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Sedimentary record of subsidence pulse at the Triassic/Jurassic boundary interval in the Slovenian Basin (eastern Southern Alps)

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Abstract: In the Alpine Realm the Early Jurassic is characterized by the disintegration and partial drowning of vast platform areas. In the eastern part of the Southern Alps (present-day NW Slovenia), the Julian Carbonate Platform and the adjacent, E–W extending Slovenian Basin underwent partial disintegration, drowning and deepening from the Pliensbachian on, whereas only nominal environmental changes developed on the large Dinaric (Friuli, Adriatic) Carbonate Platform to the south (structurally part of the Dinarides). These events, however, were preceded by an earlier — and as yet undocumented extensional event — that took place near the Triassic/Jurassic boundary. This paper provides evidence of an accelerated subsidence from four selected areas within the Slovenian Basin, which show a trend of eastwardly-decreasing deformation. In the westernmost (Mrzli vrh) section — the Upper Triassic platform-margin — massive dolomite is overlain by the earliest Jurassic toe-of-slope carbonate resediments and further, by basin-plain micritic limestone. Further east (Perbla and Liščak sections) the Triassic–Jurassic transition interval is marked by an increase in resedimented carbonates. We relate this to the increasing inclination and segmentation of the slope and adjacent basin floor. The easternmost (Mt. Porezen) area shows a rather monotonous, latest Triassic–Early Jurassic basinal sedimentation. However, changes in the thickness of the Hettangian–Pliensbachian Krikov Formation point to a tilting of tectonic blocks within the basin area. Lateral facies changes at the base of the formation indicate that the tilting occurred at and/or shortly after the Triassic/Jurassic boundary.

Keywords: Southern Alps, Slovenian Basin, rifting, Triassic/Jurassic boundary, Sinnemurian, resedimented limestones, block tilting.

Introduction

The opening of the Central Atlantic and the related marginal oceanic basins (e.g., Piemont–Liguria Ocean) brought about a major reorganization of paleogeographic units in the western Neotethys area (Schmid et al. 2008; de Graciansky et al. 2011; Masini et al. 2013). Although crustal extension has been documented for the interval extending from the Late Triassic to the Middle Jurassic, the main paleogeographic changes tend to be concentrated in a relatively short period postdating the Triassic–Jurassic boundary. On the European rifted margin, the extension resulted in an intense block-tilting along listric faults, which is reflected in pronounced lateral changes within Lower Jurassic deposits (Lemoine et al. 2000; Chevalier et al. 2003; de Graciansky et al. 2011). The entire southern Tethian rifted margin, situated on the Apulian (Adriatic) microplate, is likewise marked by the disintegration and partial drowning of the vast Late Triassic/earliest Jurassic carbonate platform. In the Austroalpine domain this resulted in a significantly reduced extension of the Hauptdolomit–Dachstein Platform (Mandl 2000; Böhm 2003; Gawlick et al. 2009, 2012), which was followed by the formation of horst and graben structure (Bernoulli & Jenkyns 1974; Eberli 1988; Krainer et al. 1994). Prominent, latest Triassic–early Lower Jurassic differentiation of the sedimentary environments is reported also from the Central and Inner Carpathian units and the Transdanubian Range unit (Vörös & Galácz 1998; Plašienka 2002, 2003; Haas et al. 2014).

In the Southern Alps, the earliest Jurassic (Late Hettangian–Sinemurian) was influenced by a diffuse rifting phase (Berra et al. 2009), with the extension resulting in the formation of four large-scale sedimentary units (Fig. 1): the internally highly-dissected Lombardian Basin to the west, the intermediate Trento Platform, the Belluno Basin, and the Friuli Platform to the east (Winterer & Bosellini 1981; Bertotti et al. 1993; Sarti et al. 1993). The latter continues to the SE as the vast Dinaric (Adriatic) Carbonate Platform (Vlahović et al. 2005). In the easternmost part of the Southern Alps (present-day northern Slovenia), however, a prominent pre-Jurassic paleotopography existed. This originated in the Middle Triassic (Buser 1989, 1996; Šmuc & Čar 2002) and was related to the opening of the Neotethys Ocean (Vrabec et al. 2009). The central paleogeographic unit was the Slovenian Basin (SB), bounded by the Julian Carbonate Platform (JCP)

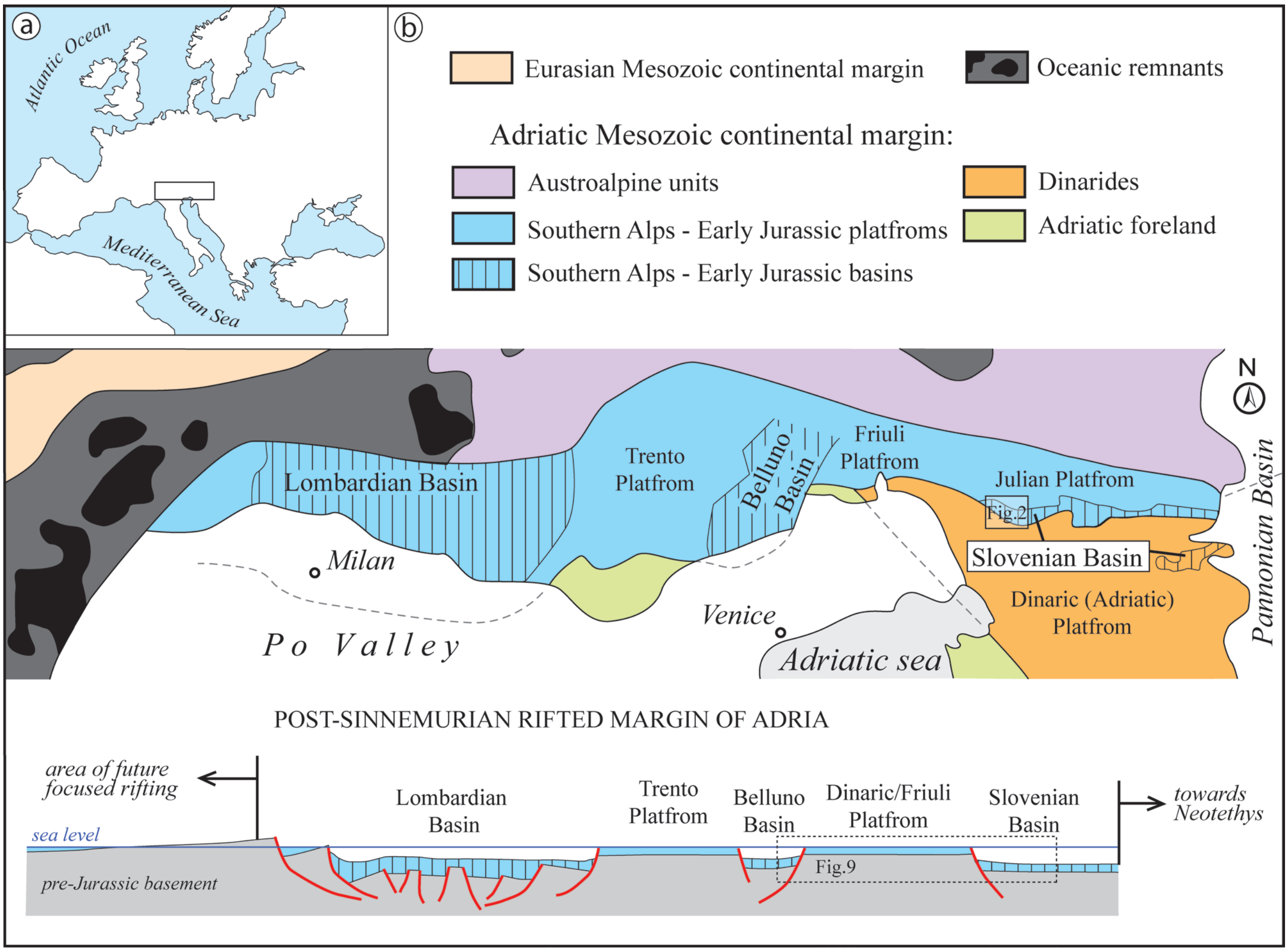

Fig. 1. a — Position in Europe (boxed area marks part of Alpine chain presented in Fig. 1b); **b** — Present-day position of Early Jurassic basins of the Southern Alps within the general structure of the Alps (please note that partly emerged areas west of the Lombardian Basin are not outlined) and schematic cross-section across the Southern Alps rifted margin of Adria after the first Early Jurassic extensional stage (modified from Bosellini et al. 1981; Channell & Kozur 1997; Placer 2008; Berra et al. 2009; Rožič 2016).

to the present north, and the Dinaric Carbonate Platform (DCP) to the present south (Cousin 1981; Buser 1989, 1996; Rožič 2016). Because this region was paleogeographically quite distant from the main rifting center of the Piemont-Liguria Ocean, and owing to the inherited pre-Jurassic relief, the aforementioned large-scale earliest Jurassic paleogeographic perturbations are not observed in the eastern sector of the Southern Alps. However, all of the previously described structural and paleogeographic changes can be recognized on a smaller scale. This paper presents the evidence of such events as recorded in the successions of the SB. Four areas were selected where sedimentary reflection of crustal deformation is best recognized: A) the Mrzli vrh section documents the drowning of the carbonate platform margins, B) the internal deformation of the basin floor is recorded at Perbla Village and Liščak Gorge, and C) the block tilting is evident from the Mt. Porezen sections. The paper presents new data related to bed-to-bed section-logging, microfacies and lithoclast analysis, and foraminiferal and conodont biostratigraphy.

Geological setting

General overview

Structure: The studied sections are located in the foothills of the Julian Alps in NW Slovenia, from the town of Tolmin in the west to the town of Cerkno in the east. The rocks of the three main paleogeographic units, namely the JCP, SB and DCP, are in thrust contacts (Fig. 2a). The DCP successions belong structurally to the External Dinarides, which were affected by post-Eocene SW-directed thrusting, whereas successions of the JCP and the SB belong to the Southern Alps and are characterized by the Miocene S-directed thrusting (Placer 1999, 2008; Vrabec & Fodor 2006). Within the Southern Alps, the Julian Nappe is made up of the formations of the JCP. It is in thrust contact with the structurally-lower Tolmin Nappe of the Southern Alps, comprising the SB successions (Placer 1999). The Tolmin Nappe is further divided into three lower-order thrust units: the lowest Podmelec Nappe, the middle Rut Nappe, and the upper Kobla

Nappe (Buser 1987). In the transitional zone between the Dinarides and the Southern Alps older NW–SE-oriented structures are overprinted by W–E-oriented South Alpine deformations (Placer & Čar 1998). The thrusts are further displaced by Pliocene to recent strike-slip faults (Placer 1999, 2008; Vrabec & Fodor 2006; Kastelic et al. 2008; Šmuc & Rožič 2010). This structural history, in combination with the highly deformable basinal rocks of the Tolmin Nappe, resulted in a fragmented

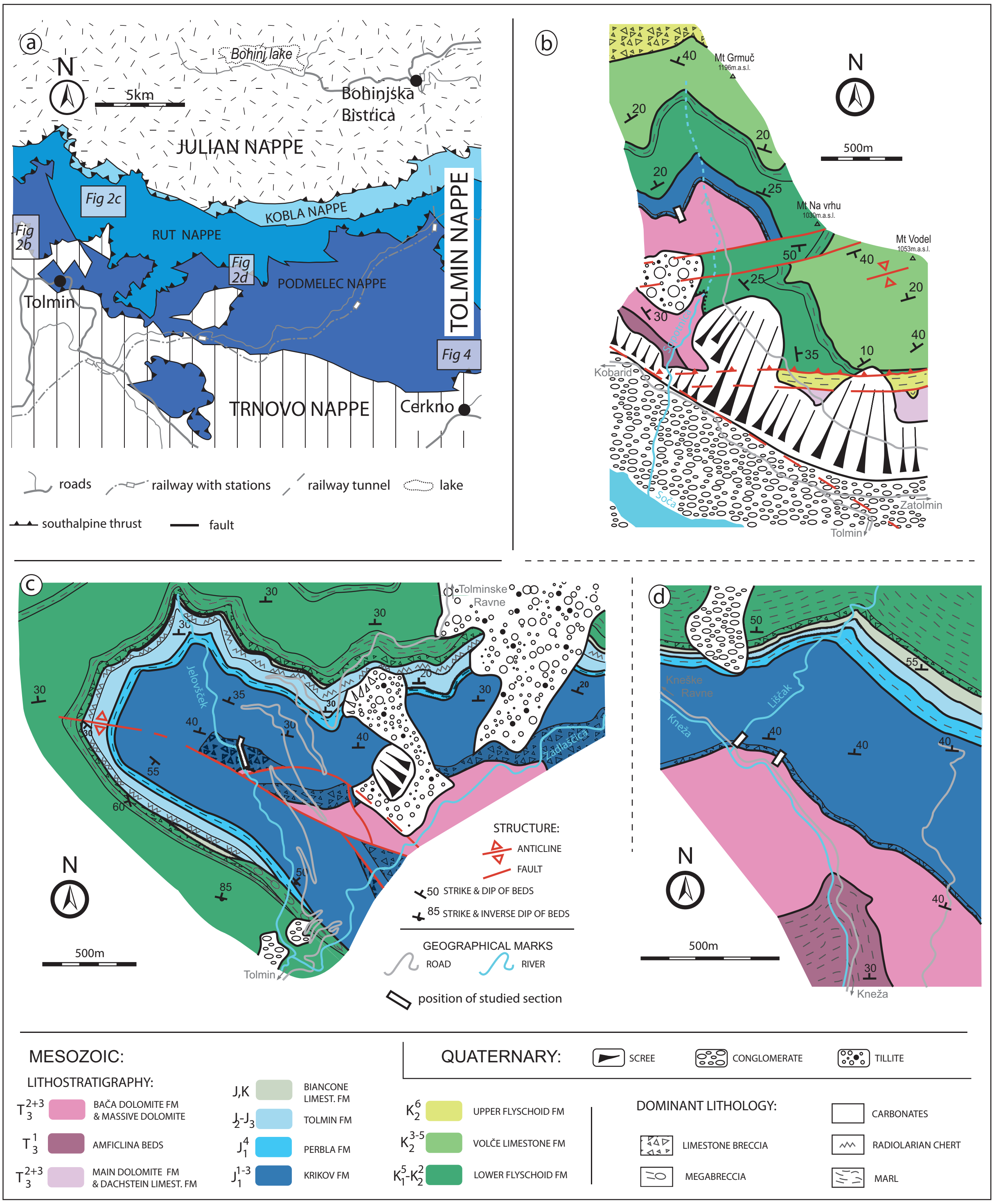

Fig. 2. a — Structural subdivision of NW Slovenia (generalized after Buser 1987). The Trnovo Nappe is the highest thrust unit of the External Dinarides composed of the DCP successions. The Tolmin Nappe forms the base of the Southern Alps, is composed of SB succession, and is divided into three lower-order thrusts. The Julian Nappe forms the upper portion of the Southern Alps and is composed of JCP successions. The boxed areas indicate the position of the detailed geological maps of: **b** — Mt. Mrzli vrh area, **c** — Perbla area, **d** — Liščak area, whereas the geological map of the Mt. Porezen area is represented in Figure 4.

and complex geological setting and led to the eradication of the original spatial relationships between the JCP, SB and DCP.

Stratigraphy: The Norian and Rhaetian stages of the SB are dominated by the Bača Dolomite, which is largely made up of bedded dolomite with chert nodules and dolomite-chert breccias, the latter being common in the middle part of the formation (Gale 2010). In the westernmost part of the Podmelec Nappe, the Bača Dolomite passes upwards into massive dolomite (partly logged in this study). In the northern part of the basin the Late Norian and Rhaetian Slatnik Formation, composed of alternating hemipelagic limestones and calciturbidites, overlies the Bača Dolomite (Rožič et al. 2009, 2013; Gale et al. 2012).

During the Hettangian and Pliensbachian, the limestone-dominated Krikov Formation became deposited. It is characterized by alternating hemipelagic limestone and calciturbidites. The latter are predominant in the northern part of the basin (Kobla Nappe), but become rarer towards the central part of the basin (Rut Nappe), and are almost entirely absent (diluted) in the southern part of the basin (Podmelec Nappe) (Rožič 2009; Goričan et al. 2012). In the westernmost outskirts of the basin, the base of the formation is dominated by a thick limestone breccia (also presented in this paper). The contact of the Krikov Formation with the overlying Toarcian, marl/shale-dominated Perbla Formation is sharp (Rožič 2009; Rožič & Šmuc 2011).

Location and tectono-stratigraphic setting of studied sections

As a result of intense tectonic deformation, areas appropriate for detailed studies are rare. Detailed geological mapping was performed for each selected area and the results are summarized herein.

The westernmost outcrops of the SB can be found on Mt. Mrzli vrh, which structurally belongs to the Podmelec Nappe (Fig. 2b) (Buser 1987). The succession is characterized by an Upper Triassic to Cretaceous succession of basinal facies, with the exception of a several hundred meters thick (?Norian–Rhaetian) massive dolomite. In the northern part of the mapped area the massive dolomite is overlain by the basinal Jurassic Krikov Formation. South of the E–W trending fault, however, the massive dolomite is followed by the late Early Cretaceous Lower Flyschoid Formation. This fault is interpreted as a reactivated Mesozoic fault (Rožič 2005). The studied section is located on the southern ridge of Mt. Mrzli vrh, between the Sopotnica gorge and the Soča Valley at an altitude of 800 m, along the trenches remaining from the First World War (E 13°42'12", N 46°12'34").

The Perbla area is situated within the Rut Nappe (Buser 1987), which in this area contains an entire Norian to end-Cretaceous succession. It is exposed in a large fold (Fig. 2c) displaced by an E–W-trending fault along its core. The displacement could not be recognized in the Toarcian and younger rocks, therefore it is presumed to be a paleofault. The section was logged in the Jelovšček gorge in the core of the anticline (E 13°45'28", N 46°13'13").

The Liščak area lies structurally within the Podmelec Nappe (Buser 1987). In the mapped area an undisturbed Late Triassic to Lower Cretaceous basinal succession was documented. The Triassic–Jurassic transition was logged in two sections close to one another (Fig. 2d). The stratigraphically lower section is located in a tributary stream of the Kneža River (E 13°50'29", N 46°11'21"). It ends with a characteristic breccia megabed, which was laterally followed to the base of the second section, which is situated at the entrance to the Liščak stream gorge (E 13°50'18", N 46°11'24"). Above the logged section, part of the Krikov Formation is dolomitized.

Mt. Porezen structurally belongs to the Podmelec Nappe (Buser 1987), and exhibits what is probably the most complete Late Triassic (maybe even Ladinian) to Cretaceous succession. Three sections were logged near the Otavnik peak at the mountain's southwestern ridge. The northwestern section is located along the Porezen stream in the Zakojška grapa gorge and along the tributary stream towards the Vasaje farm (E 13°56'54", N 46°10'7"). The southern section was measured in a gorge that cuts the southern slopes of the Ritovščica peak (E 13°58'2", N 46°9'21"). The eastern section was logged in the Zapoškar stream gorge (E 13°58'34", N 46°9'36") and was logged in two, closely situated, stratigraphically successive sections.

Description, biostratigraphy and sedimentological interpretation of studied sections

Mrzli vrh section

Description: The base of the studied section is made up of bedded dolomite with chert nodules that is overlain by thick massive dolomite several hundred meters thick. The topmost 13 m of the massive dolomite was logged in the section (Fig. 3), where it starts to exhibits indistinct bedding. It is overlain by 6 m of alternating bedded (5 to 35 cm) dolomite and partially dolomitized calcarenite. This interval contains chert nodules. Dolomite is coarsely crystalline with sub- to euhedral crystals up to 500 µm large, and texture-obliterating. Calcarenite is fine- to coarse-grained and partially dolomitized, with a still recognizable primary composition that shows characteristics of the overlying calcarenite.

The section continues with a 35 m-thick interval composed of occasionally channelized beds of limestone breccia and calcarenite that alternate with intervals of very thin-bedded calcarenite and micritic limestone. Limestone breccia is generally thick-bedded (up to 250 cm) and often grades to calcarenite. Clasts are up to 20 cm large, subangular to well rounded, elongated, and oriented parallel to the bedding planes. Calcarenite-supported breccia prevails, whereas clast-supported breccia occurs in lower portions of beds exhibiting inverse grading, locally. Breccia is rudstone with calcarenite matrix that is identical in composition to the surrounding

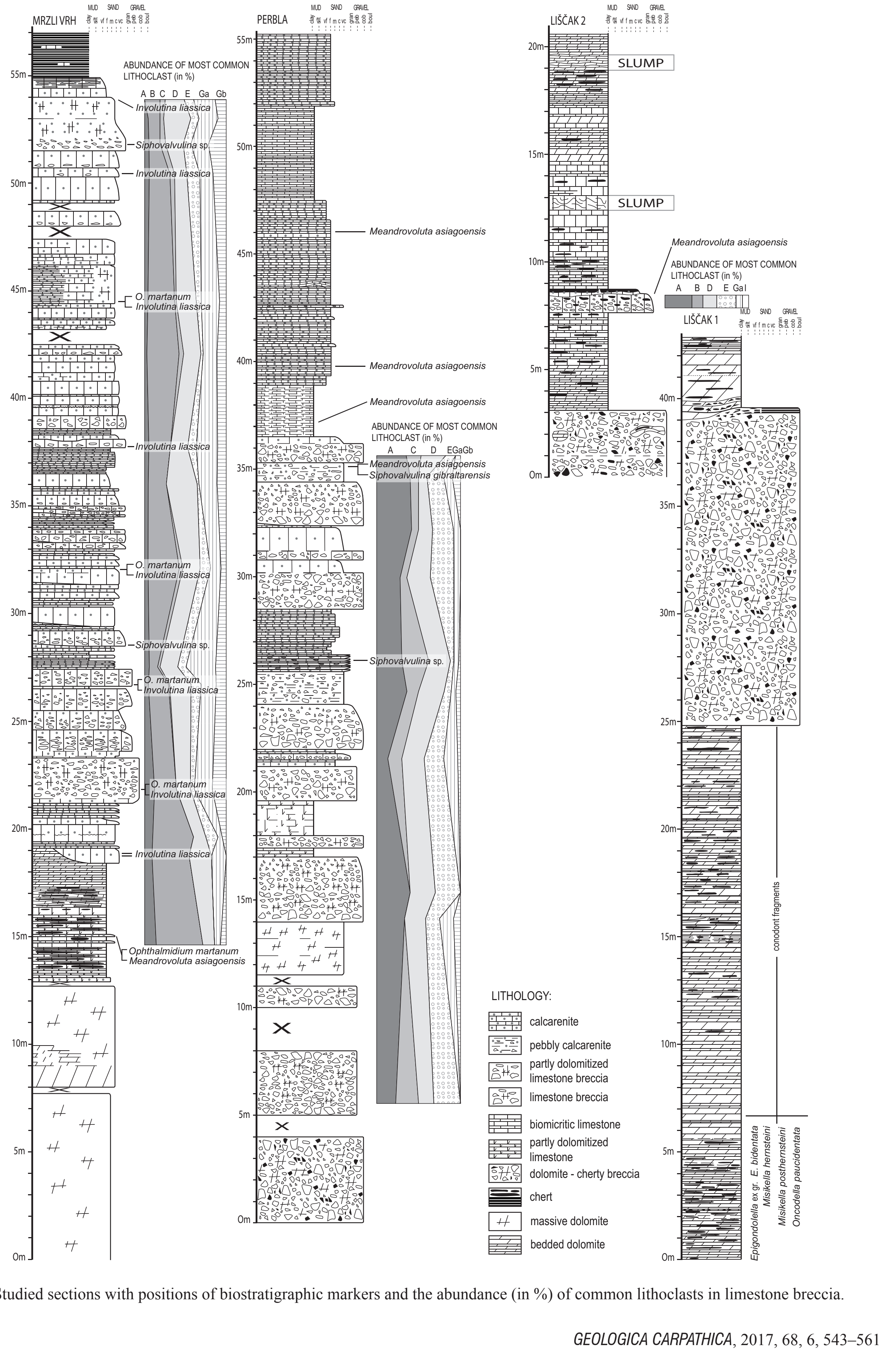

Fig. 3. Studied sections with positions of biostratigraphic markers and the abundance (in %) of common lithoclasts in limestone breccia.

calcarenites (see description below), whereas lithoclasts originated from platform, slope and basin carbonates (Fig. 4c, d; for details see Tables 1 and 2).

Calcarenite is gray to light gray and bedded (up to 90 cm), often graded and horizontally laminated, but textureless versions also occur. When alternating with micritic limestone, it displays similar characteristics, but beds are very thin (mm- or cm-sized) and contain load casts. In the upper part of the unit (from 44^{th} to 47^{th} m of the section) calcarenite is indistinctly bedded, comprised of a few thick beds (up to 180 cm) that laterally disintegrate into a larger number of thinner beds, which could also be fractures along the horizontal lamination. Coarse- to medium-grained calcarenite is grain/packstone composed predominantly of crinoids, peloids, intraclasts and lithoclasts, whereas with grading into fine-grained calcarenite it turns into packstone composed of pellets, crinoids (echinoderms) and occasional sponge spicules (Fig. 4a, b; for details see Table 1).

Micritic limestone is gray and dark gray, and occasionally horizontally laminated wackestone with pellets, radiolarians, filaments and sponge spicules. In the lower part of the interval, it is still partially dolomitized and slightly marly (for details se Table 1).

The succession ends with thin-bedded black cherts that pass upwards into thin-bedded silicified dark gray micritic limestone that is identical in composition to the underlying facies equivalent.

Age: The massive dolomite is presumably Norian–Rhaetian in age (Buser 1986). In the lower part of the overlying limestones *Meandrovoluta asiagoensis* Fugagnoli & Rettori in association with *Ophthalmidium? martanum* Farinacci were encountered in micritic limestone. Above this level, *Involutina liassica* (Jones) predominates in calcarenites and a calcarenitic matrix of breccias, occasionally in association with *O.? martanum* and *Siphovalvulina* sp.

Meandrovoluta asiagoensis is a relatively recently described species, although it has commonly been figured under different names (Fugagnoli et al. 2003). Its stratigraphic range is currently determined as Sinemurian to Toarcian (Fugagnoli et al. 2003; Velić 2007), but it occurs on the Dinaric Carbonate

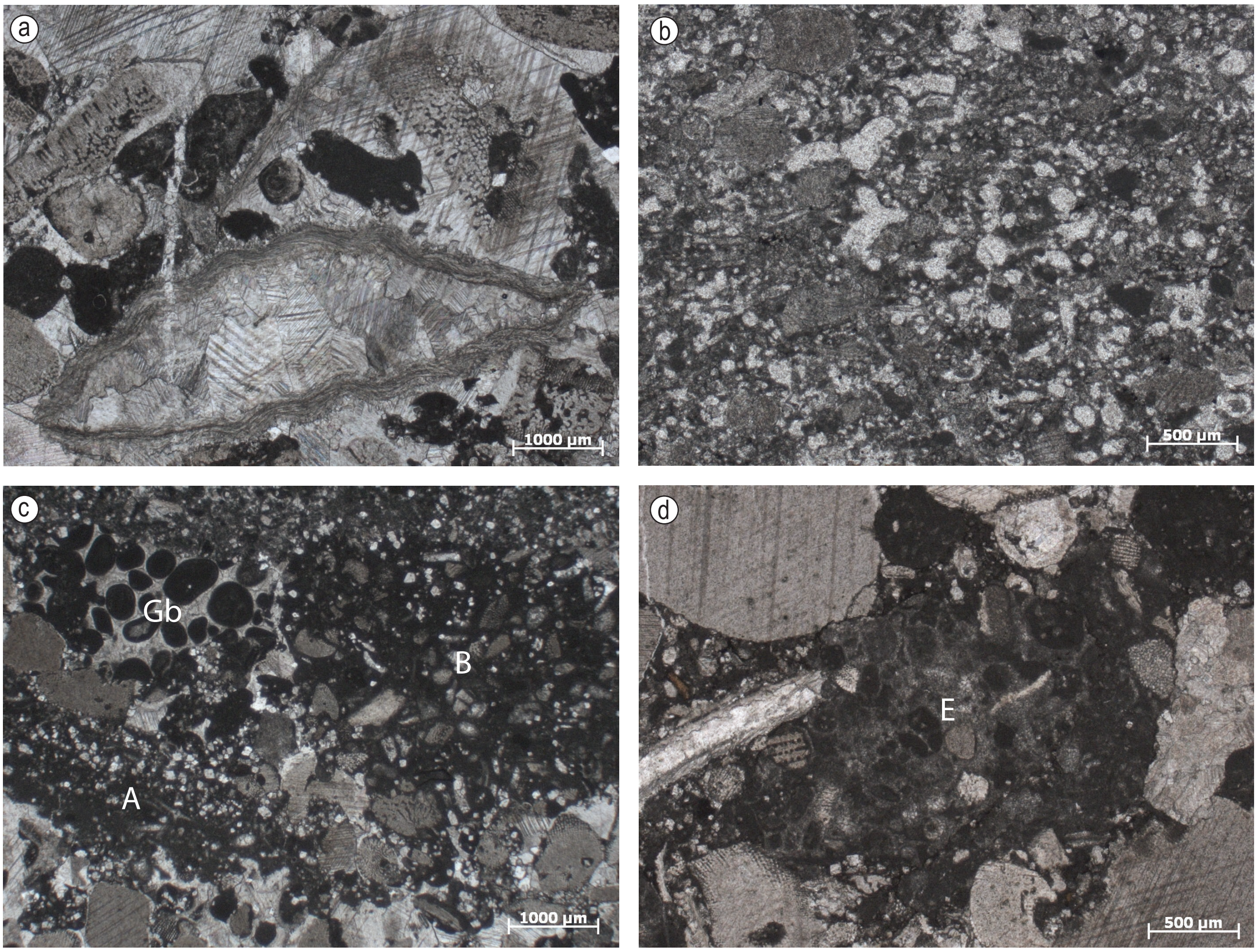

Fig. 4. Microfacies of the resedimented limestones from Mt. Mrzli vrh section: **a** — coarse grainstone with echinoderms, intraclasts and large brachiopod; **b** — fine packstone with small intraclasts/peloids and bioclasts (echinoderms, calcified sponge spicules, radiolarians); **c** — diverse lithoclasts of the limestone breccia: ooidal grainstone (type Gb), bioclastic wackestone (type-B) and basinal litho/intraclasts (type-A); **d** — packstone lithoclast (type-E) in coarse packstone.

Table 1: Summarized microfacies characteristics of Mt. Mrzli vrh section limestone lithotypes.

Lithotype		**Texture**	**Composition**	**Diagenesis**
Micritic limestone		Wackestone	Pellets, calcified radiolarians, sponge spicules, foraminifera, thin-shelled bivalves, fine bioclasts – echinoderm debris.	Partly dolomitized in lower part; minor recrystallization and silicification of matrix, laminae with abundant framboidal to subhedral pyrite.
Calcarenite	Coarse- to medium-grained:	Grainstone or packstone	Fossils, lithoclasts (the same as in limestone breccia – see description below), peloids, intraclasts, rare and strongly micritized ooids. Predominating fossils: echinoderms (crinoids) and, in the upper part of the unit, also brachiopods (Fig. 4a). Other fossils: calcisponges and foraminifera (common lagenids and textulariids), ostracods and gastropods. Non-carbonate grains are biotite, in the uppermost bed also glauconite.	Cements: Mosaic cement in the intergranular space. Syntaxial cement overgrows echinoderms. Silicification: rare and selective to bioclasts, mostly brachiopods and calcisponges. Pyrite: fine-grained between grains; framboidal pyrite inside micritic grains. Some grains show strong replacement or encrustation. Dolomitisation: intense in the lower part of the section, decreases upwards; selective to matrix and micritic grains.
	Fine grained	Packstone or occasionally grainstone	Pellets and/or fine intraclasts and bioclasts, mainly echinoderms. Other fossils: calcified radiolarians and sponge spicules (Fig. 4b), foraminifera, mostly textulariids and *Lenticulina.* Microfaulting was detected.	
Limestone breccia		Rudstone	Matrix of the breccia is coarse-grained calcarenite, equal to calcarenite described above. Most common and largest lithoclasts (described in Table 2) are type-B (Fig. 4c). Other common lithoclasts are type-D and similar to them, but rarer type-C clasts. Platform derived types E (Fig. 4d), and Ga, Gb (Fig. 4c) lithoclasts occur regularly and become more abundant upsection (see Fig. 3.). Basinal (intra) clasts (type-A; Fig. 4c) occur sporadically and types F and H lithoclasts occur very rarely. Apart from lithoclasts, large bioclasts occur: brachiopods, inozoan calcisponges, and strongly recrystallized or silicified chaetetids.	Corresponds to those from calcarenite described above.

Platform from at least the late Hettangian (Gale & Kelemen 2017). It is abundant in low-diversity assemblages, in various lagoonal environments (Fugagnoli 2004 and pers. obser. of the author) and its variable morphology corresponds to that of an opportunistic species (Dodd & Stanton 1990, p. 288). *Ophthalmidium*? *martanum* (determination of this species is still considered ambiguous) first appears in upper Sinemurian, lasting until Toarcian (Velić 2007), but earlier occurrences cannot be excluded. *Involutina liassica* ranges from the Hettangian to the Toarcian, but is restricted to platform margins and slopes (Velić 2007). *Siphovalvulina* first appears in the Hettangian, but continues to be present into the Cretaceous (BouDagher-Fadel 2008). Based on the foraminiferal association the succession above the massive dolomite is Sinemurian or Hettangian in age.

Sedimentological interpretation: The original sedimentary environment of massive dolomite is uncertain. Massive intervals within the Bača Dolomite were previously documented at other locations, and due to their sedimentary breccia structure they were interpreted as debris-flow deposits (Gale 2010). But the Mrzli vrh massive dolomite differs from those in its remarkable thickness, its lack of chert clasts and lack of primary sedimentary breccia composition. Consequently, we interpret it as dolomitized platform limestone. It was probably reef limestone, which rimmed the carbonate platform after it's progradation over marginal basinal strata, represented today by bedded dolomites with chert at the base of massive dolomite. Prograding platforms characterized by massive Dachstein reef limestone are typical for the Norian–Rheatian successions in the entire region (Reijmer et al. 1991; Mandl 2000; Gianolla et al. 2003; Krystyn et al. 2009; Gale et al. 2014, 2015). An overlying thin interval of bedded dolomites with chert nodules (still below coarse resediments) could point to an initial deepening of the platform in the earliest Jurassic.

The textures (Ta-b parts of the Bouma sequence) of the overlying calcarenites indicate sedimentation dominated by turbidites. Calcarenites that lack gradation can be interpreted as modified grain-flow deposits or highly concentrated sandy debris flows (Stow & Johansson 2000; Shanmugam 2000). Thick, inversely-graded limestone breccia at the 22 m-mark of the section is interpreted as a debris flow deposit (debrite). Crinoid-dominated sand-sized material in resediments indicates that bioclasts originated from a relatively shallow pelagic environment. Such (Hierlatz) facies are reported from the Austroalpine shelf above the Dachstein-type platform or the adjacent slope (Böhm et al. 1999; Gawlick et al. 2009), and is known also from the Lower Jurassic of the Julian Alps (Buser 1986; Šmuc & Goričan 2005; Kukoč et al. 2012; Rožič et al. 2014). Clasts in limestone breccia indicate erosion of the platform-margin, the slope, and subordinately also affected the basinal carbonates, which corresponds to the toe-of-slope sedimentary environment. Jurassic (types B, Gb, D, ?C lithoclasts) as well as Triassic (types E and ?Ga lithoclasts) strata were eroded. An upward-growing abundance of platform-derived lithoclasts (Fig. 3) indicates the increasing exposure of platform limestones. This effect could have been enhanced by their exposure on a fault-dissected slope similar to the step-like, i.e. terraced slope reported from the Transdanubian Range (Galácz 1988; Haas et al. 1997, 2014). Subordinate micritic limestone was deposited by hemipelagic sedimentation. Sporadic lamination in these beds indicates resedimentation by low-density turbidity currents.

Facies association of the entire limestone interval indicates sedimentation at the toe-of-slope. The overlying strata,

Table 2: Clast types from limestone breccia beds from Mt. Mrzli Vrh, Perbla and Liščak sections. Clast types are compared to Standard Microfacies Types (SMF; Wilson 1975; revised in Flügel & Munnecke 2010) with the goal to define their original sedimentary environments (clasts are arranged due to increasing environmental energy).

Occurrence	Texture	Composition	Diagenesis	SMF, sedimentation and age
Type A: Mrzli vrh Perbla Liščak	Wackestone, rarely mudstone	Radiolarians, sponge spicules and rare foraminifera, echinoderms, ostracods, thin-shelled bivalves (Fig. 4c). Pellets occur in some clasts.	Some are strongly dolomitized.	SMF3 Deep-water limestones (mud-chips). Age: ?syndepositional.
Type B: Mrzli vrh Perbla Liščak	Wackestone to packstone; up to few mm large grains	Peloids, intraclasts and fossils: echinoderms, brachiopods, bivalves, benthic foraminifera, and sponge spicules (Fig. 4c). Shells are often fragmented. Foraminifera: *Trocholina umbo,* common Ophthalmidium sp. and/or *Vidalina* sp.	Occasional recrystallization of matrix to microsparite.	SMF8 Fossils assemblage indicates sedimentation on outer shelf or slope. Age: ?Lower Jurassic (syndepositional).
Type C: Mrzli vrh Perbla Liščak	Wackestone	Pellets, rare unrecognizable small bioclasts and small benthic foraminifera: *Earlandia* sp.	Occasional recrystallization of matrix to microsparite.	SMF? Either of a shallow-water or open marine origin. Age: ?Lower Jurassic.
Type D: Mrzli vrh Perbla Liščak	Packstone, rarely grainstone	Pellets, rare foraminifera (Fig. 5e): *Meandrovoluta asiagoensis, Earlandia* sp. (Fig. 6c), *Vidalina* sp.	Some clasts are recrystallized.	SMF16 or SMF 2 Either of a shallow-water or open marine origin. Age: Lower Jurassic.
Type E: Mrzli vrh Perbla Liščak	Packstone; poorly sorted	Dominant pellets, but with additional larger grains, mostly foraminifera or intraclasts (Fig. 4d). In some clasts micritised ooids, echinoderms, and shells, encrusted by foraminifera. Foraminifera ?*Galeanella tollmanni*	Common recrystallization of matrix to microsparite.	SMF16 Most probably of a shallow-water, inner platform origin. Age: Norian-Rhaetian.
Type F: Mrzli vrh Perbla	Wackestone	Micritisized ooids, intraclasts, echinoderms, small benthic foraminifera and unrecognizable bioclasts.	Intense micritic rims around bioclasts.	SMF ? Low-energy environment close to ooidal shoals. Age: not determined.
Type G: Mrzli vrh Perbla Liščak	Grainstone; mostly well sorted, and usually up to 700 μm in size	Intraclasts, peloids, ooids and rare fossils, mostly echinoderms and foraminifera. The content of individual grains is variable; most commonly dominated by peloids and intraclasts (sub-type Ga), or by ooids (sub-type Gb; Fig. 4c).	Cements are circumgranular fibrous and mosaic. Rare corrosive voids filled with micrite.	SMF15 and ?11-16 Shallow-water, high energy limestones (sand shoals). Age: not determined; sub-type Gb ?Lower Jurassic.
Type H: Perbla	Grainstone	Intraclasts and cortoids, probably also foraminifera (Fig. 5e).	Recrystallization (probably prior to resedimentation).	SMF11 Platform margin shoals. Age: not determined.
Type I: Perbla Liščak	Boundstone	Inozoan calcisponges, gastropod and bivalve shells, rare dasycladacean algae, and an intergranular space filled with micrite (Fig. 5d). In Liščak section occur corrosive voids filled by rimming bladed and mosaic cements (Fig. 6c). Large bioclasts can be encrusted by calcimicrobes and foraminifera.	Primary corrosion-voids. Partial recrystallization of matrix to microsparite.	SMF7 Platform margin reefs. Age: ?Norian -Rhaetian.

dominated by micritic (hemipelagic), strongly silicified thin-bedded limestone, are characteristic for a basin-plain sedimentary environment (Mullins & Cook 1986).

The Perbla section

Description: The section was logged for 55 m. The underlying Bača Dolomite, i.e. bedded dolomite with chert nodules, is not exposed in the logged section, but according to observations during the detailed geological mapping, the contact is sharp. The base of the Krikov Formation (lower 36.5 m of logged section; Fig. 3) is dominated by thick-bedded and coarse-grained resedimented carbonates: dolomitized cherty breccia (some beds are channelized), partly dolomitized limestone breccia and calcarenite, and subordinate micritic limestone (Fig. 5a). With a sharp contact this coarse-grained interval passes into 200 m of alternating thin/medium-bedded micritic limestone and calcarenite (calciturbidites). 19.5 m of this succession were logged, and above the logged section begins to be strongly silicified in the form of chert nodules in micritic limestone and intense, often complete silicifation in calcarenite.

In the logged section, micritic limestone occurs in two levels within coarse resediments (40 and 160 cm thick, between the 17th and 19.6th m of the section, respectively) and shows indistinct internal bedding. Above the coarse resediments (above the 37.5th m of the section) it is gray to dark gray, thin-bedded and horizontally laminated. The microfacies of the micritic limestone correspond to those from Mt. Mrzli vrh.

Calcarenite is usually coarse- to medium-grained, sometimes pebbly, bedded (4–100 cm) and normally graded. It often forms the upper parts of graded limestone-breccia beds, but the transition between the two facies is usually sharp. At the 26th m of the section, a 1 m-thick package of thin-bedded (7–12 cm), inversely-graded pebbly calcarenite is present. In the upper part of the section (above the 39th m), it is thin-bedded and horizontally laminated. The composition of coarse- to medium-grained calcarenite differs from that of the Mrzli vrh section, as these beds in the Perbla section are mainly grainstone composed of ooids, peloids intraclasts, whereas bioclasts are rare

(Fig. 5b). With fining, differences from the Mrzli vrh section gradually disappear (Fig. 5c; for details compare Tables 1 and 3).

Limestone breccia in the lower part of the section is very thick bedded (1–4 m), structure-less, and strongly dolomitized. Upwards, it is graded and occasionally deposited in erosional channels, or forms the lower parts of two-component beds; i.e. it passes upwards with a sharp contact into coarse-grained calcarenite. The matrix of the breccia beds is grain/packstone akin to the surrounding calcarenite beds. The lower part of the section was affected by intense dolomitization (Fig. 5e).

Lithoclasts in breccia generally correspond to those from the Mrzli vrh section, but basin litho/intraclasts (type A) are

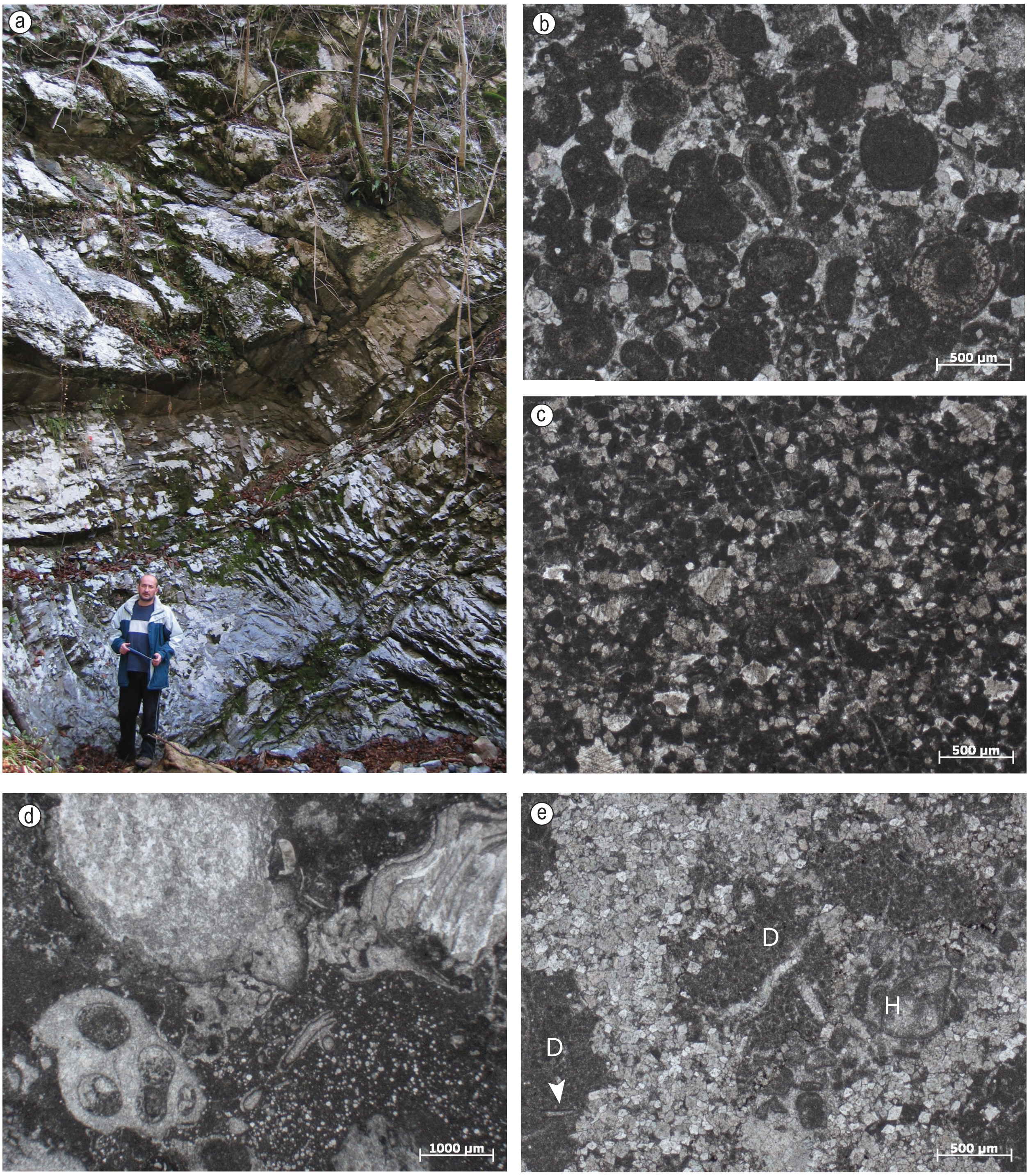

Fig. 5. Resedimented limestones from the Perbla section: **a** — thick limestone breccia beds from the middle part of the section; **b** — microfacies of coarse grainstone dominated by ooids; **c** — fine, partly dolomitized packstone composed of fine intraclasts/pellets and bioclasts (mainly echinoderms); **d** — boundstone lithoclast (type-I) from limestone breccia; **e** — limestone breccia with dolomitized matrix and cortoid grainstone (type-H) lithoclast and pelletal packstone (type-D) lithoclasts; arrow points to *Earlandia* sp. foraminifera.

Table 3: Summarized microfacies characteristics of the Perbla section.

<table>
<tr><th colspan="2">Lithotype</th><th>Texture</th><th>Composition</th><th>Diagenesis</th></tr>
<tr><td rowspan="2">Calcarenite</td><td>Coarse- to medium-grained:</td><td>Grainstone;
in thin beds occasionally packstone</td><td>Radial and tangential ooids (30% of all grains), peloids (?micritised ooids), intraclasts and rare bioclasts (up to 10% of all grains in lower part and slightly more abundant in upper part of the section) (Fig. 5b).
Bioclasts: predominated by echinoderms and codiaceans. Others are fragmented brachiopods, bivalves, benthic foraminifera, such as Lenticulina and biserial textulariids, and very rare bryozoans.
In upper part of the section gastropods appear and Meandrovoluta asiagoensis foraminifera are numerous.
Lithoclasts additionally occur in coarser beds. Their composition is the same as in the limestone breccia. Rare small grains of biotite and phosphatic minerals.</td><td rowspan="2">Cements: Mosaic cement in the intergranular space, syntaxial cement around echinoderms.
Silicification: rare and selective to bioclasts, mostly as microcrystalline quartz replacing brachiopods. Large quartz crystals (up to 2 mm) are observed in intergranular space or as replacement of large echinoderms and brachiopods.
Pyrite: fine-crystals in intergranular spaces; framboidal pyrite inside micritic grains.
Dolomitisation: strong in the lower part of the section; upwards selective to matrix and micritic grains.</td></tr>
<tr><td>Fine grained</td><td>Grainstone and packstone</td><td>Pellets, small intraclasts and bioclasts: predominant echinoderms, rare benthic foraminifera (Fig. 5c).</td></tr>
<tr><td colspan="2">Limestone breccia</td><td>Rudstone</td><td>Matrix of the breccia is coarse-grained calcarenite, equal to calcarenite of surrounding beds.
Most common lithoclasts (described in Table 2) are types A, C, D (Fig. 5e), E and also Ga and Gb. Type-B (dominant in Mt. Mrzli vrh section) occurs sporadically. Very rarely occur type- H (Fig. 5e) and type-I (Fig. 5d) lithoclasts, the later only in the upper part of the coarse-grained interval.
Large bioclasts are similar to those from Mt. Mrzli vrh section. Additionally calcimicrobes frequently occur.</td><td>Dolomitisation: strong in the lower part of the section (Fig. 5e), gradually decreases upwards.
Silicification: selective and bound mostly to bioclasts.</td></tr>
</table>

more abundant (Fig. 3), and boundstone (type I) and cortoid grainstone (type H) lithoclasts were additionally recognized (Fig. 5d, e; for details see Table 2)

Age: *Siphovalvulina* sp. is first encountered in thin-bedded breccia at 26 m in the Perbla section. Nine meters higher, *Siphovalvulina gibraltarensis* BouDagher-Fadel et al. in association with *Meandrovoluta asiagoensis* Fugagnoli & Rettori were encountered. The latter species is present in large abundance in the micritic limestone and fine-grained calcarenite, forming monospecific assemblages. The first appearance of *S. gibraltarensis* is reported from the early Sinemurian (Velić 2007; BouDagher-Fadel 2008), or Hettangian (BouDagher-Fadel & Bosence 2007). Accordingly, the Perbla section is probably early Sinemurian in age, but may also be Hettangian considering the poorly known stratigraphic ranges of the determined foraminifera.

Sedimentological interpretation: Thick-bedded, coarse limestone breccia were deposited by debris-flows, whereas graded and horizontally laminated calcarenites are attributed to turbiditic flows (Ta-b Bouma sequences). Inversely graded, thin-bedded pebbly calcarenite was probably deposited by grain-flows (Stow et al. 1996). Several composite beds occur. Their base is non-graded or slightly graded breccia deposited by debris-flows. It is followed with sharp contact by graded (occasionally pebbly) calcarenites that originated from turbidity-flows. Similar two-component gravity flows were reported from the lower slope of the Bahamas carbonate platform (Mullins & Cook 1986). The lower part of the Perbla section was deposited in toe-of-slope and/or proximal basin-plain environments.

The section ends with alternating hemipelagic limestone and calciturbidites. Such alternation points to sedimentation on a basin-plain and a shift towards more distal facies is recorded at the top of the logged section.

Lithoclasts in breccia from the Perbla section generally correspond to those of the Mrzli vrh section and therefore indicate erosion of similar parts of the platform. The more distal location of the Perbla section with respect to the Mrzli vrh section is reflected in the increased rate of basinal litho/intraclasts (type A) and a decrease in the amount of the outer platfrom/slope lithoclasts (type B). Otherwise, the content of particular lithoclasts shows no significant up-section alternation (Fig. 3). As reef limestone (type I) lithoclasts, likely of Late Triassic age, were documented solely in the upper part of the coarse-grained interval, we suppose a progressive down-cutting of erosion into the platform margin carbonates.

The major difference, when compared to the Mrzli vrh section, lies in the composition of the sand-sized material, which indicates that the source area for resediments in the Perbla section were ooidal shoals. Accordingly, different platform-basin architecture can be supposed for the two studied sections. Alternatively, the different composition can be attributed to the heterochrony of the sections. Although the foraminiferal specimens occur in turbidites, they can be considered to be contemporaneous with the studied strata, as they are present in the matrix and not in clasts, but sorting by size during down-slope transport is likely. On the basis of the known stratigraphic ranges of determined foraminifera, both studied successions are probably Sinemurian in age. The Sinemurian (or younger) age of the studied sections is also supported by *O. martanum* and *S. gibraltarensis*. The difference between *Meandrovoluta*-dominated assemblages of the Perbla section and the *Involutina*-dominated Mrzli vrh section is probably related to the different lithology, i.e. *I. liassica* appears in coarse-grained calcarenite in the Mrzli vrh section, whereas *M. asiagoensis* is present in micritic limestone and fine-grained calcarenite. Both assemblages could well originate from different parts of the platform, e.g., *Meandrovoluta* from the inner part of the platform (see Fugagnoli et al. 2003), and *Involutina* from a more agitated environment (see Piller 1978). Alternatively, the two sections might be slightly different in age, but at some sub-stage level (the current accuracy of determined foraminifera being at the stage level).

Liščak sections

Description: The succession was logged in two closely situated and correlated sections (Figs. 2d, 3). The uppermost 40 m of the Bača Dolomite consists of grey to dark grey medium-bedded dolomite with or without chert. Despite dolomitization, primary sedimentary fabric is locally still preserved, and horizontal and convolute laminations, scour structures, load casts, normal and inverse grading were all recognized. Macroscopically visible lamination reflects the difference in the size of the dolomite crystals (euhedral crystals 50 to 200 µm in size).

A single, 15 m-thick breccia megabed, which is composed of dolomite and chert clasts, occurs at the base of the Krikov Formation. The chert clasts are angular, while the dolomite clasts (up to 1 m large) are often plastically deformed. In the Liščak 2 section, the breccia is overlain by thin-bedded horizontally laminated clayey dolomite, and after 2 m by micritic limestone. An overlying mud-supported limestone breccia bed of 1 m thickness grades into strongly silicified calcarenite (Fig. 6a, b). Above, thin-bedded micritic limestone and subordinate dolomite was logged for 10 m. This interval includes two small-scale slumps. The microstructure of micritic limestone is identical to the micritic limestone described before. The calcarenite is packstone composed of ooids/micritized ooids, intraclasts and bioclasts (Fig. 6d), whereas the breccia is floatstone with lithoclasts observed also in previously described sections (Fig. 6c; for details see Tables 2 and 4).

Age: Conodont species *Epigodonella* ex gr. *bidentata* Mosher, *Misikella hernsteini* (Mostler), *Misikella posthernsteini* Kozur & Mock, and *Oncodella paucidentata* (Mostler) were recovered from the lower 7 m of logged Bača Dolomite, confirming the Rhaetian age of this interval (e.g., Krystyn et al. 2009; Buser et al. 2008; Gale et al. 2012). Only fragments of conodonts were found from the overlying bedded part of the Bača Dolomite, up to the megabreccia. The marly and

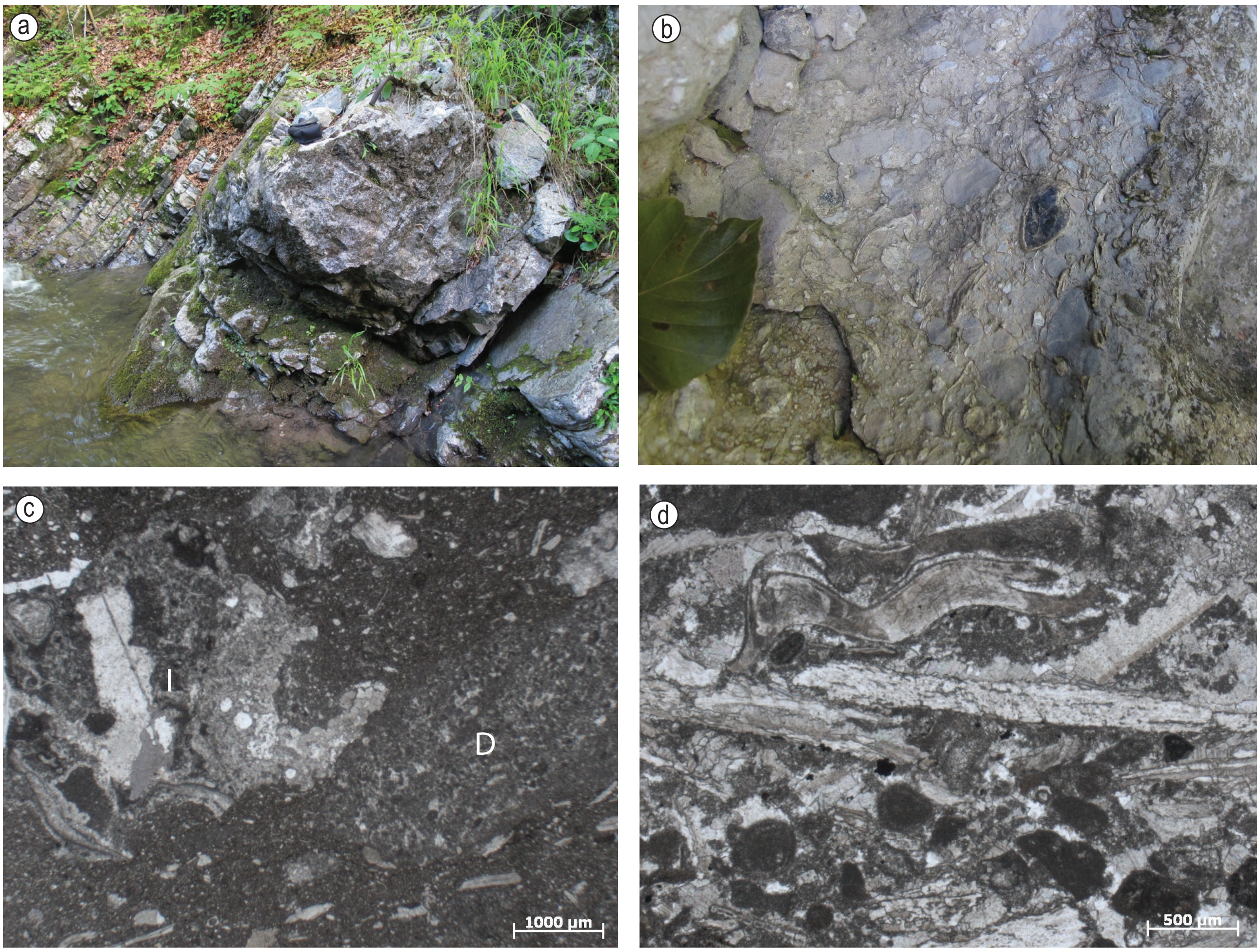

Fig. 6. a — 1 m-thick limestone breccia/silicified calcarenite bed within thin-bedded hemipelagic limestone of the Liščak section; **b** — weathered surface of the limestone breccia with silicified brachiopods; **c** — floatstone microfacies of the limestone breccia with boundstone (type-I) and pelletal packstone (type-D) lithoclasts; **d** — silicified packstone with ooids, intraclasts, brachiopods and echinoderms.

Table 4: Summarized microfacies characteristics of limestone in the Liščak section.

Lithotype	Texture	Composition	Diagenesis
Calcarenite	Partly washed-out packstone	Brachiopod shells, intraclasts (often mud-chips), peloids, echinoderms, micritized ooids and rare foraminifera (Fig. 6d).	Cements: recrystallization of matrix to microsparite, mosaic cement in washed-out intergranular spaces, syntaxial cement around echinoderms. Silicification: strong and replaces grains as well as matrix.
Limestone breccia	Floatstone	The matrix between large grains is wackestone with small fragments of brachiopod shells, ostracods, echinoderms, thin-shelled bivalves, radiolarians, pellets, rare sponge spicules, and foraminifera (Fig. 6c). Predominant large grains are brachiopod shells and large A-type litho/intraclasts (30 %) which can contain non-calcified (siliceous) radiolarians and sponge spicules. Other lithoclasts are rarer and belong to types B (13 %), C (2 %), D (16 %), E (21 %), Ga (8 %), Gb (3 %) and I (7 %). These lithoclasts are smaller in respect to predominant A-type clasts.	Dissolution seams. Strong silicification of bioclasts (mostly brachiopod shells) with chalcedony and lithoclasts with microcrystalline quartz. Sporadic pyrite as framboids or small subhedral crystals in micrite and along dissolution seams.

laminated thin-bedded dolomite and micritic limestone of the lowermost part of the Krikov Formation are devoid of microfauna. From the 1 m-thick breccia bed, shark teeth *Synechodus* sp. and *Paraorthacodus* sp. were determined, which first appear in the Early Jurassic (Paleobiology Database 2016). The Early Jurassic age is confirmed by the finding of foraminifera *Meandrovoluta asiagoensis* Fugagnoli & Rettori, whereas Cousin (1973, 1981) determined Lower Jurassic *Involutina liassica* (Jones) at the confluence of the Liščak and Kneža rivers, which corresponds to the Liščak 2 section.

Sedimentological interpretation: The sedimentary structures of the Bača Dolomite are strongly obliterated, but the formation is interpreted to have been deposited in a basin-plain environment (Mullins & Cook 1986). The thick dolomite/cherty breccia megabed that lies at the top of the formation was formed by debris-flow. As it contains large clasts of plastically deformed dolomite, it developed from slumping of the basinal strata. This different deformation of chert and dolomite clasts indicates that the mass movement occurred after the formation of chert nodules and prior to the lithification of the carbonate sediment, which at the time of redeposition could still have been calcareous.

The thin-bedded dolomite and the micritic limestone above the breccia megabed are interpreted to be hemipelagic in origin. The lamination might indicate their partial redeposition by low-density turbiditic flows. The breccia with silicified brachiopods was deposited by two-component gravity-flow: the lower part of the bed was formed by a debris-flow, the overlying calcarenite was deposited by a turbidity current. The composition of the debrite indicates the erosion of Triassic–Jurassic carbonates of basinal, slope and platform facies, whereas the turbidite carried material from a shallow water environment. In the upper part of the logged section, two additional slump intervals were recognized within the hemipelagic limestone and dolomite. Debris-flow deposits and slumps indicate agitated paleotopography within the basin during the Triassic–Jurassic interval.

Mt. Porezen sections

Description: On Mt. Porezen three sections were logged within the continuous, i.e. laterally undisturbed facies belt (Fig. 7). Some thick-bedded dolomite-cherty breccia beds are present in the underlying Bača Dolomite (not included in sections). These suggest that the fault activity started already in the latest Triassic. A Norian tectonic pulse was documented within SB (Gale 2010; Oprčkal et al. 2012) as well as in the rest of the Southern Alps (Jadoul et al. 1992; Cozzi 2000, 2002).

No dolomite-chert breccia, however, occur between the Bača Dolomite and the Krikov Formation, as is the case in the Liščak section. Instead, the top of the Bača Dolomite is characterized by bedded dolomite, which is followed by a cherty interval some several meters thick. In the Zakojška grapa (northwestern) section black chert beds alternate with strongly silicified dolomite and subordinate dolomitic marl in an interval 14 m thick. One of the chert beds is silicified calcarenite with a preserved sedimentary fabric. The cherty interval is represented in the other two sections largely as thin-bedded, pure black chert, some 4.5 m and 5 m thick in the southern (Ritovščica) and northeastern (Zapoškar) sections, respectively. In the Ritovščica section, it starts with an 80 cm-thick bed that reveals its primary calcarenite fabrics, with grain-ghosts within completely silicified parts and some locally preserved carbonate (Fig. 8c). A similar but thinner bed was recognized a few meters up-section. Bivalves of the genus *Halobia* were found in the lower part of this interval a few tens of meters laterally from the section (Fig. 8b).

The overlying Krikov Formation is dominated by thin-, and exceptionally medium-bedded, grey to dark grey, wavy and parallel laminated micritic limestone (Fig. 8a). The microfacies corresponds to that recorded in the previously described sections, but is commonly strongly recrystallized and silicified. In the Zakojška grapa section, water-escape structures were recognized in thin sections. Chert nodules occur in all sections. Marlstone is subordinate, except for the base of the

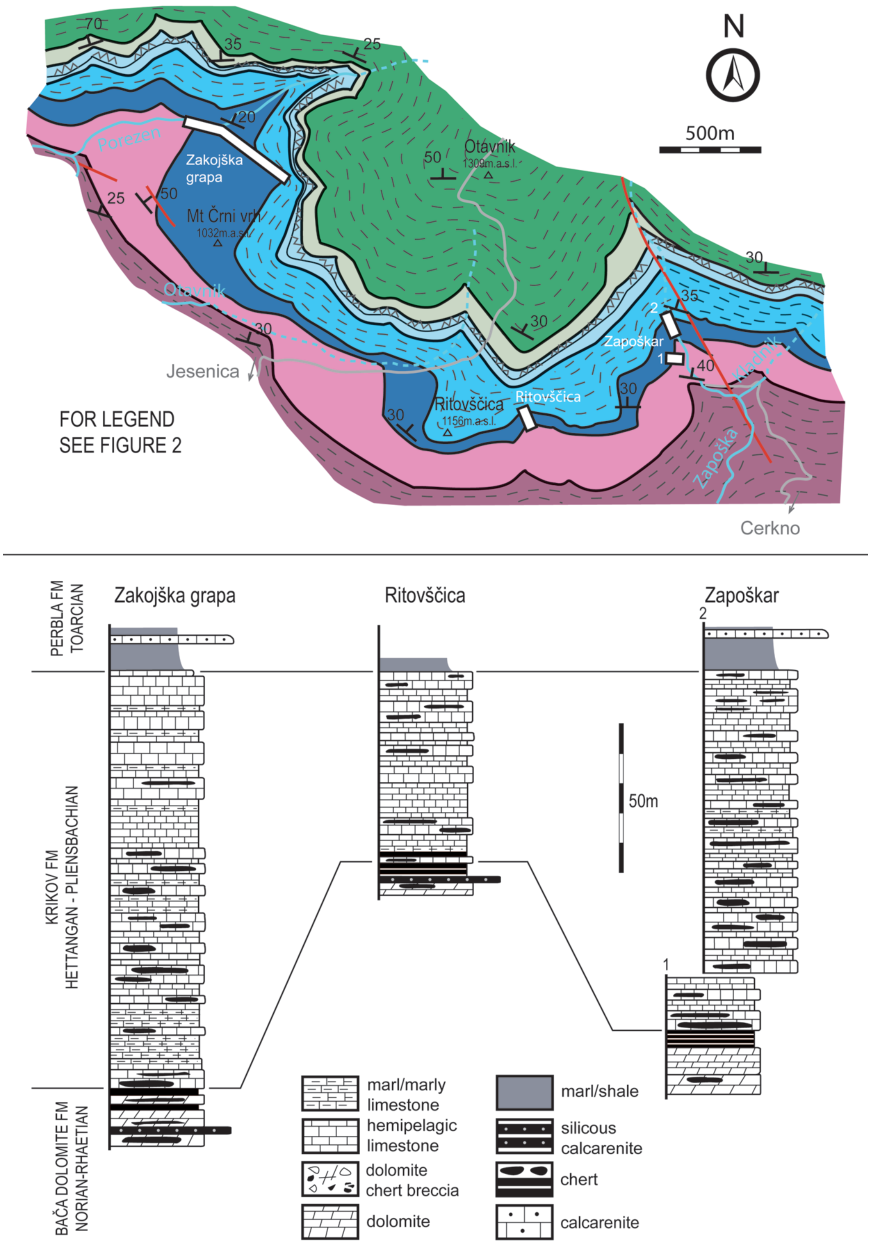

Fig. 7. Geological map and schematic sections (simplified from 1:100 logs) of Mt. Porezen: variable thickness of Krikov Formation indicates block tilting, whereas lateral facies changes at the base of the formation indicate it occurred, at least partly, at (and shortly after) the Triassic/Jurassic boundary.

Zakojška grapa section, where it forms a laminated interval that spans the 12th to 25th m section of the formation.

As in other sections from the SB (Rožič 2009), the upper boundary with the marl-dominated Perbla Formation is sharp. The thickness of the Krikov Formation (between the cherty interval and the upper boundary), however, varies significantly on Mt. Porezen. In the Zakojška grapa section, it is 135 m thick, in the Zapoškar section it reaches a thickness of approximately 115 m. In the Ritovščica section, the upper boundary is poorly exposed, but it is clear that the formation thickness does not exceed 65 m.

Age: The age of the Mt. Porezen sections remains poorly constrained and is based on scarce biostratigraphic markers and correlation (no conodonts and radiolarians were found). *Halobia* sp. bivalves found in the black chert interval during geological mapping indicate that it is, at least partly, Triassic in age. A similar and contemporaneous lithologic change from carbonate to siliceous pelagic sedimentation was reported also from the Budva Basin in the southern Dinarides (Črne et al. 2011). Based on the superposition, the Krikov Formation may represent an interval from the Hettangian to Pliensbachian. Its upper boundary is marked by the Toarcian Oceanic Anoxic Event at the base of the overlying marly Perbla Formation (Rožič 2009; Rožič & Šmuc 2011; Goričan et al. 2012).

Sedimentological interpretation: The Mt. Porezen sections encompass a longer time-interval than the previously described sections. In the lower part of the cherty interval in the Zakojška grapa and Ritovščica sections, a few beds of coarse-grained, almost completely silicified calcarenite are the only coarse grained beds derived from high-density turbidity currents during the Triassic-Jurassic transition period. Horizontal and wavy laminations in micritic limestone above the cherty interval indicate partial redeposition of hemipelagic sediments. The entire latest Triassic to Early Jurassic succession therefore shows a very monotonous, distal basin-plain sedimentation. However, the significantly variable thickness of the Krikov Formation in closely located sections can be attributed to a tilting of the tectonic block within the basin. A present-day 4° of block tilting in NW (azimuth 296°) directions was calculated for the virtual plane connecting the base of the Krikov Formation in the three logged sections (after rotating the formation's upper boundary to horizontal level). Since we did not calculate with compaction, the original inclination was steeper.

As mentioned above, the entire studied succession represents a greater time span, and due to poor datation it is impossible to specify the exact period of more intense subsidence within the Lower Jurassic strata. Some tectonic activity can be attributed also to the Pliensbachian–early

Fig. 8. Mt. Porezen sections: **a** — micritic limestone of the Krikov Formation from the Zapoškar section; **b** — *Halobia* sp. from the base of the cherty interval found close to the Ritovščica section (determination by B. Jurkovšek); **c** — microfacies of silicified calcarenite from the base of the cherty interval of the Ritovščica section (under cross-polarized light).

Toarcian subsidence pulse (Berra et al. 2009), which was well recognized in the eastern Southern Alps (Šmuc 2005; Rožič 2009; Rožič & Šmuc 2011, Goričan et al. 2012; Rožič et al. 2014), but lateral lithological variations described at the base of the Krikov Formation indicate that tilting (at least partly) occurred at the Triassic/Jurassic boundary interval: firstly, in the Ritovščica and Zapoškar sections, the transition from the Bača Dolomite to the Krikov Formation is marked by pure cherts, whereas in the Zakojška grapa the chert-rich interval is generally thicker and pure chert alternates with dolomite beds. Secondly, above the chert-rich interval in the Zakojška grapa section the succession is marked by the marly interval, which was not documented in the other two sections. Both variations can be attributed to higher latest Triassic-earliest Jurassic sedimentation rates in the Zakojška grapa section at the paleotopographically deepest part of the tilted block, which is in accordance with the largest thickness of the Krikov Formation in this section.

Discussion

The most prominent facies change is recorded in the Mt. Mrzli vrh area, where it is interpreted as the drowning of the platform margin. Here, we notice that the massive dolomite, i.e. dolomitized reef limestone, is underlain by the Amphiclina beds and the Bača Dolomite (Fig. 2), both of which formations are characteristic for the SB (Buser 1986, 1989; Gale 2010). The overlying Jurassic and Cretaceous strata are represented entirely by basin facies as well (Buser 1986; Rožič 2005). The differential sea floor paleotopography resulting in different sedimentary environments is probably related to discontinuously active syndepositional faults at the SB's westernmost margin. During the tectonically quiet Late Triassic, intense carbonate production led to platform progradation, which is in accordance with regionally recognized platform progradations (Gianolla et al. 2003; Krystyn et al. 2009; Gale et al. 2014, 2015). The progradation process was interrupted by a reef crisis at the Triassic/Jurassic boundary

(Flügel 2002; Kiessling et al. 2007), which, combined with an intensification of tectonic activity, resulted in renewed deepening along the westernmost basin margin. In suggesting an analogy with the western and central Southern Alps (Jadoul et al. 1992), we assume the reactivation of pre-existing faults at the western margin of the SB (Fig. 9).

The Perbla section is marked by a carbonate breccia interval at the Triassic/Jurassic boundary, which indicates a prominent intensification of resedimentation. Although various processes can trigger the formation of breccia megabeds (Spence & Tucker 1997), we attribute this to an increase in slope inclination as a consequence of accelerated subsidence of the basin floor. As the composition of calcarenites in the breccia-matrix and the interstratified calciturbidites differs from those of the Mrzli vrh section, a different source area can be inferred for these beds. Because the Perbla section is located in the structurally higher Rut Nappe (Fig. 2a), it may have been located not only to the east, but also to the north of the Mrzli vrh section, which lies in the structurally lower Podmelec Nappe (Buser 1987). Consequently, a north-lying Julian Carbonate Platform, which was covered by ooid shoals in the Early Jurassic (Buser 1986), seems the most probable source area of the carbonate resediments.

The composition of the lithoclasts points to a slightly diverse architecture of platform-basin transition along the transportation paths of gravity flows. In the Perbla section the resedimentation events were sourced by ooid shoals but they also contain lithoclasts derived from the eroded underlying succession, including (Late Triassic) marginal reefs (type I, also H). Outer platform/slope carbonates (type B) are subordinate,

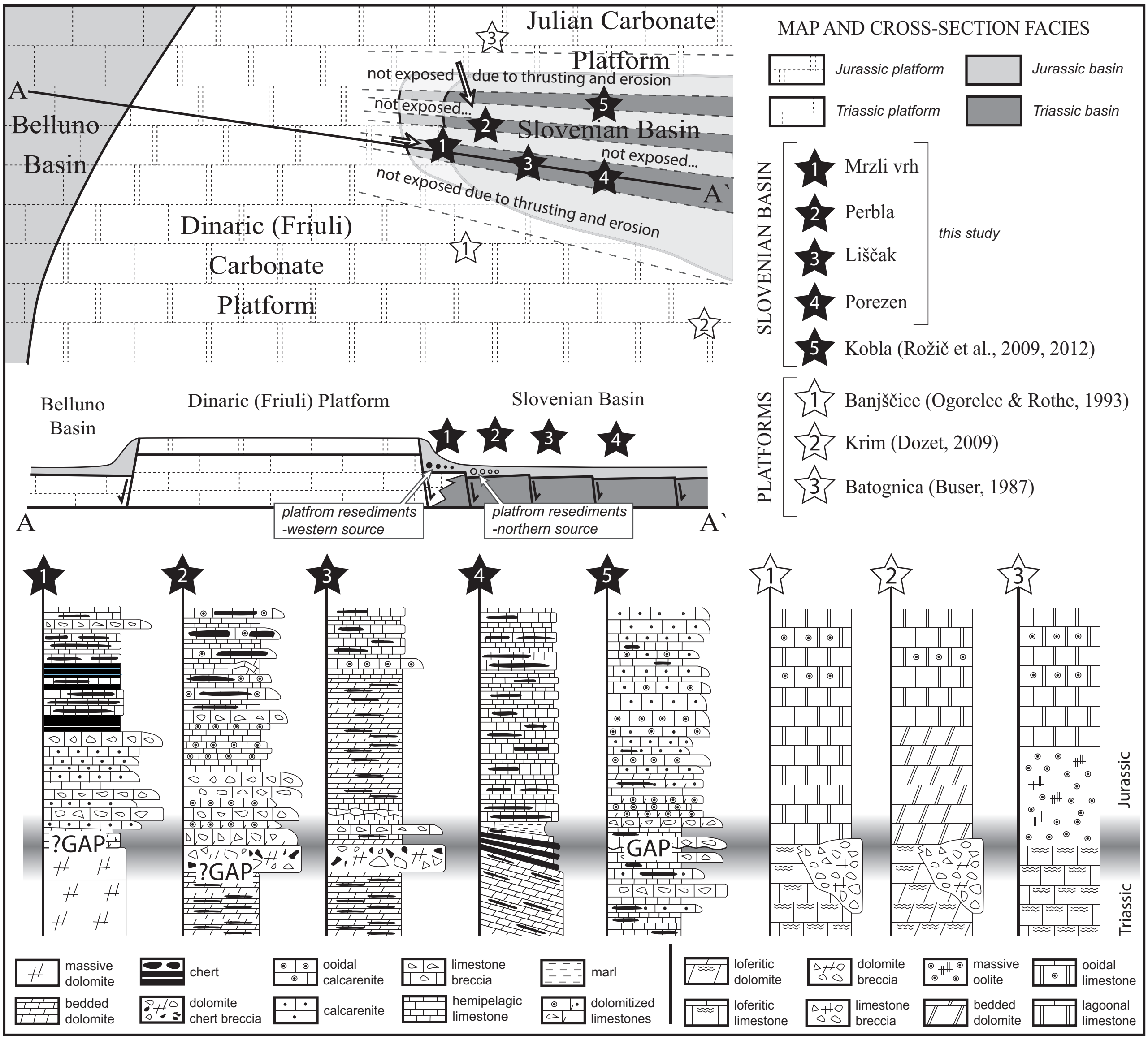

Fig. 9. Schematic paleogeographic map and cross-section of the eastern Southern Alps and north-western External Dinarids at the beginning of the Early Jurassic with predicted locations and simplified logs of studied and discussed successions of the Slovenian Basin and the surrounding platforms; arrows on map indicate proposed directions of carbonate gravity flows.

while basinal litho/intraclasts (type A) are common, which points to a more basin-ward location of the Perbla section with respect to the Mt. Mrzli vrh section. In the Mt. Mrzli vrh area, the resediments originated from the shallow pelagic environment, whereas typical lithoclasts indicate the erosion of mostly outer platform/slope carbonates (type B) and Triassic–Jurassic platform carbonates, whereas lithoclasts of marginal reef limestone (type I) were not detected. This is in accordance with our interpretation, namely that Late Triassic marginal reef limestone (completely dolomitized) lies below the resediments in the Mt. Mrzli vrh section, and that only more inner-platform Late Triassic carbonates (type E and ?Ga) were exposed on the newly developed slope.

The Liščak section also records resedimentation at the Triassic/Jurassic boundary, which can be explained by the increasingly agitated paleotopography within the basin, but the intensity of resedimentation (and also tectonic deformation) is far smaller than in the western sections. The lack of coarse-grained platform-derived resediments (with the exception of a singe 1 m-thick bed) is attributed to the larger distance from the main subsidence area at the western margins of the SB, and regionally from the rifting center further to the west. The easternmost sections, recorded on Mt. Porezen, indicate that a minor Lower Jurassic tectonic block tilting was present in this area, and lateral facies changes at the base of the Krikov Formation (see previous chapter) indicate that tilting intensified at the Triassic/Jurassic boundary interval.

The exact timing of the subsidence pulse cannot be specified due to rather poor biostratigraphic datations. It is clear, however, that it starts at, or slightly postdates the Triassic/Jurassic boundary. Foraminiferal assemblages from resedimented limestones from the Mt. Mrzli vrh and Perbla sections indicate that the subsidence intensified in the Sinemurian. This is in accordance with datations of an early rifting pulse in the western and central Southern Alps (Bertotti et al. 1993), Transdanubian Range (Haas et al. 2014), Austroalpine domain (Froitzheim & Manatschal 1996), as well as Western Alps (Chevalier et al. 2003). This extensional episode was governed by diffuse rifting and controlled by older discontinuities (Berra et al. 2009).

Another, previously studied SB location indicates the tectonic pulse discussed herein. It is situated north of Mt. Porezen in the Kobla Nappe, which is composed of the northernmost outcrops of the SB. In these sections the Triassic–Jurassic transition is marked by a continuous limestone succession from the Upper Norian/Rhaetian Slatnik Formation to the Krikov Formation (Rožič et al. 2009; Gale et al. 2012). Both formations are marked by alternating hemipelagic limestones and carbonate turbidites and debrites characteristic of proximal basin plain — lower slope environments. An interval several meters thick and dominated by distinct thin-bedded limestones occurs just above the Triassic/Jurassic boundary, but general succession shows no prominent facies alternations, which is in accordance with the previously described eastward decrease in subsidence. However, a combined carbon-isotope study and biostratigraphic analysis indicates a gap at the Triassic/Jurassic boundary (Gale et al. 2012; Rožič et al. 2012), which again can be attributed to the increasing slope inclination that resulted in erosion or by-pass of the slope area.

In the surrounding platform areas an intensified subsidence at the Triassic/Jurassic boundary is not clearly evident, but some sedimentary changes could be linked to it. On the JCP, the peritidal Norian–Rhaetian Dachstein Limestone is overlain by Lower Jurassic ooidal limestone (Buser 1986). The facies change described indicates a change from an intertidal environment to one of marginal ooid shoals, i.e. a general deepening of the sedimentary environment, which could be related to accelerated subsidence. Simultaneously, on the DCP the Triassic/Jurassic boundary transition is largely dolomitized, but the litho(chrono)stratigraphic boundary lies at the point where stromatolitic laminae, typical for the Norian–Rhaetian Main Dolomite, disappear (Buser 1989, 1996), and similar sedimentary change as described for the JCP can be predicted also for this interval. Furthermore, in the northernmost DCP outcrops, local appearances of rather thick carbonate breccia intervals were reported at the Triassic/Jurassic boundary at several locations: at Banjška planota located south of the herein presented sections (Ogorelec & Rothe 1993), at Mt. Krim near Ljubljana (Dozet 2009), and further to the east near the town of Trebnje (Buser 1965). No detailed studies of these breccias have been done, yet, but we propose that their origin is connected with the tectonic event discussed herein, as their local appearance (rapid lateral disappearance) could indicate sedimentation in a paletopographicaly segmented (fault-dissected) environment.

Conclusions

The extensional pulse that started at the Triassic/Jurassic boundary or slightly later and affected the entire western Neotethys margin is recorded also in the succession of the Slovenian Basin. In the Southern Alps, the structural unit of the Slovenian Basin, major crustal deformations are reported in their western segment, which was located close to the rifting center, i.e. a precursor of the Middle Jurassic Piemont–Liguria Ocean. Consequently, the tectonostratigraphic reflection of this event in the east-located Slovenian Basin succession is less dramatic, but can be still recognized. The westernmost Mrzli vrh section records the change from the Late Triassic massive dolomite, which is interpreted as dolomitized marginal reef, to the toe-of-slope carbonate resediments and therefore records a downfaulting-related drowning of the platform margin. The Perbla and Liščak sections record an intensified resedimentation related to the development of a segmented paleotopography, which is indicated by the presence of carbonate lithoclasts derived from the platform margin, slope and basin facies. The source areas of resediments proved diverse. The resediments in the Mrzli vrh section originated from crinoid-dominated shallow pelagic environment, whereas those from the Perbla section were shed from ooid shoals. The easternmost Mt. Porezen sections show a rather monotonous latest Triassic–Early Jurassic distal basin-plain succession, which is with accordance with eastward-declining tectonic deformation. However, the highly variable thickness of the Hettangian–Pliensbachian Krikov Formation points to block tilting and lateral facies changes concentrated at the base of the formation indicate that tilting occurred close to the Triassic/Jurassic boundary. Timing of the recorded tectonic event is loosely determined, but we relate it to an episode of diffuse rifting, the maximum subsidence of which is documented in the latest Hettangian–Sinemurian of the entire Adria as well as European rifted margins.

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