšeniška Planina (sample 590c). A few specimens of textulariid, involutinid? and nodosariid? foraminifera also could be recognized (Fig. 7a) This rock most probably originated from the Lower Jurassic Krikov Formation.

Close to the previous outcrops (sample 241, Fig. 1/11, Fig. 2c) as clasts of the breccia microfacies types of basinal facies, peloid mudstone-wackestone with thin-shelled bivalves, echinoderm fragments and foraminifers (e.g., *Lenticulina* sp.) occur (Fig. 7b, c). Based on the microfacies (e.g., see Goričan et al., 2012a, fig. 22a) it could be identified as the Lower Jurassic Krikov Formation. In the same breccia sample, in another strongly dolomitized lithoclast (Fig. 7b) a larger agglutinated foraminifera *Everticyclammina praevirguliana* is preserved as a “tiny island” (Fig. 7d). The stratigraphic range of this form is upper Sinemurian—lower Bajocian. The microfacies and the fossils indicate a shallow marine, inner platform environment. Thus, this lithoclast may come also from the calcarenite layers of the Krikov Formation as rip-up clast. Based on the occurrence of the Hettangian-Sinemurian index fossil, *Palaeodasycladus mediterraneaus* a definitely Lower Jurassic clast was found in sample 240, Flinskovo Ridge, Čemšeniška Planina (Fig. 5k, Fig. 7e).

At the NE ridge of Mt. Mrzlica (sample 338c, Fig. 1c/log 12, Fig. 2a), few types of clasts of the breccia appear that previously were neither described in the literature nor in the Ponikve Breccia Member in the western SB. The silicified rock is ocher in color with dark-purple chert nodules. Its microfacies is bioclastic mudstone-wackestone. The bioclasts are almost exclusively fragments of echinoderms, most probably crinoids. Very few ostracods, filled with sparry calcite also occur (Fig. 7f). The appearance of this strange assemblage can be explained by the fact that the skeleton of echinoderms and ostracods is more resistant to dissolution than that of other shells. Since no age-diagnostic fossils were found, the stratigraphic position of this rock type is uncertain. In some clasts (thin sections) one or more parallel or slightly undulating sets of surfaces or very thin veinlets occur (Fig. 7/g-i). The surfaces surround the fragments and give a nodular-bounding appearance (Fig. 7g). They can represent sedimentary lamination, stylolitic seams or incipient layer-parallel foliation planes, partly filled with late calcite. Dolomite crystals are scattered or arranged along the fissures. Cherty nodules of uncertain origin with few dolomite crystals are also present. This microfacies also occurs in the NW flank of Mt. Mrzlica (sample 678a Fig. 2b). Here other microfacies could be identified in thin sections, like mudstone with dissolved radiolarian skeletons; ooid packstone with strongly elongated (deformed) micritic ooids (Fig. 7i); mudstone with bird’s-eye structures of irregularly formed and distributed fenestrae, crosscutting calcite veins and stylolites and a few deformed echinoderma fragments and packstone-grainstone with distorted ooids (Fig. 7j). All of these microfacies reflect the late diagenetic selective recrystallization, mechanical distortion and pressure solution processes. There were no age-diagnostic fossils, thus the stratigraphic position of these lithoclasts is uncertain.

Fig. 5. a-j) Krikov Formation, k-v) Ponikve Breccia Member of Tolmin Formation. The scale bar is 400 µm, except k) where 6 mm. a) sample 333 of the outcrop on the ridge of Mt Mrzlica NE, dolomitized carbonate mudstone-wackestone texture with “ghosts” of benthic foraminifera as involutinid (I) and textulariid (T); b-d) sample 337, Mrzlica NW, b) silicified bioclastic (sponge spicules, thin-shelled bivalves) packstone limestone, with Characeae gyrogonite (C) and spirillinid (S); c) textulariid foraminifera; d) involutinid foraminifera *Licispirella* sp.; e-j) sample 662a, Čemšeniška Planina; e) remnants of the peloid-ooid-bioclastic wackestone/packstone texture after the silicification, with agglutinated foraminifera, ?*Siphovalvulina* (S); f) *Marginulina* sp.; g) *Involutina farinacciae* Brönnimann & Koehn-Zaninetti; h) *Ophthalmidium* mg. *kaptarenkoae* Danitch; i) *Ophthalmidium* mg. *terquemi* Pazdrowa; j) miliolid aperture with tooth; k) photomicrograph of the thin section of sample 240, Čemšeniška Planina, on the right: the peloidal grainstone with gastropods, Dasycladacean algae, Echinodermata fragments and foraminifers, on the left: partly dolomitized matrix and different lithoclasts: Triassic (T) intraclastic packstone-grainstone clast with stromatoporoid, sponges, gastropods and foraminifers (see Fig. 6z for enlarged image), Lower Jurassic clast (J) with bioclastic grainstone fabric and algae (see Fig. 7e for enlarged image), dolomite clast (D), vermetus tubes (V), strongly dolomitized mudstone clast (M), peloidal mudstone clast (P); l) deformed ooids of the breccia matrix with *Protopeneroplis striata* Weynschenk, sample 674, Čemšeniška Planina; m) *Protopeneroplis striata* Weynschenk, sample 590, Čemšeniška Planina; n-o) *Coscinoconus palastiniensis* Henson, high (n) and low (o) spired forms, sample 240, Čemšeniška Planina; p) ?*Siphovalvulina* sp., sample 240, Čemšeniška Planina; q) *Glomospira* sp. and miliolids, sample 240, Čemšeniška Planina; r) *Trochammina* sp.; s) textulariid (?*Valvulina* sp.), sample 240, Čemšeniška Planina; t) *Ophthalmidium* mg. *concentricum* (Terquem & Berthelin), sample 674, Čemšeniška Planina; u) *Crescentiella morronensis* (Crescenti), sample 241, Čemšeniška Planina; v) microproblematicum, sample 240, Čemšeniška Planina.

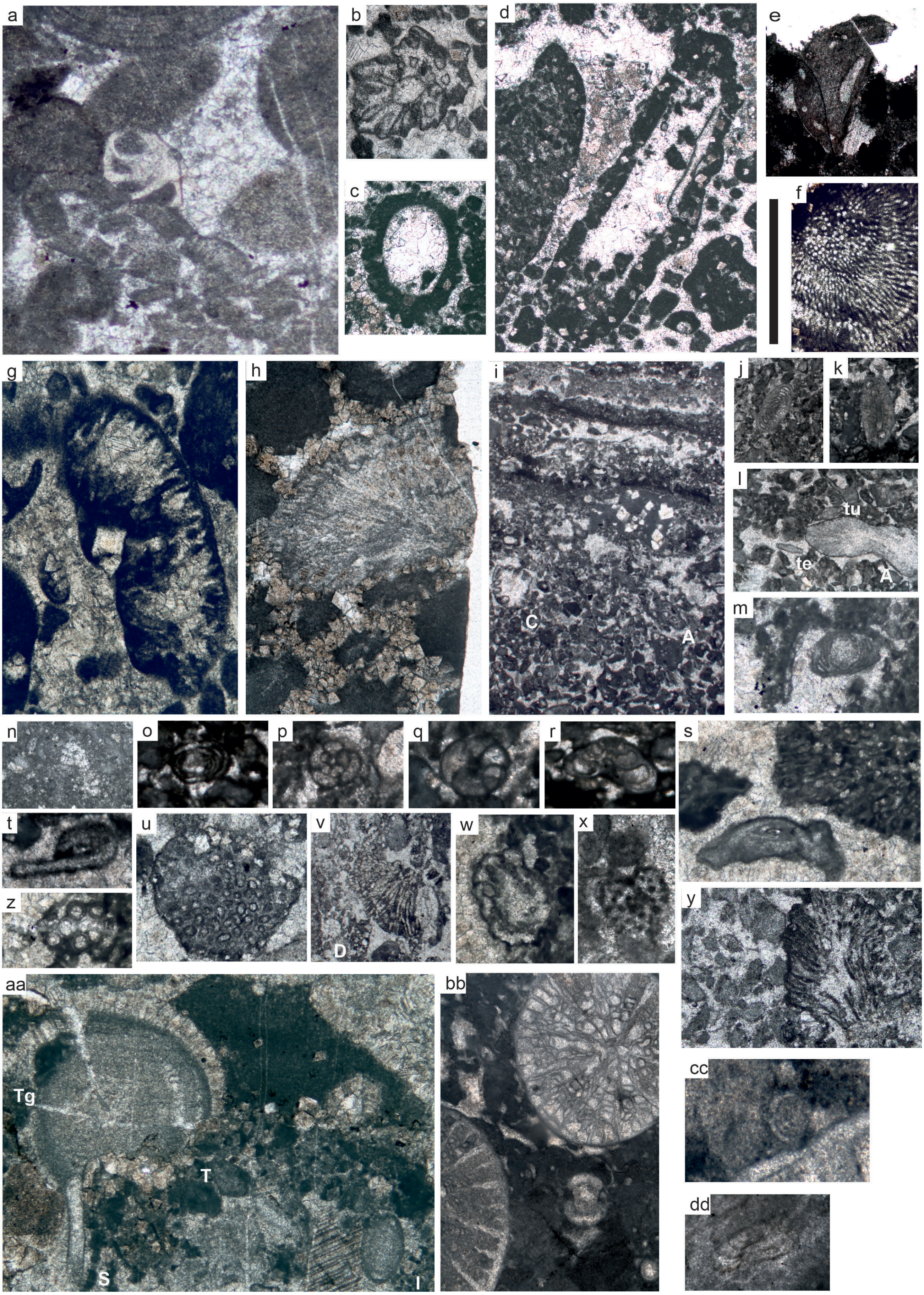

Fig. 6.

Based on the field studies, microfacies and microfossils analyses the provenance of the matrix was threshold lines in the photic zone. The breccia formed on the upper slope environment and is characterized by the bimodal grain size, larger clasts, and well-sorted, sand-sized grains amidst them. It means that the Ponikve Breccia is a typical mass-flow breccia (e.g., sensu Flügel, 2010).

Tolmin Formation Upper Member(?)

It is worth mentioning that we could not find the contact of the Ponikve Breccia Member and Biancone Limestone on the field thus further observation is needed. On the topography, however, a linear depression marks the transitional interval of the two formations, the thickness of which was estimated to be approximately 10 m (Fig. 1c/log 11, 12; Fig. 2a, c). Although we did not find any outcrop of chert, shale or marl, this soil-covered depression may suggest a softer sedimentary rock between the formations. We postulate that this can correspond either to the Upper Member of the Tolmin Formation, which is in the topmost part often characterized by alternating radiolarite and marl/shale beds (Rožič, 2009). Alternatively, this covered part may correspond to the marly basal part of the Biancone Limestone.

Biancone Limestone Formation

The Biancone Formation is composed of white, yellow, light pink or grey thin-bedded limestone and the colours are often varying within the same bed. The macroscopic texture is fine-grained micritic (porcelain). The thinly bedded (or foliated?) limestones could be identified at the Tuhinj area (outcrop 672, Fig. 3a), the northern slope of the Flinskovo ridge and the Čemšeniška Planina (outcrops 241-246, Fig. 2c, and outcrop 246 Fig. 4a) and on the NW slope of Mt. Mrzlica (outcrop 681 Fig. 3e). On the eastern slope of the Flinskovo Ridge (outcrop 241a, Fig. 2c), a dm-scale closed fold was measured, which could be considered a slump fold. Here we include the description of the rocks near the Stari Grad (Fig. 2c) although they do not belong to the SB succession.

Near the base of the sequence two different stratigraphic sequences with similar facies could be studied. In the Flinskovo ridge in outcrop 241a, the rock is light red to yellow micritic limestone, wackestone, and slightly dolomitized. In the thin section, fine lamination could be recognized due to the parallel orientation of the elongated calcite particles (“filaments”). The stylolites and the microcracks with offsets indicate slight layer-perpendicular shortening. The veins differ in width and their voids are filled with coarse crystalline calcite. A few calcified radiolarians, ostracods, and scattered opaque grains could be identified (Fig. 7k). From the second type of stratigraphic sequence north from Stari grad at outcrop 586 (Fig. 2c) pink-yellow variegated, silicified mudstone (wackestone) appears. In thin-section, this showed irregular crosscutting calcite veins often associated with irregular clay seams (Fig. 7m). A few stylolites and scattered pyrite crystals also occur. It did not contain identifiable fossils. Based on the microscopic features these rocks could be the hemipelagic uppermost part of the Tolmin or the base of the Biancone Limestone Formations although macroscopic characters support the latter option.

Due to the diagenetic process, at each studied area (Fig. 2a–c), the Biancone Limestone is often chertified to varying degrees and often dolomitized (Fig. 3a, e; Fig. 4a). In some outcrops, chert nodules could be recognized (e.g., Čemšeniška Planina section, outcrop 246, Fig. 4a). The calcareous character becomes slightly more marly upward while in site 245 yellow silicified calcareous marlstone is the dominant rock type (Fig. 2c). Based on the microfacies study, its original depositional texture was most probably mudstone. Wavy stylolitic seams often filled with dark clay, dispersed opaque minerals, rhomboid dolomite crystals, and few radiolarians were recognized (Fig. 7l). The thickness of the formation is approximately 50–100 m at all three areas (Fig. 1c/log 10-12).

Fig. 6. Ponikve Breccia Member of the Tomin Formation a-h) Middle Jurassic microfossils in clasts and matrix, i-aa) Triassic clasts. The scale bar is 1 mm, except g and bb where it is 3 mm a) broken radial-fibrous, and micritic ooids with *Lenticulina* sp., sample 590, Čemšeniška Planina; b-e) outcrop 240, Čemšeniška Planina; b) *Selliporella* mg. *donzellii* Sartoni & Crestenci; c-d) *Salpingoporella* sp., e) ?*Megaporella* sp.; f) *Rivularia lissaviensis* (Bornemann), sample 241, Čemšeniška Planina; g) algae indet., sample 674, Čemšeniška Planina; h) “*Cayeuxia*” sp., ooids with dolomite crsystal rim, sample 240, Čemšeniška Planina; i-y) sample 674, Čemšeniška Planina: i) laminated pelmicritic packstone-grainstone with stromatolite layers with *Frentzenella crassa* (Kristan) (T) and ?*Acicularia* sp. (A); j) *Aulotortus communis* (Kristan); k) *Aulotortus sinuosus* Weynschenk; l) *Aulotortus tenuis* (Kristan) (te), *A. tumidus* (Kristan-Tollmann) (tu) and *Arabicodium* sp. (A); m) *Parvalamella friedli* (Kristan-Tollmann); n) *Trocholina ultraspirata* Blau; o) *Gandinella falsofriedli* (Salaj, Borza & Samuel); p-q) “*Trochammina*” *almtalensis* Koehn-Zaninetti; r) ?*Trochammina alpina* Kristan-Tollmann; s) cf. *Paraophthalmidium* sp. and ?*Petrascula* sp.; t) cf. *Paraophthalmidium*; u) ?*Petrascula* sp.; v) dasycladacean organ (D) and *Rivularia lissaviensis* (Bornemann); w) *Bystrickyella ottii* Barattolo, Cozzi & Romano; x) *Salpingoporella austriaca* Schlagintweit, Mandl & Ebli; y) *Arabicodium* sp.; z) *Patruliuspora*; aa) Triassic clast with *Aulotortus sinuosus* Weynschenk (I), *Semiinvoluta* sp. (S) and *Triasina hantkeni* Majzon (T) encrusted with *Tolypammina gregaria* Wendt (Tg); bb-dd sample 592, Čemšeniška Planina: bb) *Styllophyllopsis* sp. and ammonite embryo; cc) *Coronipora etrusca* (Pirini); dd) *Semiinvoluta* sp.

It is to note that the rock exhibits a densely packed set of slightly undulating, wavy or planar surfaces. Locally the dark solution residue point to strong pressure solution. The interpretation is twofold: either they represent sedimentary lamination overprinted by pressure solution or the stylolitic surfaces are already the sign the incipient layer-parallel foliation induced by layer-perpendicular (vertical) shortening (Fig. 7k-m). Despite the absence of age-determining fossils, the macroscopic and microscopic characteristics of the rock match well with the development of the Biancone Limestone in the SB. The projected age is late Tithonian to Berriasian (Rožič et al., 2009; Goričan et al., 2012b).

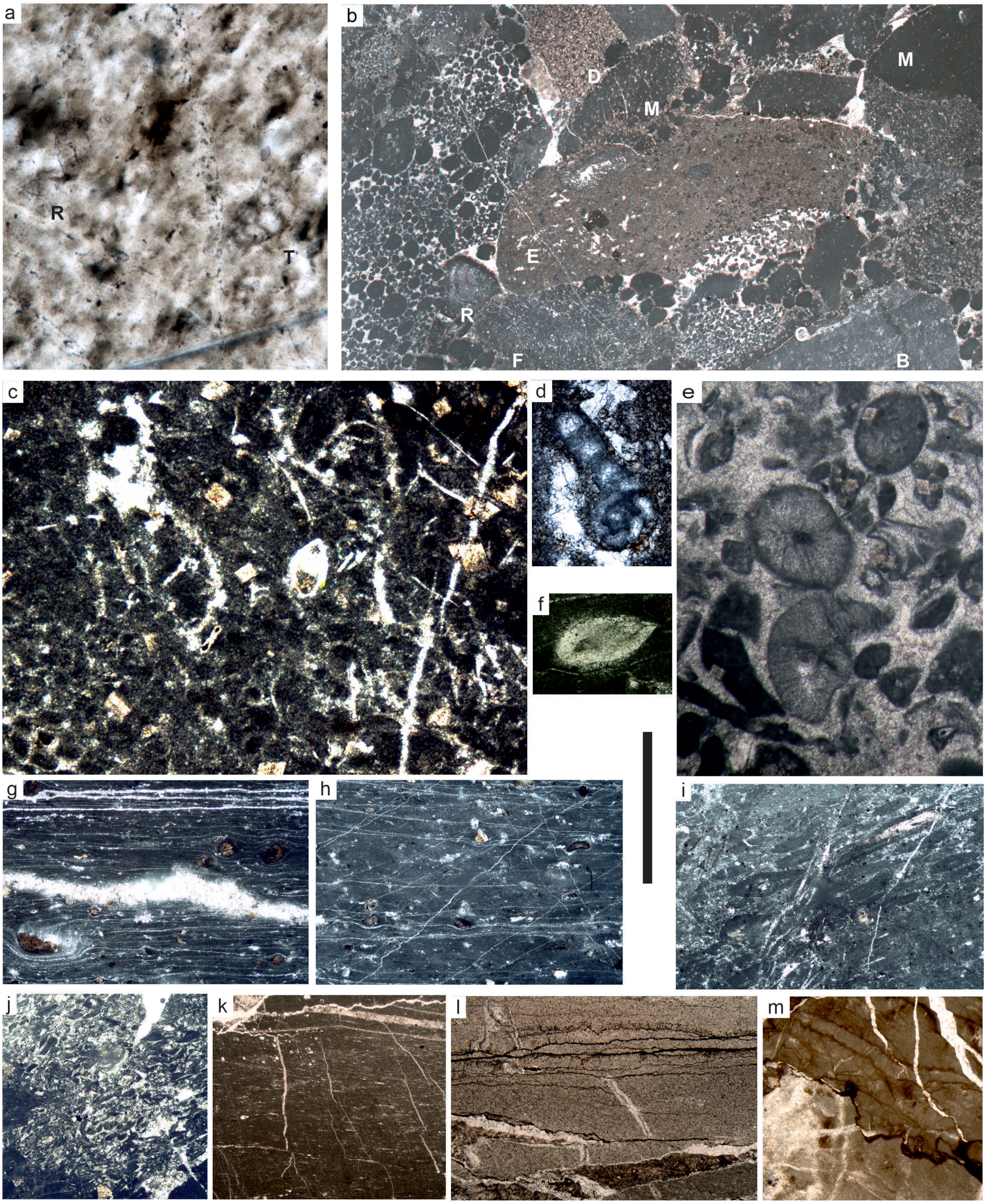

Fig. 7.

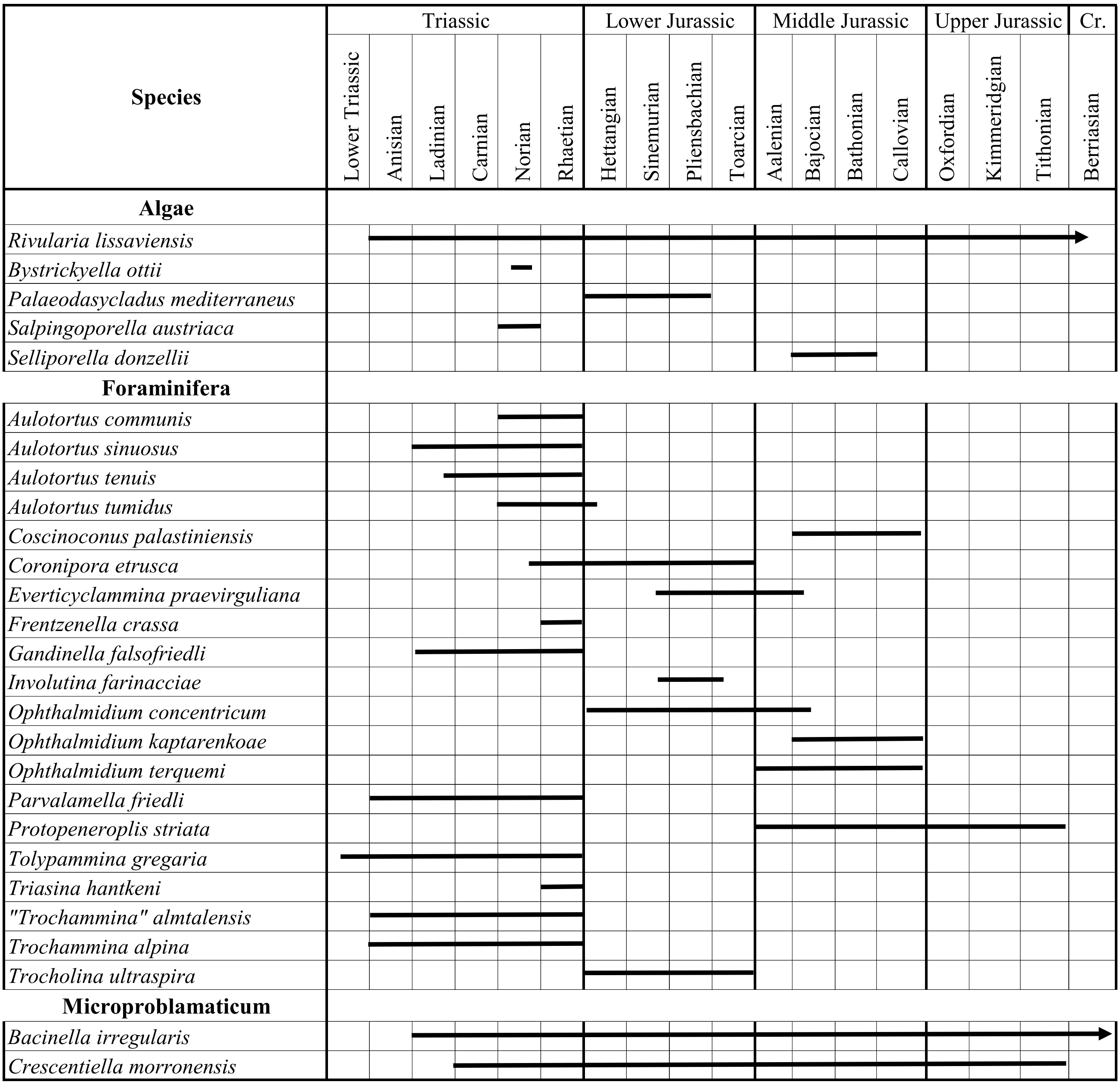

Fig. 8. Stratigraphic range of the most important age-determining fossils based on the literature cited in the appendix.

Fig. 7. a-e) Lower Jurassic clasts, f-j) clast of unknown age of the Ponikve Breccia Member of Tolmin Formation, k) basinal facies of the Tolmin Formation or Biancone Limestone Formation, l-m) Biancone Limestone Formation. The scale bar is 10 mm, except a, c, d and f where it is 1 mm a) Silicified clast, bioclastic (radiolarians and sponge spicules) packstone with nassellarian Radiolaria (R) and textulariid foraminifera (T), sample 590c, Čemšeniška Planina; b) clast with the matrix of the breccia, which is dolomitized ooid–peloid grainstone with microsparite-sparite matrix and different angular lithoclasts. In the matrix, there are *Rivularia lissaviensis* (Bornemann) (R), *Crescentiella* mg. *morronensis* (C = Fig. 5u) and foraminifers. The lithoclasts are the following: dolomite (D), mudstone with *Bacinella irregularis* Radoičić (B, see also Fig. 7c) and stromatolite (Triassic?), dolomitized, basinal peloid mudstone-wackestone facies, with filaments and foraminifers (F, enlarged on Fig. 7d) Lower Jurassic clast from the Krikov Formation, mudstone with dolomite crystals (M), dolomitized lithoclast with a larger agglutinated foraminifera, *Everticyclammina praevirguliana* Fugagnoli, sample 241, Čemšeniška Planina; c) enlarged peloid mudstone-wackestone clast of Fig. 7b) with filaments, Echinodermata fragments and *Lenticulina* sp.; d) enlarged part of b), *Everticyclammina praevirguliana* Fugagnoli; e) *Palaeodasycladus mediterraneaus* (Pia) from the Jurassic lithoclast of sample 240, Čemšeniška Planina; f-h) sample 338a, NE ridge of Mt. Mrzlica: f) ostracod filled with sparry calcite, g) nodular-bounding appearance of stylolites with undulose surfaces and arranged in parallel sets, with Echinodermata fragments; h) calcite veins arranged in different sets; i-j) sample 678, NW flank of Mt Mrzlica, i) ooid packstone with micritic matrix and strongly elongated micritic ooids with crosscutting calcite veins; j) grainstone with distorted ooids; k) slightly dolomitized, micritic hemipelagic limestone, wackestone with elongated calcite particles (most probably calcified radiolarians) giving a fine lamination appearance, sample 241a, Čemšeniška Planina; l) chertified thin-bedded limestone mudstone with wavy foliation, which is filled with dark clay, sample 245, Čemšeniška Planina; m) chertified mudstone, irregular crosscutting quartz veins associated with irregular clay foliations, sample 586, Čemšeniška Planina.

The Lower Flyschoid Formation

This formation is more common in the western SB. The thickness of the formation is approximately 50–100 m at the Tuhinj area (Fig. 1c/log 10). Its age is late Aptian/Albian to middle Cenomanian (Buser, 1986; Demšar, 2016) or Turonian (Cousin, 1981; Rožič et al., 2014).

At the Tuhinj area, we observed a small outcrop composed of very fine-grained material, grey marlstone and shale (outcrop 673, Fig. 1c/ log 10, Fig. 3b). This is the uppermost member of the Tuhinj area succession. The sedimentological features, laminated appearance, high clay content with a few cm thick carbonate-rich layers, and stratigraphic position support the identification of this formation as the Lower Flyschoid Formation of the SB.

Short description of the detailed maps (stratigraphy and structures)

Mount Mrzlica

Mt. Mrzlica is located 5 km SW from Žalec with three ridges descending northward from the peak. The SB succession is only present on the north-western flank and the north-eastern ridge while the northern flank in between is composed of Permian to Lower Triassic rocks. The Mrzlica NW map (Fig. 2a) is located on the north-western flank of Mt. Mrzlica, 1 km northwest of the peak. Buser (1978) only indicated a unified Jurassic sequence over Triassic platform limestones and on the eastern part the equivalent of Bača Formation. Buser (2009) indicated the presence of the Bača Dolomite, Biancone Limestone and Triassic platform limestone in this order from north to south on the northern side of Mt. Mrzlica. Our study indicates that the succession is composed of the Bača Dolomite, Krikov Formation, Ponikve Breccia Member of the Tolmin Formation, and the Biancone Limestone. The Perbla Formation and the other three members of the Tolmin Formation, typical for more continuous Slovenian Basin successions (Rožič, 2009), are missing from the succession. There are two thrust faults; the hanging wall of the older thrust comprises the SB succession (Fig. 2a, Thrust Fault I.), and the footwall is the Middle Triassic Schlern Formation and the Lower Triassic Werfen Formation. This thrust was responsible for the displacement of the SB units over the Triassic Units of the Dinarides. The second thrust (Fig. 2, Thrust Fault II.) is interpreted as being younger, with a very steep angle; it is responsible for the overthrusting of the SB succession with the Middle Triassic Pseudozilian Formation and the overlying Triassic to Cretaceous succession.

The map Mrzlica NE (Fig. 2b) is located 1.5 km northeast of the peak of Mt. Mrzlica. Previous maps (Buser, 1978, 2010) indicated the Bača Dolomite in this area. During our mapping, several formations of the SB were observed, partly based on lithological similarities of rocks to the succession of the Mrzlica NW section. At this part of Mt. Mrzlica two thrust faults are interpreted. The older one (Fig. 2b Thrust Fault II. a) is responsible for thrusting the Bača Dolomite over the succession of younger SB members. The younger thrust (Fig. 2b, Thrust Fault II. b) is responsible for the displacement of the Pseudozilian Formation over the SB units, shown also on the Mrzlica NW map (Fig. 2a). This younger thrust is then cut by a NW-SE trending dextral strike-slip fault that was already active before the second thrust. A west-dipping normal fault is cutting through the SB formations surely postdating the first thrust and probably predating the younger thrust.

Flinskovo and Čemšeniška Planina

In this area, the formations of the SB start from Ladinian Pseudozilian resedimented volcaniclastic rocks and sandstone, followed by the Bača Dolomite. We emphasise that this contact could as well be a thrust fault meaning that the lower boundary of the Bača Dolomite can be tectonic (similar to Fig. 2a, Thrust Fault I.). In the latter case, however, the Pseudozilian Formation would structurally belong to the Dinarides. Above the Bača Dolomite, follows the Lower Jurassic Krikov Formation, the Middle Jurassic Ponikve Breccia Member, and finally the Upper Jurassic to Lower Cretaceous Biancone Limestone. The SB succession seems to form a klippe above the Carboniferous to Lower Triassic sequence of the Dinarides, as judged from the map of Placer (2008). The eastern boundary of this klippe, just east of the Flinskovo ridge a north–south striking normal fault is positioned between the footwall Pseudozilian and Schlern Formations of the Dinarides and the hanging wall SB units (Fig. 2c). Later, a younger east-west striking thrust (Fig. 2c, Thrust Fault II.) displaced the Triassic Pseudozilian Formation over the SB succession (in the west) with an analogue role as in the Mt. Mrzlica area. In the eastern part of the map, the younger thrust cut across and repeats a Mesozoic succession composed of the Pseudozilian, Schlern and the Biancone Limestone Formations without the presence of the Jurassic rocks of the SB succession; this part does not belong to the SB. Near the Stari Grad we postulate stratigraphic contact between the Schlern and Biancone Formations because such stratigraphic order was followed between the Mt. Krvavica and Mt. Mrzlica (Scherman et al. 2022).

Discussion and Conclusions

Our observations and paleontological studies corroborate previous suggestions (Buser, 1996; Placer, 2008; Rožič, 2016), that the SB units extend eastward of the Ljubljana Quaternary basin, i.e., along the northern flank of the Sava Folds. The studied locations represent the important connection between the eastern and western sequences of SB units studied so far. SB successions are characterized by prominent stratigraphic gaps and are similarly developed in all three research areas. The successions start with the rather thick Bača Dolomite Formation, but its base seems to be a thrust plane near the Tuhinj Valley and on the Mrzlica Mts. An exception is the Čemšeniška Planina where it is not excluded that the succession starts with the Pseudozilian Formation and the basal thrust is just below it. In fact, all the map disposition suggests the dual position of the Pseudozilian Formation; north of the young steep E-W striking thrust the Pseudozilian Formation does not seem to be part of the SB succession, because the Jurassic formations are missing (Stari Grad Fig. 2c, and north of the Mt. Mrzlica, Fig. 2a, b). On the other hand, on the south-eastern corner of the Čemšeniška Planina the Pseudozilian Fm. can be the lower preserved unit of the overlying SB succession, like in many cases in the western SB (Rožič 2006; Gale 2010).

The Bača Formation is followed by the Krikov Formation, documented in two of our sections at Čemšeniška Planina and Mrzlica areas (Fig. 1c/logs 11, 12). No observations of the Krikov Formation were made in the Tuhinj area; however, a 300 m gap in observation could also suggest its possible presence (Fig. 1c/log 10). The Krikov Formation from the study area is dominated by hemipelagic limestone, with the subordinate occurrence of resedimented limestones. Similar successions are found in the Mrzli vrh and Mirna sections (Rožič, 2006; Rožič et al., 2017, 2022), whereas similar developments are found along the entire SB southern margin (Rožič, 2006; Rožič et al., 2019, 2022).

The Perbla Formation and the Lower Member of the Tolmin Formation are missing from the studied sections. The Ponikve Breccia Member was observed and proven by paleontological data from all three areas (Fig. 1c/logs 10, 11, 12). This lithostratigraphic unit was described recently from the entire SB southern margin. The most similar thickness is reported from the Mrzli Vrh, the Ponikve Plateau and Podpurflca sections (Fig.1c/logs 1, 3, 6) (Rožič et al., 2022). The Ponikve breccia passes towards the basin gradually into the lower resedimented limestones that at the type locality (Fig. 1c/log 3, Rožič et al., 2022) occur as calciturbidite interbeds within siliceous limestone and radiolarite. In some transitional sections (Mrzli Vrh, Ponikve Plateau, Trnje, sites 1, 3, 7 on Fig. 1c), the Ponikve Breccia is overlain by these siliceous pelagic sediments (Rožič et al., 2013, 2019, 2022). Our observations at the Čemšeniška Planina area could be similar to the Ponikve Plateau (Rožič et al., 2019), where the fully covered, several meters thick stripe occurs between the Ponikve Breccia and Biancone Limestone. In other studied locations, the Biancone Limestone could lie directly over the Ponikve Breccia, which is observed also in the Mirna Valley sections (Rožič et al., 2019; 2022, see detailed discussion therein). The contact with the overlying Lower Flyschoid Formation is generally erosional in the SB, and the stratigraphic gap encompasses a large part of the Lower Cretaceous and is found practically in all SB successions. The formation is shale-dominated, which is characteristic for some other comparable sections, such as Zapoškar, Škofja Loka (Podpurflca, Dešna, Trnje) and Mirna River sections (Rožič et al., 2022). Our observation near Tuhinj corroborates this general knowledge although the lower contact was not observed.

We conclude that within the northern flank of the Sava Folds, the outcrops of the SB can be traced. The three investigated successions (Fig. 1c/log 10, 11, 12) show close similarities to almost all previously studied Jurassic sections at the southernmost margin sequences of the SB (Rožič et al., 2019, 2022). Therefore, the newly studied successions establish the connection between the western and eastern Slovenian Basin successions. If the studied successions would represent the eastward continuation of the Podmelec Nappe (lowermost imbricate unit of the Tolmin Nappe) needs further consideration.

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Appendix: Microfossils species and their stratigraphic range and palaeoenvironment

The species of each fossil group are listed in alphabetical order.

Cyanophyta

Rivularia lissaviensis (Bornemann, 1887)
Stratigraphic range: Middle Triassic – Aptian.
Environment: this species appears in the silent water of the back reef or lagoon (Haas et al., 2019).

Chlorophyta

Dasycladales
Bystrickyella ottii Barattolo, Rozzi & Romano, 2008
Stratigraphic range: this species was established from the middle Norian.
Environment: shallow marine, platform facies (Barottolo et al., 2008).

Palaeodasycladus mediterraneus (Pia, 1920):
Stratigraphic range: Hettangian – Pliensbachian.
Environment: low-energy inner platform (Rychliński et al., 2018).

Salpingoporella austriaca Schlagintweit, Mandl & Ebli, 2001
Stratigraphic range: Norian.
Environment: inner platform, near the reef (Carras et al., 2006).

Selliporella mg. *donzellii* Sartoni & Crestenci, 1962
Stratigraphic range: lower Bajocian – upper Bathonian.
Environment: low-energy inner platform (Sokač & Grgasović, 2017).

Foraminifera

Aulotortus communis (Kristan, 1957)
Stratigraphic range: Norian – Rhaetian.
Environment: shallow marine platform (Gale et al., 2012).

Aulotortus sinuosus Weynschenk, 1956
Stratigraphic range: Ladinian – Rhaetian.
Environment: shallow marine platform (Gale et al., 2012).

Aulotortus tenuis (Kristan, 1957)
Stratigraphic range: Ladinian? Carnian – Rhaetian.
Environment: shallow marine platform (Haas et al., 2010).

Aulotortus tumidus (Kristan-Tollmann, l964)
Stratigraphic range: Norian – Liassic?
Environment: shallow marine platform (Haas et al., 2010).

Coscinoconus palastiniensis Henson*,* 1847
Stratigraphic range: Bajocian – Callovian (Haas et al. 2006).
Environment: it is common in the mud facies of the inner platform (Haas et al., 2012).

Coronipora etrusca (Pirini, 1966)
Stratigraphic range: upper Norian – Liassic.
Environment: well-oxygenated low-energy environment (Blau & Haas, 1991).

Everticyclammina praevirguliana Fugagnoli, 2000
Stratigraphic range: upper Sinemurian – lower Bajocian.
Environment: shallow marine low-energy environments in the inner platform (Haas et al., 2019).

Frentzenella crassa (Kristan, 1957)
Stratigraphic range: Rhaetian.
Environment: shallow marine, platform and reef (Rigaud et al., 2013).

Gandinella falsofriedli (Salaj, Borza & Samuel, 1983)
Stratigraphic range: Ladinian – Rhaetian.
Environment: Different shallow marine environments, such as lagoons or upper slopes (Gale, 2012).

Involutina farinacciae Brönnimann & Koehn-Zaninetti, 1969
Stratigraphic range: upper Sinemurian – lower Toarcian.
Environment: ooidal-peloidal facies of the outer platform (Haas et al., 2019).

Ophthalmidium concentricum (Terquem & Berthelin, 1875)
Stratigraphic range: Hettangian – lower Bajocian.
Environment: outer platform environment (Clerc, 2005).

Ophthalmidium kaptarenkoae Danitch, 1971
Stratigraphic range: Bajocian – Callovian.
Environment: inner and middle shelf environment (Clerc, 2005).

Ophthalmidium terquemi Pazdrowa, 1958
Stratigraphic range: Aalenian – Callovian.
Environment: inner and middle shelf environment (Clerc, 2005).

Parvalamella friedli (Kristan-Tollmann, 1962)
Stratigraphic range: Anisian – Rhaetian.
Environment: Low-energy shallow water environment, such as lagoonal, back-reefal environment or shoal facies (Haas et al. 2019).

Protopeneroplis striata Weynschenk, 1950
Stratigraphic range: Aaleni – end of the Tithonian.
Environment: outer platform ooid shoal environment (Haas et al., 2006).

Tolypammina gregaria Wendt, 1969
Stratigraphic range: Lower Triassic – Rhaetian
Environment: It is an attached epifaunal foraminifera related to low sedimentation rate and mesotrophic conditions (Rodríguez-Martínez et al., 2011).

Triasina hantkeni Majzon, 1954
Stratigraphic range: Rhaetian.
Environment: shallow platform environment (Gale et al., 2012).

“*Trochammina*” *almtalensis* Koehn-Zaninetti, 1969
Stratigraphic range: Anisian – Rhaetian.
Environment: shallow marine, platform (Gale et al., 2012).

Trochammina alpina Kristan-Tollmann, 1964
Stratigraphic range: Anisian – Rhaetian (Salaj et al., 1983).
Environment: shallow marine, platform and reef (Bernecker, 2005).

Trocholina ultraspirata Blau, 1987
Stratigraphic range: Lower Jurassic.
Environment: shallow marine, platform and reef (Rigaud et al., 2013).

Microproblematicum

Bacinella irregularis Radoičić, 1959 emend. Schlagintweit and Bover Arnal, 2013
Stratigraphic range: Genus Bacinella described from the Ladinian – Albian of the Tethys (Schlagintweit and Bover Arnal, 2012).
Environment: This species is a typical biostrome builder of backreefal or peritidal depositional settings environment (Granier, 2021).

Crescentiella mg. *morronensis* (Crescenti, 1969)
Stratigraphic range: Upper Triassic-Upper Jurassic.
Environment: Shallow marine, mainly in a reef environment (Senowbari-Daryan et al., 2008, Senowbari-Daryan, 2013).