GEOLOGICA CARPATHICA, APRIL 2010, 61, 2, 89–109 doi: 10.2478/v10096-010-0003-6

Triassic metasediments in the internal Dinarides (Kopaonik area, southern Serbia): stratigraphy, paleogeographic and tectonic significance

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(Manuscript received June 1, 2009; accepted in revised form October 2, 2009)

Abstract: Strongly deformed and metamorphosed sediments in the Studenica Valley and Kopaonik area in southern Serbia expose the easternmost occurrences of Triassic sediments in the Dinarides. In these areas, Upper Paleozoic terrigenous sediments are overlain by Lower Triassic siliciclastics and limestones and by Anisian shallow-water carbonates. A pronounced facies change to hemipelagic and distal turbiditic, cherty metalimestones (Kopaonik Formation) testifies a Late Anisian drowning of the former shallow-water carbonate shelf. Sedimentation of the Kopaonik Formation was contemporaneous with shallow-water carbonate production on nearby carbonate platforms that were the source areas of diluted turbidity currents reaching the depositional area of this formation. The Kopaonik Formation was dated by conodont faunas as Late Anisian to Norian and possibly extends into the Early Jurassic. It is therefore considered an equivalent of the grey Hallstatt facies of the Eastern Alps, the Western Carpathians, and the Albanides–Hellenides. The coeval carbonate platforms were generally situated in more proximal areas of the Adriatic margin, whereas the distal margin was dominated by hemipelagic/pelagic and distal turbiditic sedimentation, facing the evolving Neotethys Ocean to the east. A similar arrangement of Triassic facies belts can be recognized all along the evolving Meliata-Maliac-Vardar branch of Neotethys, which is in line with a 'one-ocean-hypothesis' for the Dinarides: all the ophiolites presently located southwest of the Drina-Ivanjica and Kopaonik thrust sheets are derived from an area to the east, and the Drina-Ivanjica and Kopaonik units emerge in tectonic windows from below this ophiolite nappe. On the base of the Triassic facies distribution we see neither argument for an independent Dinaridic Ocean nor evidence for isolated terranes or blocks.

Key words: Triassic, Dinarides, Kopaonik, Serbia, stratigraphy, conodonts.

Introduction

Whereas the stratigraphy of the external zones of the Dinarides is relatively well known, the sedimentary and paleotectonic evolution of the internal zones is less understood. In part this is due to Alpine metamorphic overprint, in part to the structural complexities of the area. In particular, there exists an ongoing controversy about the original paleogeography and how many basins underlain by oceanic lithosphere existed in Mesozoic times between the Adriatic microcontinent, of which the external Dinarides are part, and Europe including smaller continental fragments (Tisza, Dacia) detached from it. The case of a one-ocean model has been argued for by authors on different occasions (e.g. Bernoulli & Laubscher 1972; Gawlick et al. 2008; Schmid et al. 2008) and will not be discussed in detail here. In brief, the one-ocean model according to Schmid et al. (2008) proposes that (a) all the Jurassic-age ophiolites of the Dinarides, including their supra-subduction magmatic rocks, originate from one and the same ocean and (b) this ocean also included Triassic-age oceanic crust bordering the Mesozoic Adriatic margin, from which only fragments referred to as Meliata in Slovakia and Maliac in Greece are preserved. Consequently, we shall call this oceanic branch of the Neotethys the Meliata-Maliac-Vardar Ocean. In contrast to our one-ocean model, Robertson & Karamata (1994), Dimitrijević (1997, 2001) and Karamata (2006) envisage at least two different oceanic basins floored by Jurassic oceanic crust originally separated from each other by intervening 'terranes' of continental crust, the Drina-Ivanjica, Jadar and Kopaonik 'terranes' (see Robertson et al. 2009 for discussion). In our interpretation, however, these 'terranes' are tectonic windows of the distal Adriatic margin below an ophiolite nappe referred to as Western Vardar Ophiolitic Unit, obducted in the Late Jurassic (Schlagintweit et al. 2008; Schmid et al. 2008) and including all ophiolites of the Dinarides west of the Sava Zone (Fig. 1; Western Vardar Ophiolites). In addition, our one-ocean model is in contrast to earlier models that attributed the remnants of Triassic-age oceanic crust found within Jurassic mélanges in Slovakia (Meliata; Channell & Kozur 1997), within Jurassic mélanges tectonically underlying obducted Jurassic ophiolites in the Dinarides (Vishnevskaya et al. 2009) or as tectonic imbricates below obducted Jurassic ophiolites in Greece (Maliac; Ferrière 1982) to other separate oceanic basins (e.g. Stampfli & Borel 2004). The basement complexes of the Drina-Ivanjica and the Jadar-Kopaonik thrust sheets including their formerly emplaced allochthonous ophiolitic cover have been involved in further out-of-sequence and frontal thrusting onto the more external East Bosnian-Durmitor thrust sheet during the Late Cretaceous (Rampnoux 1970, 1974; Schmid et al. 2008).

The reconstruction of the Triassic-Jurassic paleogeography of the Dinarides, which involves the reconstruction of the facies belts of the Triassic shallow-water carbonate platforms and their transition to the hemipelagic and pelagic ('Hallstatt') facies belt, play an important role for the various tectonic concepts and paleogeographic reconstructions. In a one-ocean model, we would expect a single continental-margin wedge of marine sediments with a general proximal-to-distal transition from shallow- to deep-water, facing the Triassic to Jurassic Meliata-Maliac-Vardar Ocean (or Neotethys) to the east. In contrast, according to various more-than-one ocean models, we would expect isolated fragments of shallow- or deep-water deposits with differing facies evolutions. In this contribution, we attempt to characterize the Mesozoic sedimentary evolution of an internal part of the Drina-Ivanjica thrust sheet ('Studenica slice' of Dimitrijević 1997) and of the Jadar-Kopaonik thrust sheet near Ušće in western Serbia (Fig. 2), which expose the easternmost occurrences of Triassic sediments in the Dinarides in windows below the ophiolites (Grubić et al. 1995: their fig. 1).

Geological setting and metamorphism

The study area includes a metamorphic part of the internal Drina-Ivanjica thrust sheet ('Studenica slice') and the low-grade metamorphic Kopaonik thrust sheet. Both carry their previously emplaced allochthonous ophiolite covers (Fig. 2) (Schmid et al. 2008). These two units have been considered to be part of the Vardar Zone as originally defined by Kossmat (1924) also including the successions underlying the ophiolites (e.g. Rampnoux 1974; Charvet 1978; Dimitrijević 1997, 2001). However, the co-occurrence of oceanic and continental basement rocks precludes such a simple definition and is unfortunate because the term 'Vardar' is usually associated with ophiolites. In our interpretation, both the Studenica slice and Jadar-Kopaonik thrust sheet are part of the distal Adriatic margin, covered by the obducted Upper Jurassic ophiolite nappe. The Studenica Metamorphic Series and the Kopaonik Metamorphic Series (Egli 2008; Schefer et al. 2008) of the internal Drina-Ivanjica and the Jadar-Kopaonik thrust sheet, respectively (Fig. 2), include a Paleozoic metasedimentary basement, overlain by metamorphic Triassic to Middle/?Upper Jurassic sediments. The Studenica Metamorphic Series and the Kopaonik Metamorphic Series

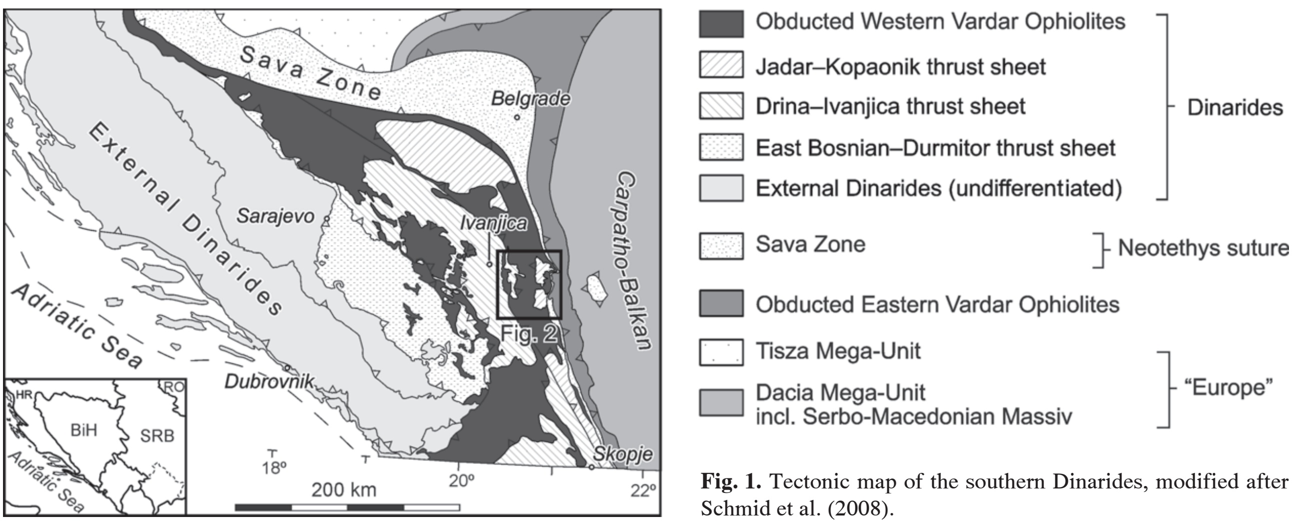
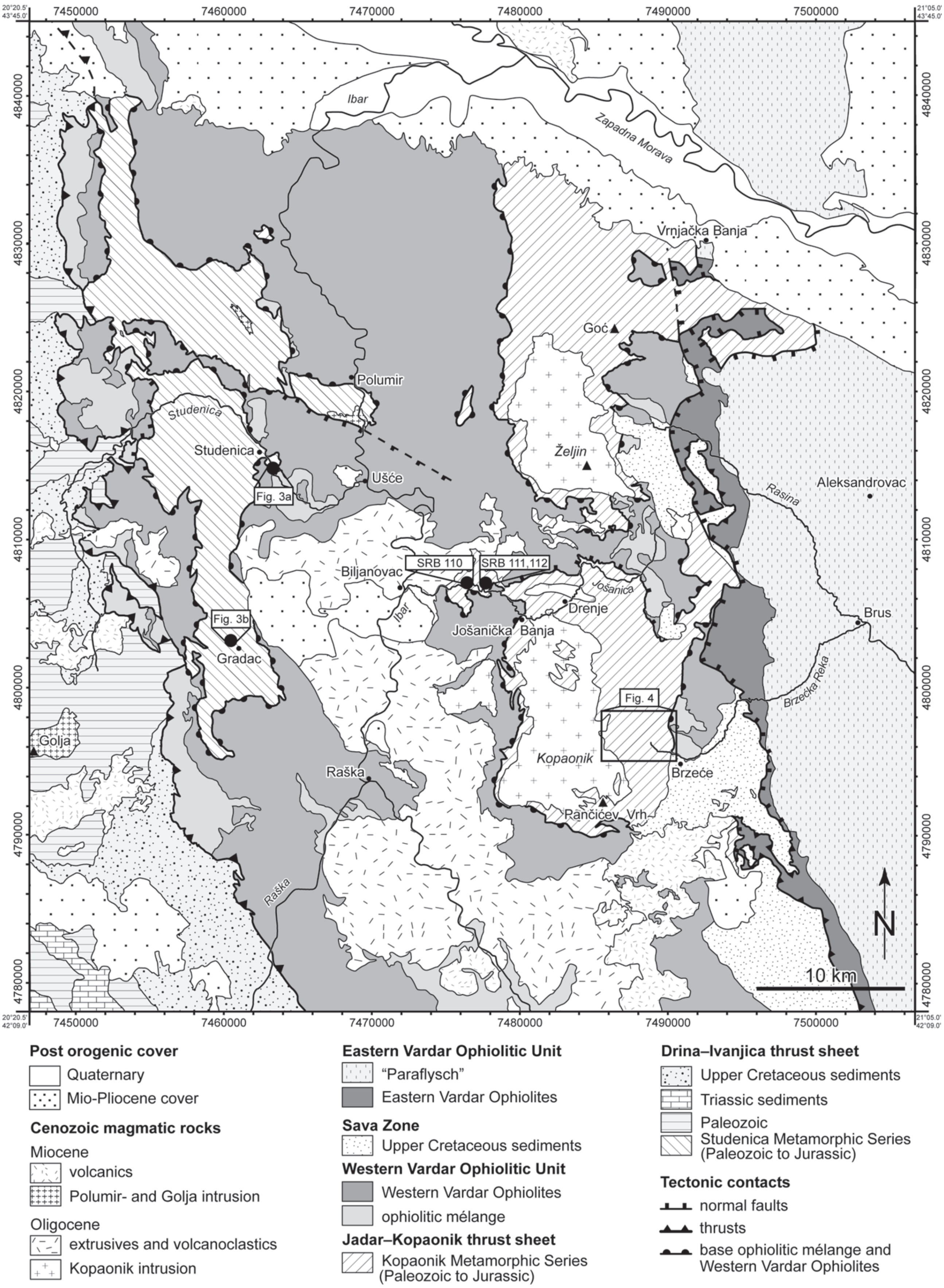


Fig. 1. Tectonic map of the southern Dinarides, modified after Schmid et al. (2008).

Fig. 2. Tectonic map of the Kopaonik area, based on mapping by S. Schefer and D. Egli and on the Basic Geological Map of the SFRY (1:100,000), Sheets Novi Pazar (Urošević et al. 1970a, 1973a), Vrnjci (Urošević et al. 1970b, 1973b), Sjenica (Mojsilović et al. 1978, 1980) and Ivanjica (Brković et al. 1976, 1977) as well as Simić (1956) for the Studenica area. Coordinates are in MGI Balkan 7.


7450000
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20°20.5'
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21°05.0'
42°09.0'
Ibar
Zapadna Morava
Vrnjačka Banja
Goć
Polumir
Studenica
Studenica
Fig. 3a
Ušće
Željin
Aleksandrovac
Rasina
Biljanovac
SRB 110
SRB 111,112
Jošanica
Drenje
Ibar
Jošanička Banja
Brus
Fig. 3b
Gradac
Brzećka Reka
Fig. 4
Golja
Kopaonik
Brzeće
Raška
Pančićev Vrh
Raška
N
10 km
Post orogenic cover
Quaternary
Mio-Pliocene cover
Cenozoic magmatic rocks
Miocene
volcanics
Polumir- and Golja intrusion
Oligocene
extrusives and volcanoclastics
Kopaonik intrusion
Eastern Vardar Ophiolitic Unit
"Paraflysch"
Eastern Vardar Ophiolites
Sava Zone
Upper Cretaceous sediments
Western Vardar Ophiolitic Unit
Western Vardar Ophiolites
ophiolitic mélange
Jadar–Kopaonik thrust sheet
Kopaonik Metamorphic Series
(Paleozoic to Jurassic)
Drina–Ivanjica thrust sheet
Upper Cretaceous sediments
Triassic sediments
Paleozoic
Studenica Metamorphic Series
(Paleozoic to Jurassic)
Tectonic contacts
normal faults
thrusts
base ophiolitic mélange and
Western Vardar Ophiolites

Fig. 2.

have been thrust, together with their ophiolitic covers, as a composite nappe onto the Drina-Ivanjica thrust sheet to the west during the Late Cretaceous (Fig. 2).

The Mesozoic metasediments of the Kopaonik and Studenica Metamorphic Series show a polyphase penetrative tectonic overprint (Egli 2008), associated with polyphase Cretaceous and Paleogene greenschist-facies metamorphism that locally reaches lower-amphibolite grade conditions (Schefer et al. 2008). This greenschist-facies metamorphism is also reflected by the thermal alteration of conodonts, which change their colour from yellow to light brown, then to dark brown and black, later to grey and finally to white. This conodont colour change is expressed in terms of the Conodont Colour Alteration Index (CAI-values 1–8) that can be related to certain temperature intervals ranging from less than 80 °C to more than 600 °C (Epstein et al. 1977; Harris 1979; Rejebian et al. 1987). In addition, structural modifications of conodonts also provide information on contact-metamorphic/hydrothermal events (Epstein et al. 1977; Rejebian et al. 1987; Königshof 1992; Burnett et al. 1994). In part of our samples, conodonts with CAI 5.5–6.0 occur together with scarce specimens that exhibit CAI values of up to CAI 7.0. Such conodonts show a whitish patina and corrosion on their surface, in contrast to conodonts of CAI 5.5–6.0. We interpret the higher CAI-values related to a contact metamorphic event overprinting the already deformed and metamorphosed rocks. This later event can be correlated with the Oligocene intrusion of the Kopaonik granodiorite (Schefer et al. 2008) that thermally altered the surrounding host rocks (Knežević et al. 1995).

According to Knežević et al. (1995), the contact-metamorphic rocks (skarn and hornfelses) around the Kopaonik granodiorite record P-T-conditions of 565 °C and 100 ± 50 MPa, which is in line with CAI values of up to 7.0 (Epstein et al. 1977; Harris 1979) assuming a short time interval of heating to more than 550 °C (Nöth 1991; Burnett et al. 1994) associated with hot-fluid circulation derived from the Kopaonik intrusion. These mixed CAI values of CAI 5.5 and CAI 6.5–7.0 in one sample can only be explained by the contact-metamorphic overprint by the Kopaonik intrusion while the lower CAI values of 5.5–6.0 record the earlier regional metamorphic event contemporaneous with the main deformation (Egli 2008).

Because of the metamorphic overprint, all metamorphic sequences in the Kopaonik region and those developed west of the Ibar Valley were often mapped as Paleozoic (Urošević et al. 1970a,b, 1973a,b; Brković et al. 1976, 1977; Mojsilović et al. 1978, 1980), although a Triassic-age of the carbonates in the Studenica area was postulated much earlier (Simić 1956). Indeed, conodonts of Carnian age were discovered in the metamorphic rocks of the Kopaonik area ('Central Kopaonik Series' in the north: Mićić et al. 1972; 'Metamorphic Trepča Series' in the south: Klisić et al. 1972). Sudar (1986) confirmed this Carnian age, and in addition, found Norian conodonts; he also established a biostratigraphic subdivision of the cherty limestones into conodont zones. The metamorphosed and ductilely deformed conodonts (CAI values 5–7) from Kopaonik Mountains were first described and illustrated by Sudar & Kovács (2006).

Location of sections

Studenica

This section (Fig. 3a) is located downstream from the Studenica monastery (Fig. 2) near a bridge over the Studenica River. After the Studenica quarry it follows the road for about 500 m downstream from the bridge. The northwestern base of the section is located at coordinates 7463300/4815000 (this and all following localities are given in the MGI Balkan7 Cartesian coordinates also used for the 1 : 100,000 geological maps of former Yugoslavia). The highly deformed rocks were recrystallized under greenschist-facies conditions and show a strong and occasionally mylonitic foliation and NNW–SSE-oriented stretching lineation. This resulted in a considerably reduced thickness of the sequence. The section starts with massive Anisian dolostones and ends in the ophiolitic mélange underlying the ophiolite nappe (Fig. 3a).

Gradac

The two sections near the village of Gradac are located further south in the Studenica unit, west of the Ibar River (Fig. 2). Both profiles, particularly section Gradac 2, show intense deformation under greenschist-grade metamorphic conditions. Section Gradac 1 starts 3 km west of Gradac village and stretches along the road to Ivanjica between coordinates 7460710/4803253 and 7461274/4802826. This section includes the succession from the upper part of the Lower Triassic Werfen Formation (probably Campil Beds) to Anisian shallow-water carbonates. Section Gradac 2 is located north of the hamlet Jokovići and along the road to Dolovi, between coordinates 7460889/4806460 and 7461163/4806257. It also starts with the Werfen Formation (probably Campil Beds) but exposes the succession up to the siliceous metalimestones of the Kopaonik Formation (Fig. 3b); however, part of the succession is cut out by faults. In this section, the rocks are strongly deformed, showing a distinct stretching lineation and top-to-the-north shear-senses, whereas Gradac 1 is only slightly deformed, showing minor stretching in a NW–SE direction and open folding.

Kopaonik area

This area located east of the Ibar River and on the south-eastern slope of the Kopaonik Mountain (NE of Pančićev Vrh) was mapped at the scale 1:10,000 by Egli (2008) (Fig. 4). The oldest rocks are quartz-phyllites of probably Paleozoic age, overlain by the Werfen Formation followed up-section by shallow-water carbonate sediments ('Gutenstein' and 'Steinalm' equivalents). A vast amount of the outcropping rocks, however, consists of well-bedded cherty metalimestones of the newly defined Kopaonik Formation (see below). This stratigraphic succession underwent strong polyphase folding under greenschist-facies conditions (Egli 2008; Zelić et al. 2010). Near-isoclinal D2-folds dominate the map pattern. In the vicinity of the Kopaonik granodioritic intrusion (30.7–30.9 Ma; Schefer et al. 2008) we also find contact metamorphic rocks (skarns and hornfelses). Field

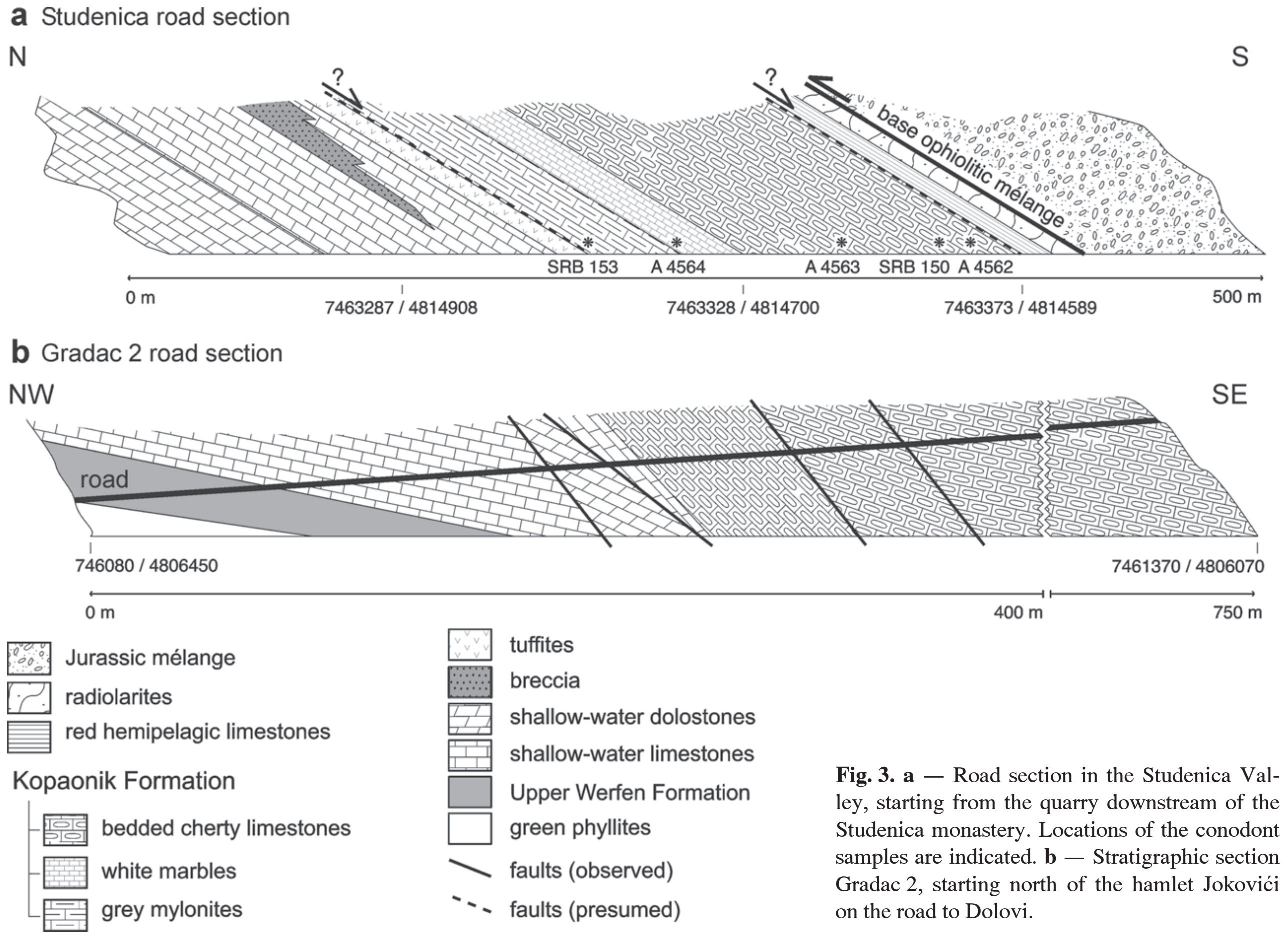

Fig. 3. a — Road section in the Studenica Valley, starting from the quarry downstream of the Studenica monastery. Locations of the conodont samples are indicated. **b** — Stratigraphic section Gradac 2, starting north of the hamlet Jokovići on the road to Dolovi.

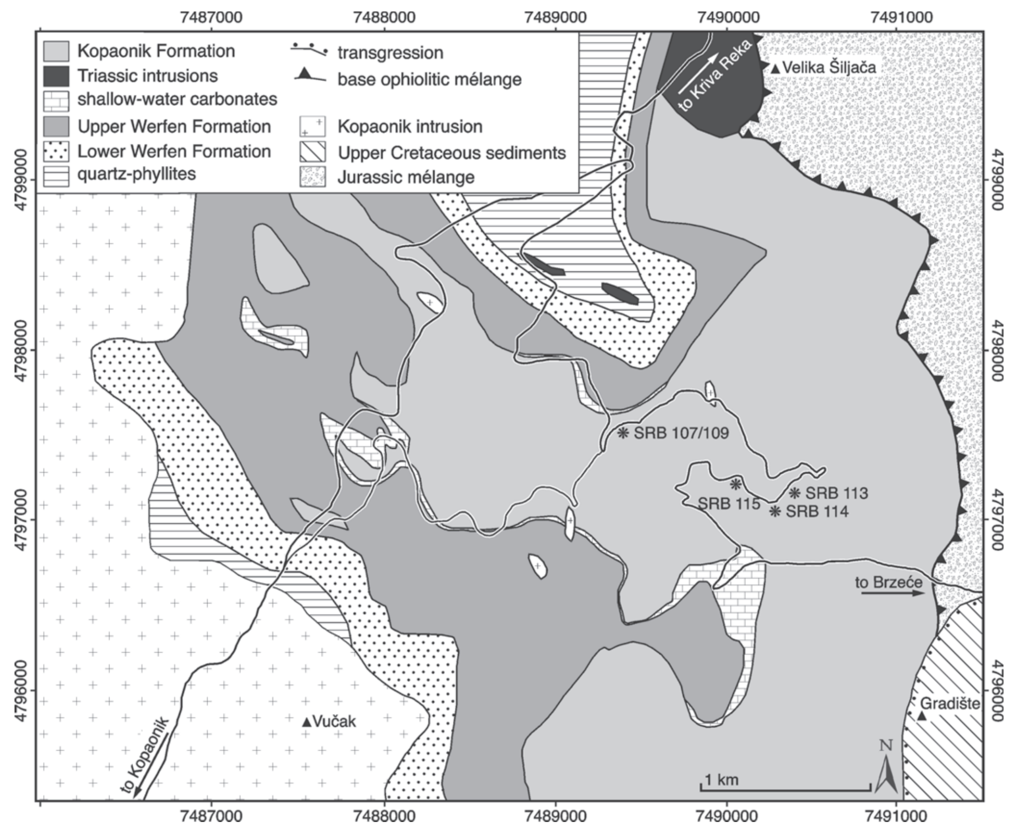

Fig. 4. Geological map of the eastern Kopaonik area between Brzeće and the Kopaonik ski resort (mapped at scale 1 : 10,000 by D. Egli, coordinates are in MGI Balkan 7). Locations of the conodont samples are indicated.

evidence shows that intrusion and contact metamorphism postdate regional metamorphism and main deformation.

Stratigraphy

Quartz-phyllites

In the Kopaonik area, this formation is only preserved in some small outcrops bordering the Kopaonik granodiorite (Fig. 4). Layers of pelitic composition are interbedded with quartzitic layers. On weathered surfaces, the finely laminated rocks are grey to reddish in colour, but grey to greenish on fresh surfaces. While a narrow-spaced bedding-parallel foliation develops in the phyllitic layers, the quartzitic layers are often boudinaged. These rocks are probably of Paleozoic age but, alternatively, they may represent the lowermost part of the Lower Triassic Werfen Formation.

Werfen Formation

In the Kopaonik area, massive metasandstones, typical for the lower part of the Werfen Formation, are visible in small outcrops located close to the intrusion (Egli 2008). The sandstones are brownish to reddish on weathered surfaces and dark brown to black on fresh surfaces. Detrital grains (usually <1 mm) and cement are entirely made up of quartz. In coarse-grained layers, cross-bedding (Fig. 5a) or a faint parallel lamination, as well as a bedding-parallel foliation can be observed. In thin-section, small biotite flakes defining the foliation are present besides quartz. In the vicinity of the intrusion, the rocks are overprinted by contact metamorphism, which leads to the formation of white mica, garnet and brown amphiboles with grains between 0.1 and 1 mm (Egli 2008).

The upper part of the Werfen Formation shows similarities with the basal part of the Gradac 1 and 2 successions and

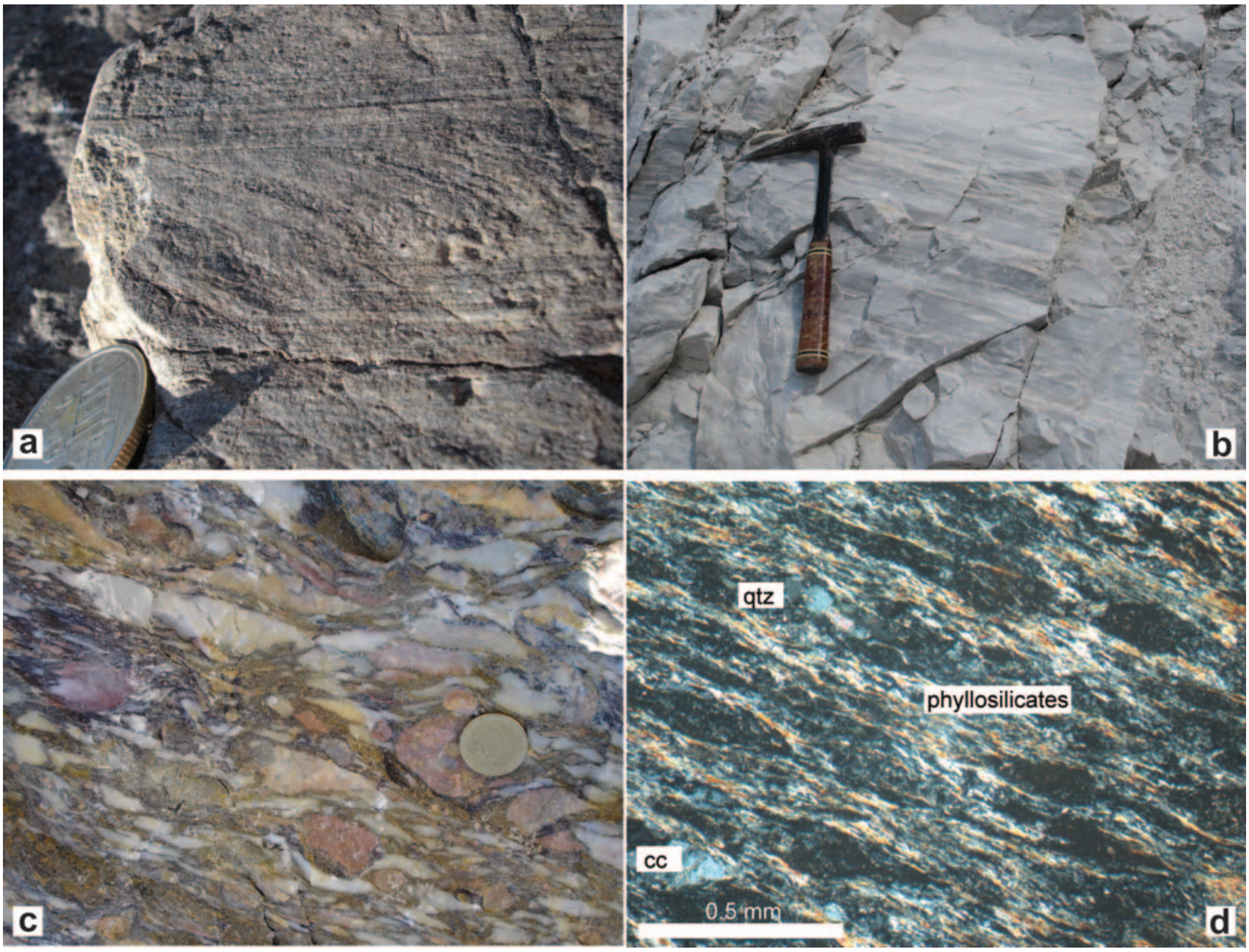

Fig. 5. Lower and Middle Triassic lithofacies. **a** — Cross-bedded sandstone, Lower Werfen Formation, Kopaonik area (7486570/4795890). **b** — Calcite-mylonite attributed to the Steinalm Formation (Anisian), Studenica quarry. **c** — Polymictic breccia overlying the Steinalm Formation, Studenica quarry. **d** — Tuffite, presumably Anisian/Ladinian boundary, Studenica quarry, thin-section crossed polarizers.

Fig. 6. Lithofacies of Kopaonik Formation, Middle to Late Triassic, along road from Brzeće to Kopaonik. **a, b** — Intensely deformed and slightly contact-metamorphic grey, hemipelagic limestones with bands of diagenetic replacement chert (now quartzite). **c** — Graded fine-grained calcarenite, with diagenetic replacement chert, only weakly deformed. **d** — Chevron-type folds in a limestone-marl succession with

may stratigraphically overlie the siliciclastic sediments of the lower Werfen Formation in the Kopaonik area. There it consists of interbedded shales, sandstones and limestones with bed thicknesses of up to one meter. Sandy layers consist of quartz and limestone clasts of varying grain size, embedded in calcite cement. In section Gradac 1, shell fragments, mostly bivalves and gastropods, are preserved in the limestone layers. The pelitic layers are non-calcareous, show a strong foliation and reach thicknesses between one millimeter and several centimeters; stratification is arrhythmic.

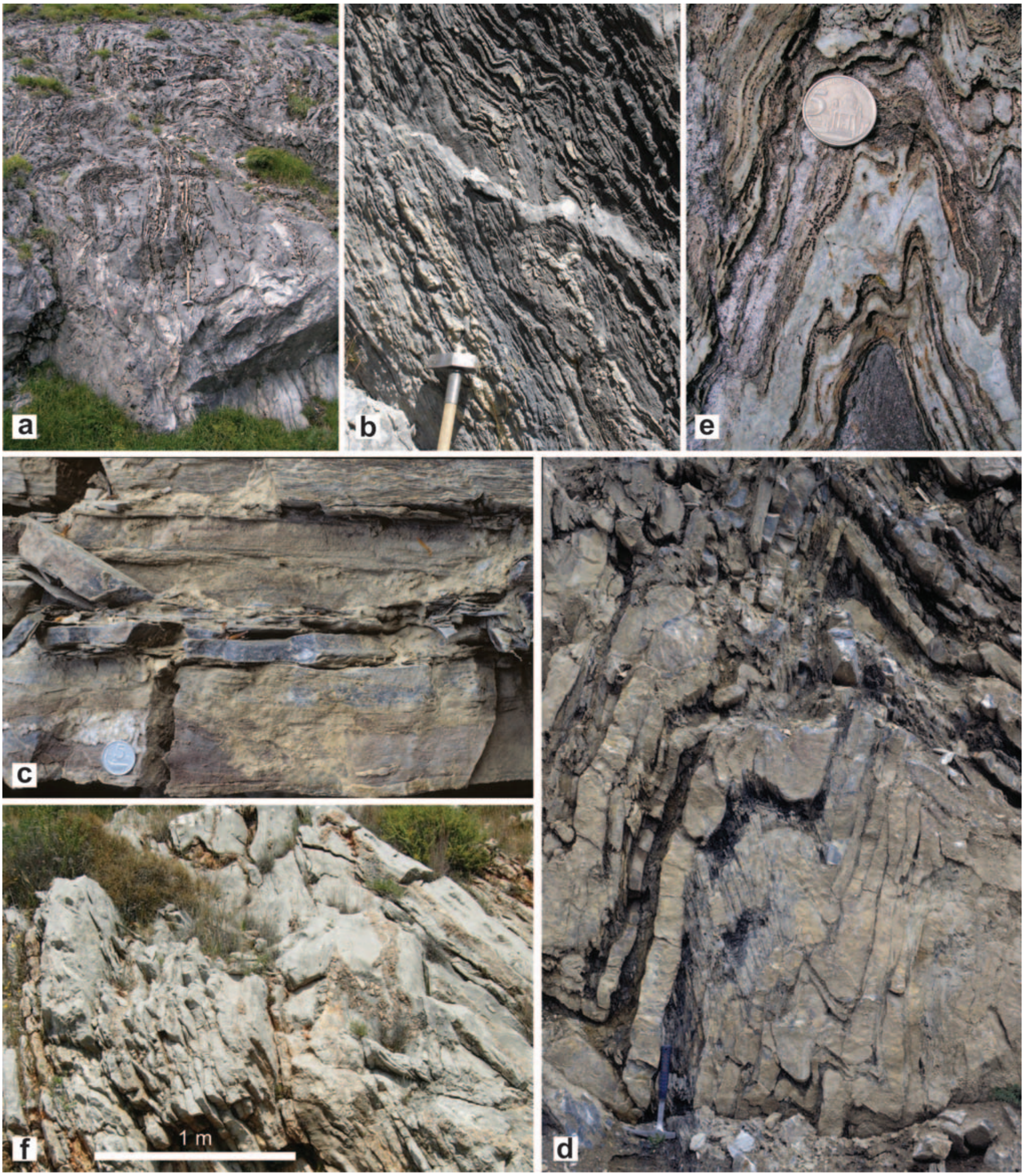

Fig. 6. *Continued:*
well defined axial-plane schistosity in the marly layers. **e** — Cherty limestones transformed into calc-silicate rock due to contact metamorphism. **f** — Pelagic limestone with marly interbeds and bands of early diagenetic replacement chert, Adhami Limestone, Late Triassic–Sinemurian, Askiplion unit, road Palaio Epidhavros-Koliaki, Argolis, Greece; for details see Baumgartner (1985).

In section Gradac 2 the Werfen Formation is more calcareous and less sandy. In the lower part there is a rhythmic stratification on a small scale: centimeter-thick layers of limestone are intercalated with pelitic material that becomes more abundant up-section, leading to a purely pelitic sequence. These pelitic layers are pale green with a silvery shine due to the relatively higher degree of metamorphism compared to section Gradac 1. The deformation, characterized by a pervasive bedding-parallel foliation and by isoclinal folding, is also more intense than in section Gradac 2.

In the Kopaonik area, the Werfen Formation is again characterized by a rhythmic bedding pattern of non-calcareous shales, partly calcite-cemented sandstones and marlstones. Dynamically grown well-oriented biotite flakes, grown during regional metamorphism, define a bedding-parallel foliation visible in thin-section. In the immediate vicinity to the intrusion where contact metamorphism is accentuated, the abundance of calcareous beds diminishes (Egli 2008).

Shallow-water carbonates ('Wurstelkalk'; Gutenstein and Steinalm Formation equivalents)

The transition from the Werfen Formation into massive dark metalimestones is particularly well visible in section Gradac 1. Several meters of bioturbated, well-bedded grey to brownish weathering limestones are reminiscent of the basal Gutenstein Formation ('Wurstelkalk') of the Eastern Alps (Tollmann 1976) or the Szinpetri Limestone Formation in the Silica nappes (Aggtelek Unit, Hungary) of the Inner Western Carpathians (Hips 2006). Up-section, these sediments give way to massive, dark grey to nearly black, slightly metamorphic limestones with quartz veins (middle to upper Gutenstein Formation equivalent).

In section Gradac 2 (Fig. 3b), these rocks are strongly deformed, and bioturbation is no longer visible in the lower part of the succession. The marbles show a distinct spaced cleavage of centimeter to decimeter size and a N–S-oriented stretching lineation. Fissures filled with quartz and calcite are oriented perpendicular to the foliation. Calcite marble, probably belonging to the Gutenstein Formation, is followed by massive dolomitic marble of light grey colour with chaotic fissures without foliation. The latter is interpreted as shallow-water carbonate of the Steinalm Formation.

Dolostones reminiscent of the Steinalm Formation define the lowermost part of the Studenica section. The dolostones are massive, however, and no cleavage is visible. These dolostones are followed by a several tens of meters thick sequence of calcite marble. These marbles are strongly deformed and mylonitized (Fig. 5b), showing an alternation of differently coloured domains. An intense stretching lineation is NW–SE oriented. Minor amounts of dolomite are also found in the calcite marbles, dolomitic layers being less deformed and boudinaged, which leads to the development of sigma-clasts exhibiting top-to-the-north shear senses (Egli 2008).

In the Kopaonik area the marbles derived from shallow-water limestones reach a thickness of a few decameters; often they are only present as small layers or they may even be completely missing. The grain size of the marbles increases with the vicinity to the Kopaonik intrusion. The usually dark-coloured sediments pass into white coarse-grained marbles.

Breccia horizon in the uppermost Steinalm Formation equivalent

Only in the Studenica section, intercalated within the uppermost Steinalm Formation equivalent, limited to the quarry and wedging out towards the street (Fig. 3a), a layer of breccias of about 4 m thickness can be observed. The polymictic breccia is poorly sorted and consists of clasts one millimeter to several centimeters across (Fig. 5c). Rounded to sub-angular limestone clasts dominate, dolomite-marble clasts are rare. The matrix consists of red and greenish tuffites with a strong cleavage. Such tuffites may also occur as clasts in this breccia. The matrix becomes calcitic towards the top of the breccia, and is finally marly in the uppermost part. Isolated quartz grains and dynamically grown micas are also found in the matrix. Relics of probable foraminifers and pellets suggest a shallow-water origin of some of the components. The competence contrast between the different components causes heterogeneous deformation, which results in an undulating appearance and stretching lineations visible on the foliation planes. Strain analysis (Egli 2008) after Ramsay & Huber (1983) suggests thinning to 25 % of the original thickness for the breccia horizon. This value is considered representative for the entire Studenica section, except for the dolomitic part at the base.

Tuffites and metabasalts

Intensely foliated tuffites, overlying the Steinalm Formation equivalent and with an intercalated breccia horizon at their top, can be observed only in the Studenica section. Their thickness is about 5 m. These tuffites of red and green

Fig. 7. Microfacies of the ?Upper Ladinian to (Lower) Carnian fine-grained hemipelagic grey limestones in the Kopaonik region (Brzeće) and of the Lower Norian grey micritic and partly cherty limestones of Studenica section. **A** — Laminated micritic limestone, strongly recrystallized. All fossil remnants are destroyed by recrystallization due to metamorphic overprint. The preserved laminae probably indicate a low engergy turbiditic character of sedimentation and less bioturbation. Sample SRB 113. **B** — Relatively homogeneous micritic limestone with less content of clay and pyrite, recrystallized. Sample SRB 115. **C** — Relatively homogeneous micritic limestone with pyrite. Some ghosts of organisms resemble filaments and radiolarians and probably peloids. Sample SRB 116. **D** — Partly some ghost of organisms are visible, problably representing remnants of crinoids and radiolarians. Sample SRB 115. **E** — The contact between the light and dark grey biomicrite is relatively sharp. The dark grey biomicrite is much richer in organisms, partly the shape of radiolarians is relatively well preserved. The dark grey biomicrite represents a more condensed facies in comparison with light grey micrite indicating highstand shedding. Sample SRB 150. **F** — Ghosts of radiolarians and filament-remnants occur mostly in the very fine-grained turbidites. Sample SRB 153. **G** — Overview showing the alternation of relatively organism-free light grey micrite and organism enriched more condensed dark grey biomicrite. Sample SRB 153. **H** — Fig. E enlarged. Most organism/components are completely recrystallized and occur only as ghosts.

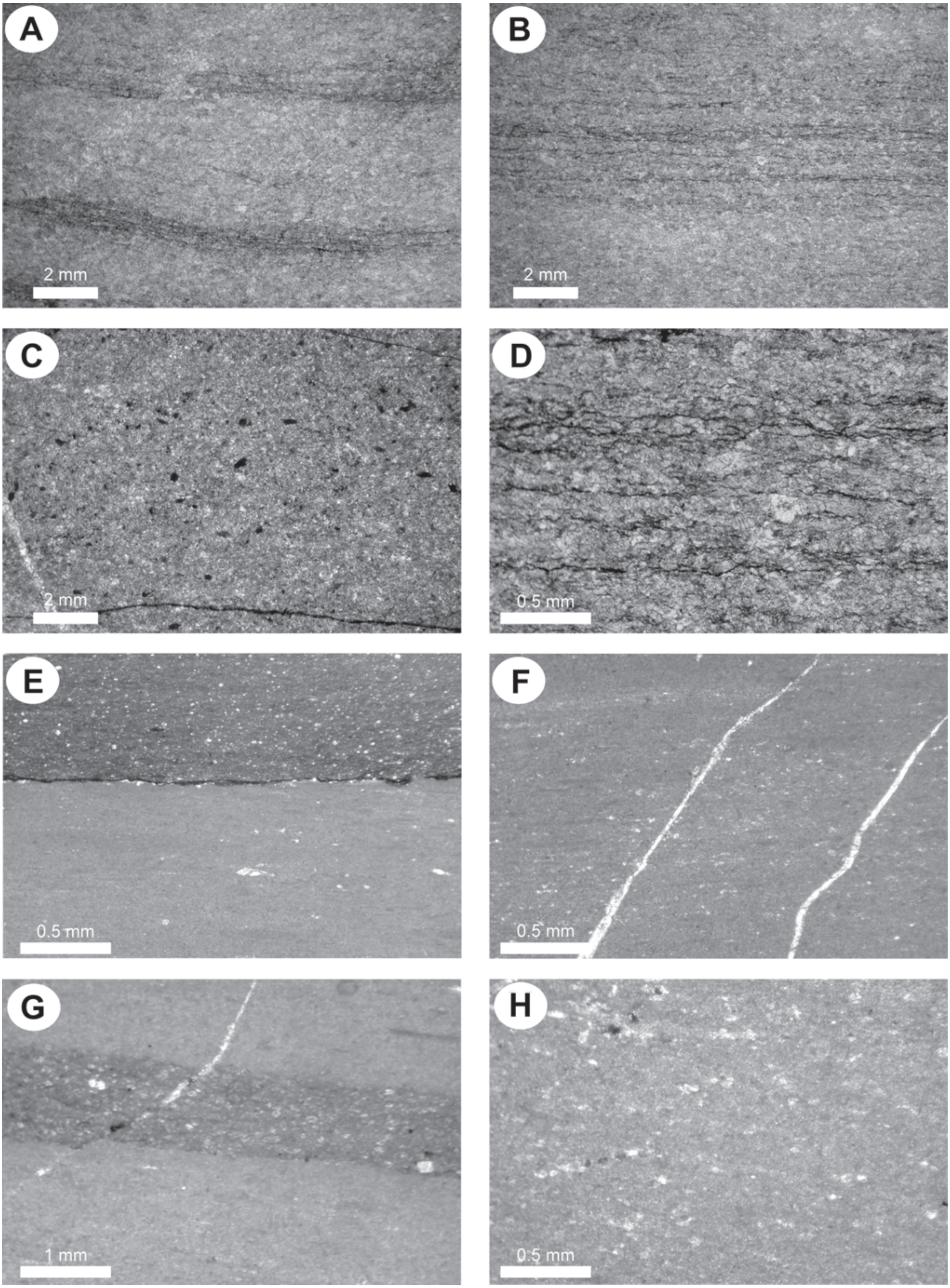

Fig. 7.

colour are similar to those in the matrix of the underlying breccias (Fig. 5d). These rocks consist mainly of mica with some up to millimeter-sized clasts of quartz, dolomite, calcite and feldspar. According to Sudar (1986) these volcanoclastic sediments in the inner Dinarides were deposited near the Anisian-Ladinian boundary and up to the end of the Early Ladinian.

Kopaonik Formation

In the Studenica section and in the Kopaonik area, the shallow-water carbonates of the Middle Triassic and the associated tuffites are overlain by thin-bedded metalimestones with bands and nodules of chert (Fig. 6a,b). We refer to this formation as the Kopaonik Formation based on the following definition:

Derivatio nominis: After Kopaonik Mountain area (SW Serbia). Compare 'Central Kopaonik Series' of Sudar (1986) and Sudar & Kovács (2006).

History: See chapter on geological setting and metamorphism.

Definition: Bedded, hemipelagic grey metalimestones, in certain stratigraphic intervals including fine-grained calcarenites consisting of shallow-water components; chert nodules and/or marly and clayey intercalations are frequent (**Fig. 7**). The area of deposition appears to be far from shallow-water ramps or platforms.

Type area: Kopaonik thrust sheet and Studenica slice. A complete type section cannot be defined because deformation and metamorphism are too intense in the Kopaonik area. The formation overlies the shallow-water carbonates of the equivalents of the Steinalm Formation and is overlain by red hemipelagic limestones of probable Jurassic age.

Other localities: Smrekovnica limestones, 'Metamorphic Trepča Series', southern Kopaonik Mountain area, Kosovo (Sudar 1986; Sudar & Kovács 2006).

Age: Latest Anisian to (Late) Norian, defined by conodonts (this paper, Sudar 1986 and Sudar & Kovács 2006).

Facies: Grey hemipelagic basinal metalimestones with fine-grained redeposited calcarenites (deposited by low-density turbidity currents).

Differences to other and similar formations: The Kopaonik Formation is in parts similar to the Gučevo Limestone Formation (Sudar 1986; Filipović et al. 2003) or to the Grivska Formation (Dimitrijević 1997). However, the hemipelagic metalimestones of the latter include significantly more shallow-water debris from nearby carbonate platforms. By contrast, the hemipelagic condensed or grey metalimestones of the Kopaonik Formation and the classical Hallstatt Limestones are devoid of coarser re-deposited shallow-water turbidites.

Remarks: The succession resembles that of the grey Hallstatt facies occurring within the Reifling and Pötschen Formations of the Eastern Alps (e.g. Lein 1987) as well as the Felsötárkány Limestone Formation of the Bükk Mountains, NE Hungary (Kozur 1991; Less et al. 2005). In addition, similar facies have been described from different locations in the internal Dinarides without specific formational names (Rampnoux 1974; Charvet 1978). A similar succession with hemipelagic Middle/Upper Triassic metalimestones was described in Korabi/Pelagonia units of eastern Albania (Meco & Aliaj 2000; Gawlick et al. 2008).

In the Studenica section, the Steinalm Limestones are separated from the Kopaonik Formation by sparse outcrops of

Table 1: Triassic conodont faunas of the Kopaonik and Studenica areas, southern Serbia.

Sample No. (Coord. MGI)	**Conodont fauna**	**Age**	**CAI-values**
Županj 1 (sample-nr. on Fig. 2)			
SRB 110 (7476443/4807045)	*Norigondolella* sp. *Epigondolella* sp. (*abneptis*-group)	Early–Middle Norian	5.5–6.0
Županj 2 (sample-nrs. on Fig. 2)			
SRB 111 (7477694/4806995)	*Neogondolella* cf. *excelsa* *Neogondolella* cf. *eotrammeri* *Neogondolella* cf. *cornuta*	Late Anisian	5.5–6.0
SRB 112 (7477694/4806995)	*Neogondolella* cf. *inclinata* (or *M. polygnathiformis*)	Ladinian–(Carnian)	5.5–6.0
Brzeće (Fig. 4)			
SRB 113 (7489302/4796146)	*Metapolygnathus* cf. *polygnathiformis*	Carnian	(5.0–)5.5 and 6.5–7.0
SRB 114 (7489269/4796084)	*Neogondolella* sp.	?Ladinian–Carnian	5.5
SRB 115 (7489107/4796221)	*Metapolygnathus polygnathiformis*	Carnian	5.5–6.0
Studenica (7463291/4814897, Fig. 3)			
A 4562	*Epigondolella quadrata*	Lacian (high 1 to 2)	5.5–6.0
A 4563	*Norigondolella* sp. *Epigondolella* sp.	Norian	5.5–6.0
A 4564	*Epigondolella* sp. indet *Neohindeodella triassica*	Norian	5.5–6.0
SRB 150	*Norigondolella navicula* *Norigondolella* cf. *hallstattensis* *Epigondolella* cf. *triangularis*	Lacian 2	5.5–6.0
SRB 153	*Norigondolella navicula* *Norigondolella* cf. *hallstattensis* *Epigondolella* sp. indet	Lacian 2	5.5–6.0

grey-weathering calcite mylonites ('grey mylonites') with a strong cleavage and with a few intercalated pelitic layers (Fig. 6c). In thin-section, the calcite grains are elongated and form sigma-clasts indicating top-to-the-northwest shear-sense. The white marbles overlying the mylonites are reminiscent of the Steinalm marbles found lower down in the Studenica section. However, the mylonites (sample SRB 153, Fig. 3a), the white marbles (sample A 4564), and the overlying well-bedded metalimestones with chert nodules (samples A 4563, SRB 150, A 4562, Table 1) include Norian conodonts (Figs. 8 and 9, Table 1). The conodont faunas cover only a very short time interval of the Early Norian, ranging from the higher part of the Lacian 1 or basal Lacian 2 (*Epigondolella quadrata*) to the Lacian 2 (*Epigondolella triangularis* and *Norigondolella*

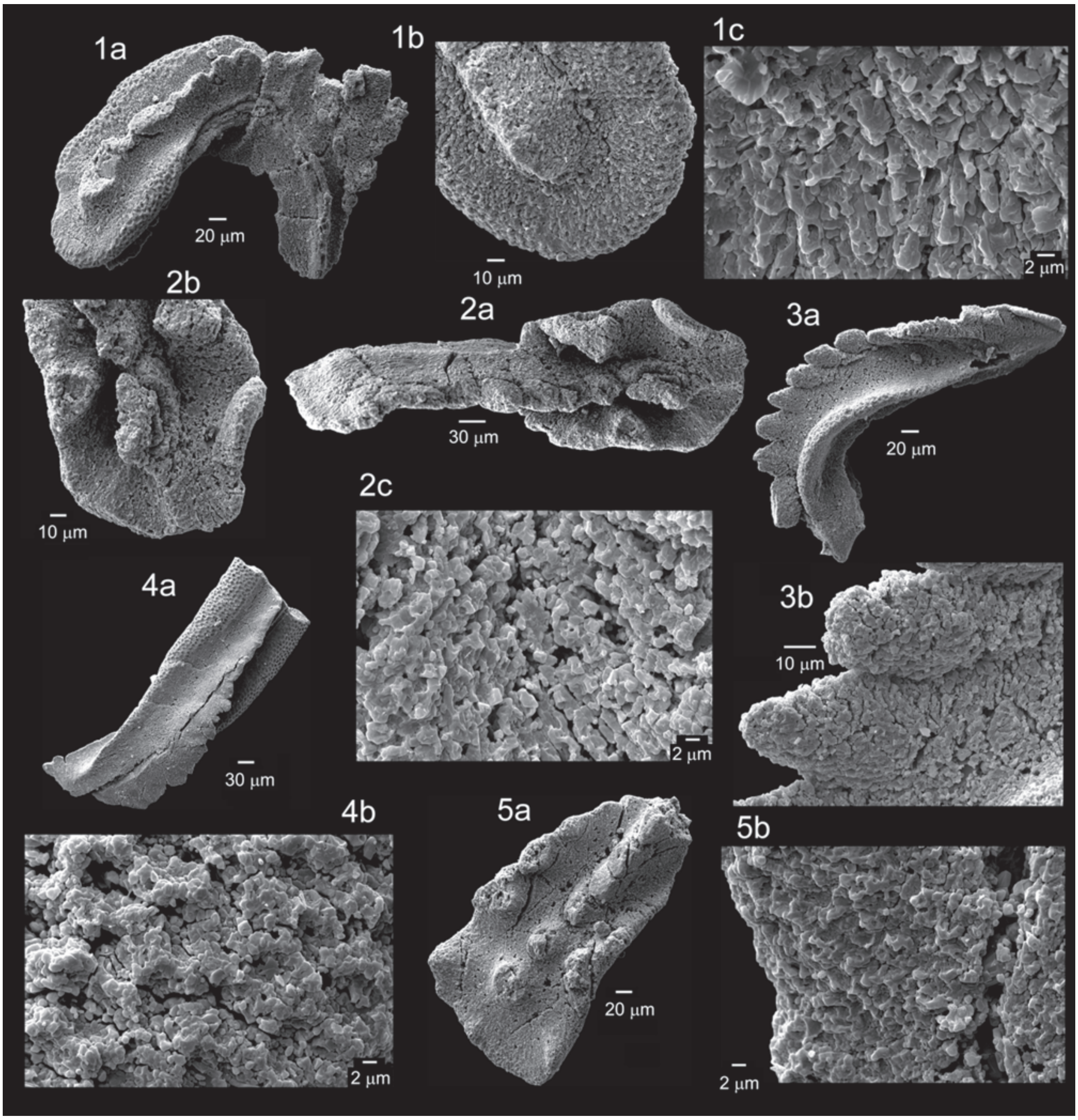

Fig. 8. Metamorphosed and deformed conodonts with Conodont Colour Alteration (CAI) values 5.5–6.0 from the Studenica section (Sample SRB150). These conodonts occur in grey cherty metalimestones and are of Early Norian (Lacian) age. **1a** — Ductilely deformed *Norigondolella navicula*. In this view the original ornamentation on the platform surface looks undeformed. **1b** — Platform end of *Norigondolella navicula*, enlarged, showing complete recrystallization of the original ornamentation by apatite crystal growth. **1c** — Enlarged detail of 1b showing the growth of the apatite crystals. Corrosion is missing. **2a** — Slightly deformed *Epigondolella triangularis*. **2b** — Enlarged platform end showing the complete and relatively homogeneous recrystallization of the conodont. **2c** — Enlarged detail showing the growth of apatite crystals. **3a** — Ductilely deformed *Norigondolella navicula*. **3b** — Recrystallized fabric, enlarged from 3a. **4a** — Deformed and recrystallized part of ?*Norigondolella navicula*. The original ornamentation on the platform surface is preserved and looks undeformed. **4b** — Enlarged view on the ornamentation showing complete recrystallization of the ornamentation. **5a** — Undeformed but totally recrystallized *Epigondolella triangularis*. **5b** — Recrystallized fabric, enlarged from 5a.

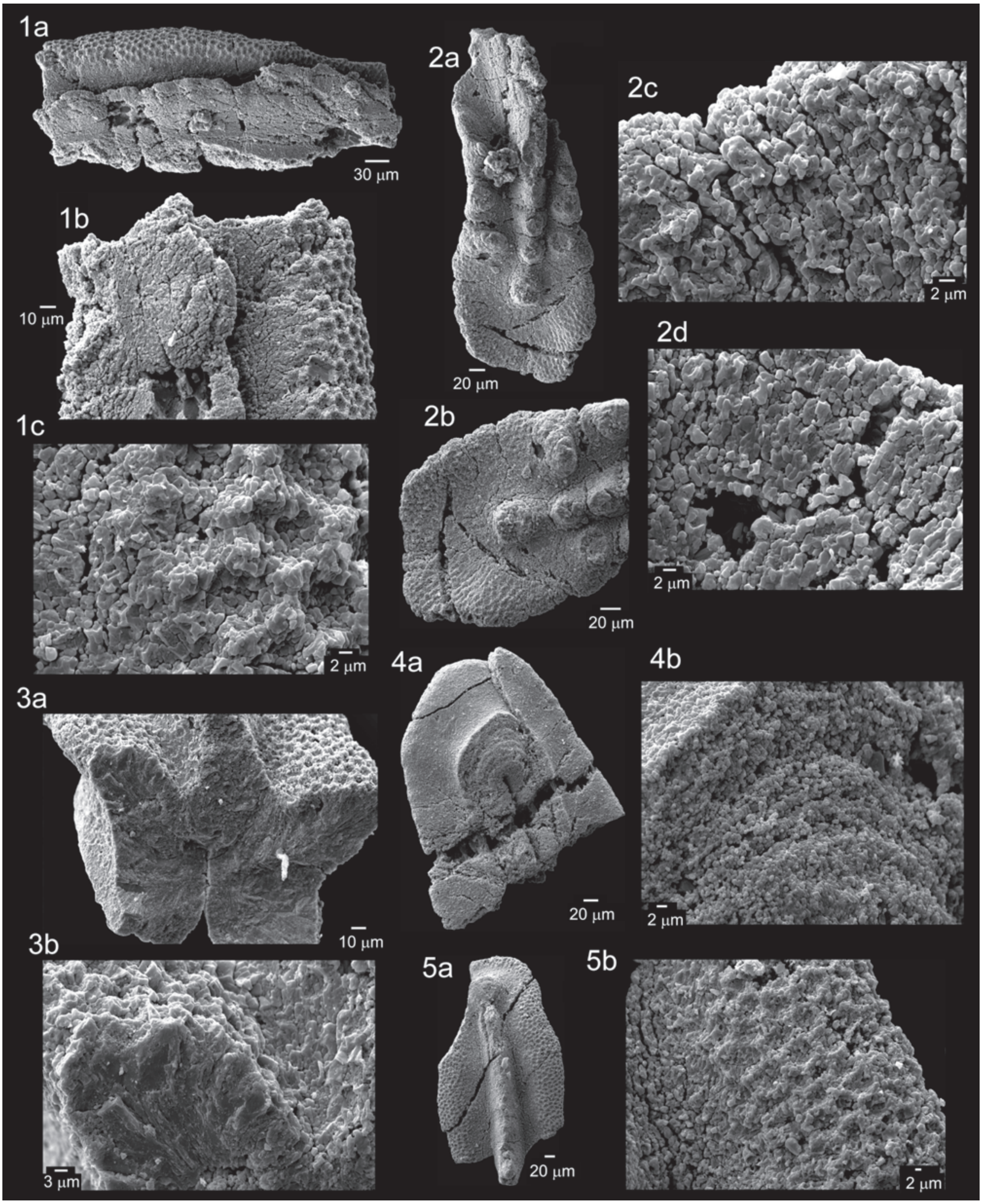

Fig. 9. Metamorphosed and partly ductilely deformed conodonts with Conodont Colour Alteration (CAI) values 5.5–6.0 from the Studenica section (sample SRB 153). These conodonts are from Lower Norian (Lacian) grey cherty metalimestones. **1a** — Slightly deformed and recrystallized *Norigondollela* sp. From this view, the original ornamentation on the platform surface looks undeformed. **1b** — Platform end, enlarged, showing complete recrystallization. **1c** — Enlarged view on the ornamentation showing the complete recrystallization of the ornamentation. **2a** — Undeformed but totally recrystallized *Epigondolella* sp. **2b** — Enlarged view of platform showing strong recrystallization. **2c, d** — Details of recrystallization, enlarged from 2b. **3a** — Broken *Norigondolella* sp. showing recrystallization in the inner part of the conodont. **3b** — Enlarged detail from 3a. **4a** — Basal view of *Norigondolella navicula*. **4b** — Enlarged detail from 4a. **5a** — Broken *Norigondolella* cf. *hallstattensis*. The original ornamentation on the platform surface is preserved and looks undeformed. **5b** — Enlarged view of the ornamentation showing complete recrystallization of the ornamentation.

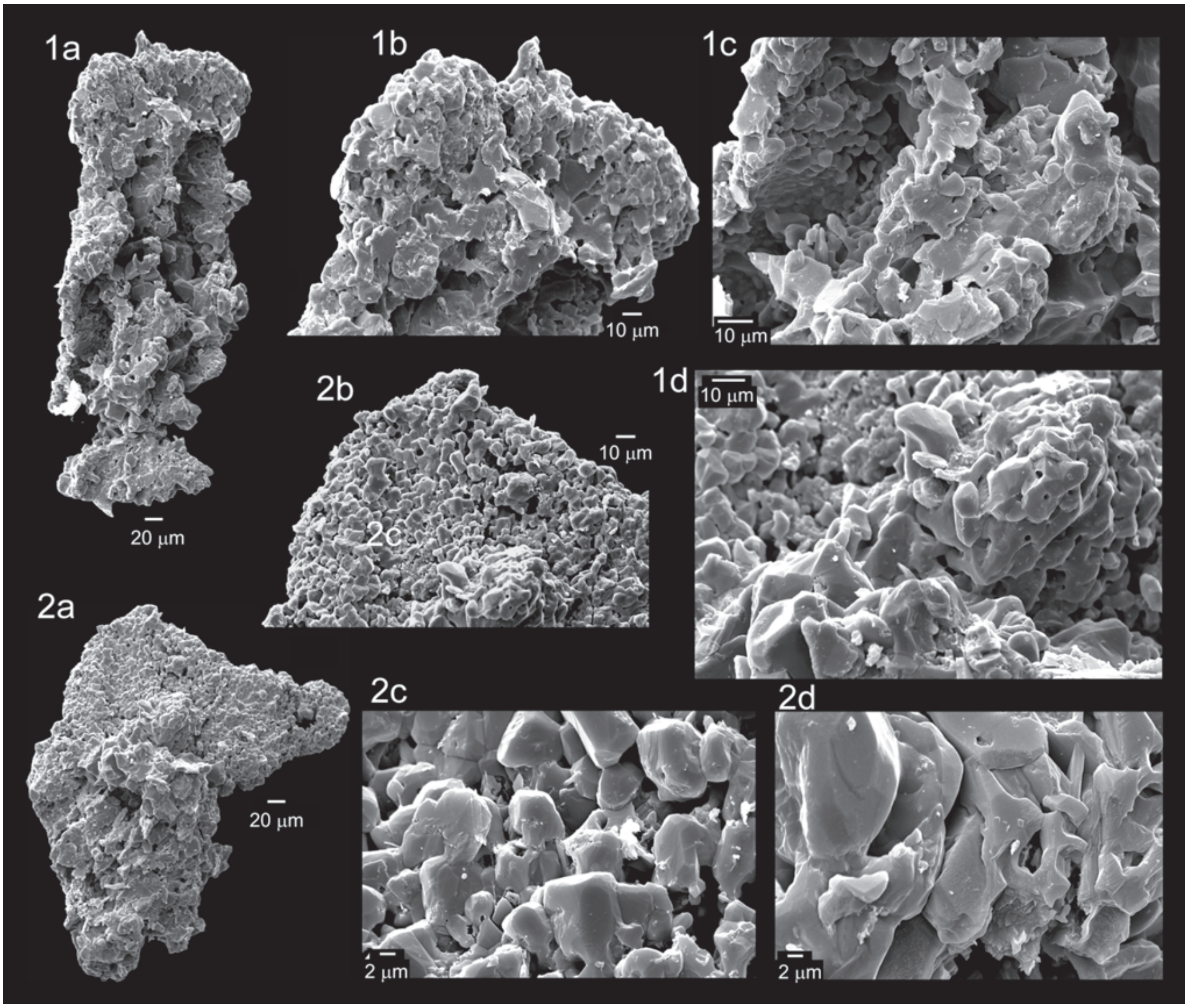

Fig. 10. Metamorphosed and ductilely deformed conodonts (*Metapolygnathus polygnathiformis*) with Conodont Colour Alteration (CAI) values in average CAI 5.5–6.0 from Kopaonik, Brzeće section (sample SRB 115). These conodonts come from probably Upper Carnian grey metalimestones. **1a** — Strongly recrystallized and corroded specimen. CAI 5.5–6.0. **1b** — Platform end enlarged showing strong recrystallization and growth of the apatite crystals. **1c** — Enlarged detail with strong recrystallization and partial corrosion of the surface. **1d** — Detail of the surface with relatively large apatite crystals. **2a** — Strongly recrystallized and slightly deformed specimen. CAI 6.0. **2b** — Platform end enlarged showing strong recrystallization and growth of the apatite crystals. The original surface is completely destroyed by recrystallization. **2c** — Enlarged detail showing strong recrystallization and growth of individual apatite crystals. **2d** — Enlarged detail showing strong recrystallization of apatite and enlargement of the crystallites.

hallstattensis). Because some important details of the conodont morphology were destroyed by intense deformation and low-grade metamorphism (CAI-values between CAI 5.5 and 6.0), the determination of the conodonts species cannot be more precise.

The conodont data from the grey calcite-mylonites, that is from the Early Norian age pose a problem: obviously Ladinian and Carnian strata are missing in the Studenica section. As a primary stratigraphic gap by non-deposition and/or erosion appears unlikely to be the case, we suggest a tectonic contact along the calcite-mylonites.

In the Gradac 2 section, the Kopaonik Formation consists of thin-bedded marbles with interbedded marls. Weathering and fresh surfaces of the marbles are dark; the intercalated pelitic layers are yellowish. After a few meters of rhythmic alternations the metalimestones and marls give way to metalimestones with chert layers.

In the type area (Fig. 4), the Kopaonik Formation makes up large cliffs and the most conspicuous outcrops. The formation is well stratified; calcareous beds alternate with chert-rich metalimestones or marly intercalations. The thickness of the beds varies between centimeters and decimeters (Fig. 6d). Where marly layers are absent, the chert layers and nodules are diagnostic for this formation. Weathered surfaces are greyish to brownish, depending on the amount of clay. In the vicinity of the intrusion, the Kopaonik Formation is transformed into massive skarns and hornfelses due to contact metamorphism (Fig. 6e). Metamorphosed chert layers and calcsilicates

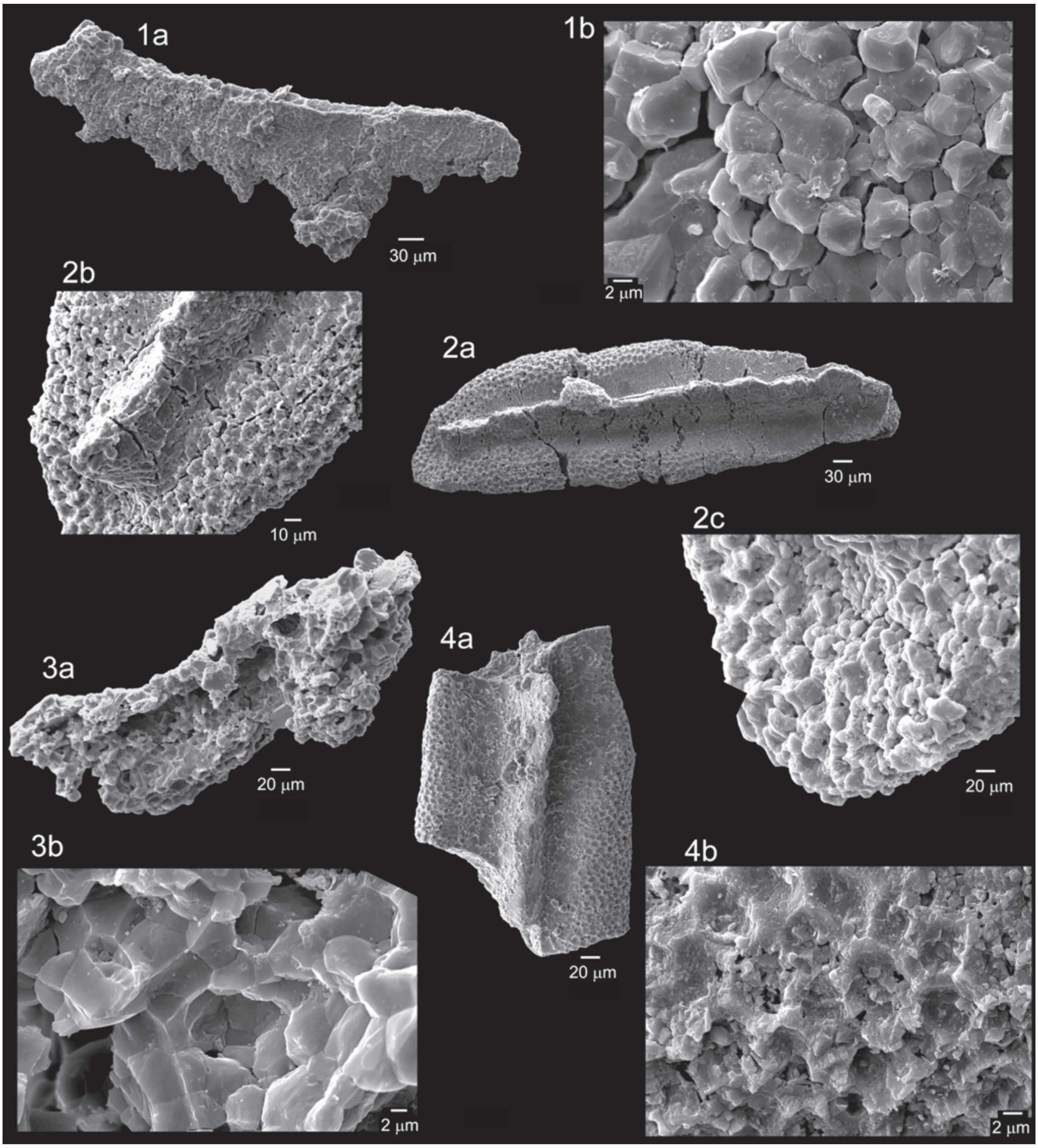

Fig. 11. Metamorphosed and only slightly ductilely deformed conodonts from the Late Anisian or Late Ladinian to ?Early Carnian of locality Županje 2 with Conodont Colour Alteration (CAI) values of CAI 5.5–6.0. Samples SRB 111 and SRB 112. **1a** — *Neogondolella* cf. *cornuta*. CAI 5.5–6.0. **1b** — Enlarged part from 1a showing the strong recrystallization and growth of the apatite crystals. The typical surface is completely destroyed by recrystallization. **2a** — *Neogondolella* cf. *eotrammeri*. CAI 5.5–6.0. **2b** — Enlarged platform end of the specimen figured in 2a showing the complete recrystallization of the ornamentation. **2c** — Growth of apatite crystals, enlarged part from 2b. **3a** — *Gondolella* cf. *excelsa*, extremely recrystallized. **3b** — Same specimen, enlarged part showing the strong recrystallization and growth of the apatite crystals. **4a** — Broken piece from the platform element of *Neogondolella* cf. *inclinata*. **4b** — Enlarged part from 4a showing strong recrystallization and growth of apatite crystals in the area of platform ornamentation.

in marbles define the layering. In thin-section diopside, clinopyroxene, hornblende, garnet, and biotite are found. Calcite is consumed by reaction with quartz.

Our new conodont faunas from the Kopaonik Formation in the type area and near the village of Brzeće, indicate a probable Early Carnian age based on the occurrence of *Metapolygnathus polygnathiformis* (samples SRB 113, SRB 114, SRB 115; Fig. 4, Table 1); however, a Late Ladinian to Late Carnian age cannot be excluded (Sudar 1986; Sudar & Kovács 2006) because the surface of *Metapolygnathus polygnathifor-*

mis is destroyed by extreme polyphase deformation and (low-grade) metamorphism (CAI-values of CAI 5.5–6.0, reaching locally CAI 6.5–7.0, Fig. 10).

Two successions of metalimestones within the Kopaonik Formation are developed in the wider area of Kovači village, that is in Županj hamlet (north of the road from Jošanička Banja towards Biljanovac). In the locality Županj 1 an Early to Middle Norian conodont fauna, including *Norigondolella* sp. and *Epigondolella* sp. could be isolated from dark grey micritic limestone beds (sample SRB 110 in Fig. 2, Table 1). These micritic metalimestones overlie a thick series of dark grey, bedded metalimestones with fine-grained siliciclastic intercalations. In the locality Županj 2 (samples SRB 111, 112 in Fig. 2) a stratigraphically reduced series of dark grey cherty and deformed metalimestones is dated as Late Anisian by the occurrence of *Neogondolella* cf. *excelsa* and *Neogondolella* cf. *cornuta*, and, higher up, as Late Ladinian/?Early Carnian by the occurrence of *Neogondolella* cf. *inclinata*. Due to the strong deformation of the conodonts a determination as *Metapolygnathus polygnathiformis* also seems possible (Fig. 11, Table 1). This locality is of special interest because it provides evidence of Middle Triassic (Late Anisian to Ladinian?) hemipelagic grey metalimestones in the Kopaonik region for the first time. Near to our samples from Županj 2, Sudar (1986) found several Carnian conodonts.

Red hemipelagic limestones and radiolarites

Only in the Studenica section are such younger sediments exposed. Here, the Kopaonik Formation is overlain by red to violet hemipelagic limestones with a thickness of only 1–2 meters showing a strong penetrative foliation. Limestone laminae, only up to one millimeter in thickness, are separated by thin films of clay and occasional white marble layers. In thin-section accessory quartz grains and relics of radiolarians are visible. These red hemipelagic limestones probably represent an equivalent of the Middle Jurassic condensed Klaus Limestone of the Eastern Alps and Western Carpathians (Krystyn 1971; Tollmann 1976; Gawlick et al. 2009a), or of the Toarcian–Middle Jurassic Rosso Ammonitico of the internal Hellenides (e.g. Baumgartner 1985). Similar condensed red Bositra limestones of Middle Jurassic age below siliceous sedimentary rocks were recently described also in SW Serbia (Radoičić et al. 2009). They are followed up-section by some meters of metamorphosed massive radiolarites of supposed late Middle to Late Jurassic age.

Ophiolitic mélange

An ophiolite-bearing mélange of considerable thickness tectonically overlies the Triassic–Jurassic succession in the Studenica section. In the Kopaonik area, the mélange is thrust on top of the Kopaonik Formation while the sections Gradac 1 and Gradac 2 do not expose the contact to the mélange. The mélange contains, embedded in a brown to reddish mud matrix, blocks predominantly of serpentinite; basalts, turbiditic sandstones and carbonate rocks are also found as blocks. In the Studenica section the mélange is often foliated due to a strong younger tectono-metamorphic overprint.

Regional correlation and reconstruction of the original sedimentary succession

Based on lithofacies and age dating we can correlate both the intensely folded strata of the Kopaonik area with the not visibly folded yet strongly foliated and metamorphosed strata from the sections Studenica and Gradac 1 and 2 (Fig. 12). It appears that all our sections are stratigraphically incomplete due to intense deformation leading to the thinning of strata. Hence each of the sections only reveals a part of what might be considered an originally complete stratigraphic succession for the study area.

According to our stratigraphic interpretation of the Studenica section, Ladinian as well as Carnian sediments are clearly missing in this section because the Anisian–Ladinian boundary tuffites are directly overlain by marbles yielding Norian (Lacian 1–2) conodonts that we attribute to the Kopaonik Formation. This omission of strata could have been caused by normal faulting; however, we were unable to detect normal faults in this section. On the other hand, strong penetrative deformation has reduced marbles and limestones in the Studenica section to 25 % of their original thickness as shown by a representative strain analysis of the breccia horizon (Egli 2008).

During mapping of the Kopaonik area, all Anisian shallow-water carbonates identified in the other profiles were included into one single formation (‘shallow-water carbonates’ in Fig. 4) because the succession is in most places too thin (or even lacking) to allow a subdivision into Gutenstein and/or Steinalm Formation. In this area, these formations are either stratigraphically reduced or tectonically thinned, or both.

In the Kopaonik area and in the section Gradac 2 the Kopaonik Formation mostly consists of typical fine-grained calcilutites with interbedded marls, cherty layers and nodules and calcarenites with some shallow-water material derived from a carbonate platform.

The overall sedimentary evolution of the Kopaonik Formation in the type-area can be summarized as follows: after shallow-water carbonate sedimentation prevailing during most of the Anisian, hemipelagic sedimentation started with a relatively thin succession of Upper Anisian to Ladinian grey cherty limestones that pass into a thick series of Lower Carnian limestones with some marls and few cherts, followed by Upper Carnian to Lower Norian micritic limestones with an increase of cherts in the Middle Norian.

In the Studenica section the Kopaonik Formation is overlain by Jurassic hemipelagic limestones and radiolarites. These Jurassic sedimentary rocks occur a few meters above the Norian (Lacian 1–2) conodont-bearing horizon and testify to continuing subsidence of the distal continental margin before obduction of the ophiolites. In addition to continuing subsidence, shallowing of the calcite compensation depth (CCD) in the Middle–Late Jurassic, brought about by changes in plankton productivity, export of carbonate mud from adjacent platforms and in other paleoceanographic variables (e.g. Bernoulli & Jenkyns 2009), might have led to deposition of radiolarites near or below the CCD. The age of the distal continental-margin radiolarites is generally dated as Middle Jurassic in the internal Dinaride–Hellenide realm (e.g. Baumgartner 1985;

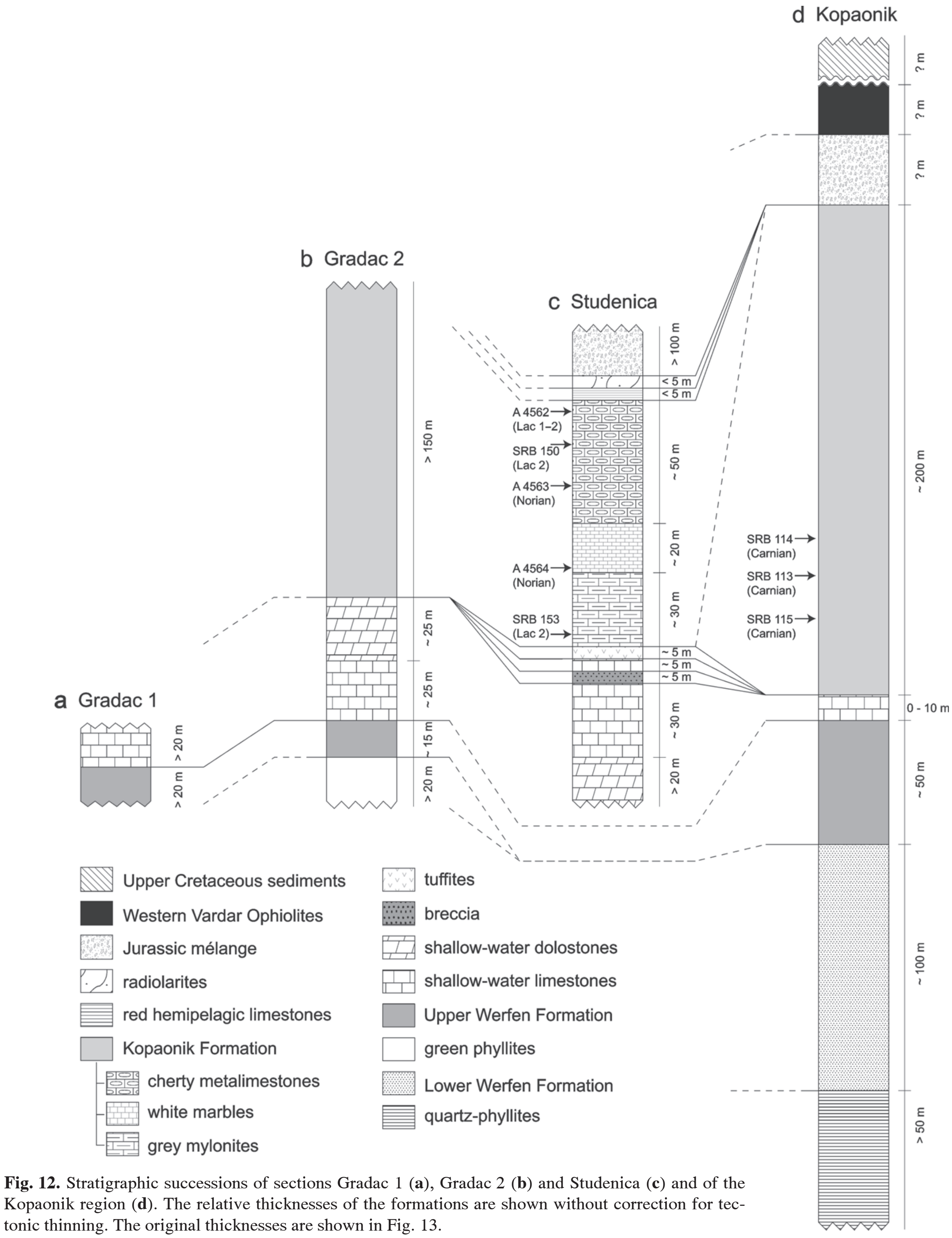

Fig. 12. Stratigraphic successions of sections Gradac 1 (**a**), Gradac 2 (**b**) and Studenica (**c**) and of the Kopaonik region (**d**). The relative thicknesses of the formations are shown without correction for tectonic thinning. The original thicknesses are shown in Fig. 13.

Obradović & Goričan 1988; Djerić et al. 2007a,b), whereas the onset of radiolarite sedimentation in the more proximal parts of the continental margin occurred somewhat later (e.g. Charvet 1978; Obradović & Goričan 1988). Furthermore Middle Jurassic formation ages of ophiolitic mélanges in the Dinarides–Albanides (e.g. Goričan et al. 1999, 2005; Halamić et al. 1999; Babić et al. 2002; Chiari et al. 2002; Gawlick et al. 2008, 2009b) suggest that early Late Jurassic obduction of the ophiolites was presumably preceded by the emplacement of olistostromes that were tectonically overprinted forming the mélanges below the ophiolites. In the closer Kopaonik region, however, sediments younger than the Kopaonik Formation were not found below the ophiolitic mélange, probably because obduction-related thrusts cut across older formations in this area.

Combining the four stratigraphic sections correlated in Fig. 12 with the other outcrops and the conodont data allows us to draw a reconstructed synthetic stratigraphic succession from the Upper Paleozoic up to the Upper Cretaceous showing the overall facies evolution (Fig. 13). Overlying an Upper Paleozoic basement, the some 100 m thick sedimentary succession starts with siliciclastic sediments, comparable to the Werfen Formation. A Late Permian onset of sedimentation cannot be excluded. Carbonate production started with the uppermost Werfen Formation, perhaps during the late Early Triassic, as in the Southern or Eastern Alps. The Middle Triassic sequence starts with shallow-water carbonates (Gutenstein and Steinalm Formation equivalents), followed by Upper Anisian hemipelagic sediments in the wake of the drowning of the Steinalm ramp/platform. Hemipelagic carbonate sedimentation is proven for nearly the entire Middle and Late Triassic. The only preserved Jurassic sediments in the area consist of pelagic red metalimestones and radiolarites of probably Middle–?Late Jurassic age. These are followed by a ?Middle–Upper Jurassic ophiolitic mélange and the overriding West Vardar Ophiolites. From this reconstructed stratigraphic succession, where original thicknesses are estimated based on a representative strain determination (Egli 2008), it becomes clear that the original thickness of the Kopaonik Formation is at least 400 meters. In the Kopaonik area, this is also apparent from the large outcrop areas appearing on the geological map (Fig. 4).

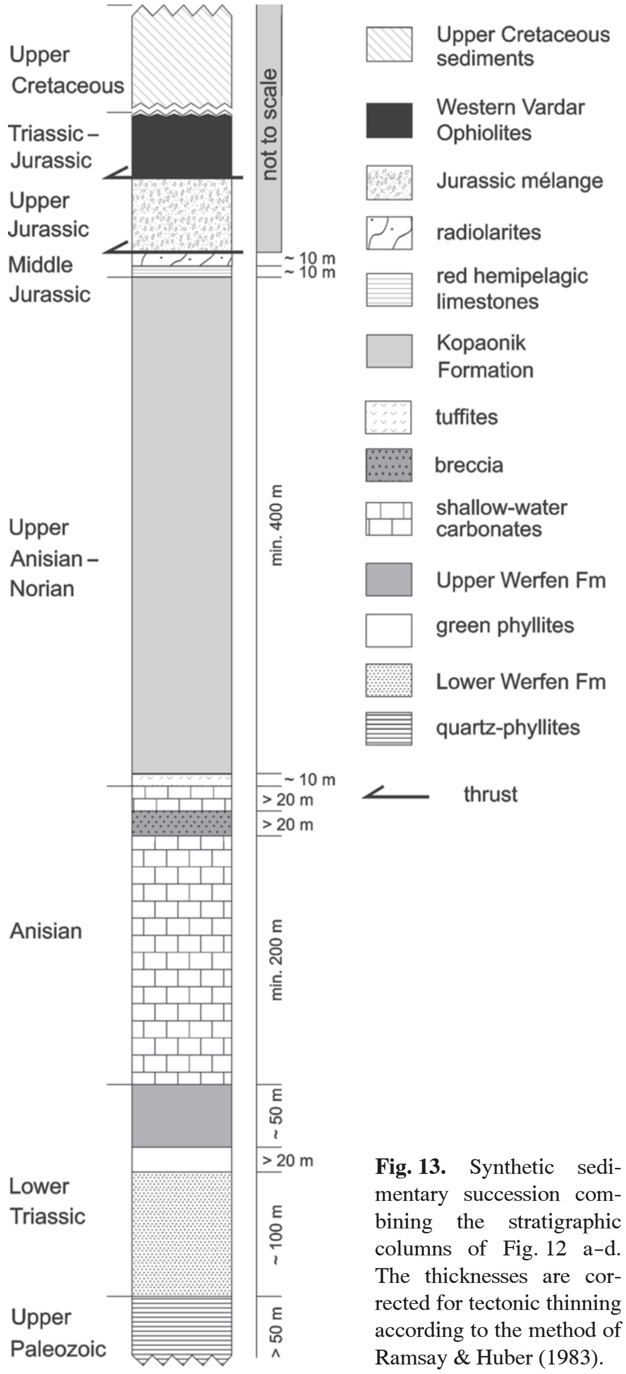

Fig. 13. Synthetic sedimentary succession combining the stratigraphic columns of Fig. 12 a–d. The thicknesses are corrected for tectonic thinning according to the method of Ramsay & Huber (1983).

Discussion

Before discussing the paleogeographic setting of our study area in a wider context within the Alps-Carpathians-Dinarides system we compare the stratigraphy and facies of the study area with that of other parts of the Dinarides. The Mesozoic stratigraphy is rather well established in the more external units, namely in the main parts of the Drina-Ivanjica thrust sheet southwest of our study area (= 'Zone de Golija' of Aubouin et al. 1970) and in the East Bosnian-Durmitor thrust sheet (= 'Zone Serbe' of Aubouin et al. 1970), based on the work of Cadet (1970, 1978), Charvet (1970, 1978), Rampnoux (1970, 1974), Sudar (1986), Dimitrijević & Dimitrijević (1991), Dimitrijević (1997) and Sudar et al. (2008). In these areas a first platform-drowning event, which follows shallow-water carbonate sedimentation of the Gutenstein and Steinalm Formations is also recorded during the latest Anisian by the onset of condensed red pelagic limestones (Bulog Limestone of Rosso Ammonitico-type), first described by Hauer (1888, 1892). This facies is usually followed by volcanic tuffs that often occur around the Anisian/Ladinian boundary (Sudar 1986).

In our study area, the transition from shallow-water to hemipelagic sedimentation coincides with the occurrence of a breccia below the main tuffite horizon in the Studenica section. A similar breccia horizon ('Podbukovi Conglomerate Member') is observed in the uppermost Anisian dolomitic limestones of the Jablanica Formation (an equivalent of Steinalm Limestone) of the Jadar-Kopaonik thrust sheet (i.e. in the 'Jadar Block Terrane' of Filipović et al. 2003). In the same area this breccia horizon is overlain by volcanics (metaandesites and accompanying pyroclastics of the Tronoša Formation).

According to our conodont data from Županj localities, the drowning in the Kopaonik area occurred during the latest Anisian (Fig. 13). Occasional calcarenites with shallow-water components in the ?Lower Carnian succession suggest redeposition of carbonate material derived from carbonate platforms, together with shedding of fine carbonate silt and lutum from the platforms during sea-level highstands (Schlager et al. 1994). This may explain the relatively high sedimentation rates during this time interval. A hemipelagic/deep-benthic setting, equivalent to the grey Hallstatt facies of the Eastern Alps–Western Carpathians (Lein 1987) is in line with the faunal content (radiolarians, conodonts, pelagic bivalves).

The most important facies difference with respect to the more external parts of the Drina-Ivanjica thrust sheet (including strata within so-called 'olistoplaka', which Dimitrijević (1997) interpreted as gravitationally emplaced olistoliths and that we regard as an integral part of the Drina-Ivanjica thrust sheet) and part of the East Bosnian-Durmitor thrust sheet is, that the strata found up-section from the Bulog Limestone and the tuffites are typically shallow-water carbonate sequences, and so equivalents of the Upper Ladinian to Carnian Wetterstein and the Norian to Rhaetian Dachstein formations (Dimitrijević & Dimitrijević 1991; Sudar et al. 2008). In some localities within these two more external thrust sheets, however, a base-of-slope to basinal hemipelagic facies of poorly known age (Middle to Late Triassic and/or Early to Middle Jurassic?) develops, that resembles the Kopaonik Formation (Fig. 13). It also consists of detrital carbonate and siliceous sediments and was referred to as Grivska Formation by Dimitrijević (1997). In the more external East Bosnian–Durmitor thrust sheet Rampnoux (1970, 1974) described a similar basinal facies, his 'calcaires lités pélagiques à silex', for example from the 'sillon de Zlatar', which should be bordered, according to this author, by Wetterstein- and Dachstein-type platforms. The Grivska Formation and the age-equivalent Wetterstein and Dachstein platforms are overlain by Jurassic hemipelagic limestone and radiolarites (Djerić et al. 2007a,b; Vishnevskaya et al. 2009) similar to those above the Kopaonik Formation in the Studenica section, followed by the ophiolitic mélange. Carnian to Norian cherty limestones with conodonts (Gučevo Limestone) were also described from other parts of the Jadar-Kopaonik thrust sheet ('Jadar Zone' of Sudar 1986, 'Jadar Block Terrane' of Filipović et al. 2003).

In spite of some lithological similarities between the Grivska and the Kopaonik Formation we like to emphasize that the limestone succession of the Grivska Formation includes significantly more shallow-water debris from the nearby Ladinian to Rhaetian carbonate platforms. In addition, the Grivska Formation appears to be restricted to the more external paleogeographic domain (the Drina-Ivanjica and the East Bosnian-Durmitor thrust sheets). Moreover, Bulog-type limestones and equivalents of the Wetterstein and Dachstein Formations were not found in our area. All this suggests that the grey hemipelagic sequences of the Kopaonik Formation, though yielding fine-grained shallow-water debris, represent a more distal facies of the Adriatic margin.

A paleogeographic position of the facies of the Kopaonik Formation at the distal Adriatic margin adjacent to the Neotethys (i.e. the Meliata-Maliac-Vardar Ocean) becomes even more convincing when we compare our area with the Eastern Alps and the Albanides–Hellenides. In the Northern Calcareous Alps of Austria (Lein 1987) and the Korabi-Pelagonia zone in Albania (Meco & Aliaj 2000; Gawlick et al. 2008), similar deposits are interpreted to have been deposited in a distal continental margin position (Haas et al. 1995; Gawlick et al. 1999, 2008) after rifting began during the Late Pelsonian leading to the opening of the Neotethys (Vardar-Meliata branch of Velledits 2006). The Kopaonik Formation also resembles the so-called 'grey Hallstatt facies' or Zlambach facies zone (Pötschen Limestone) of the Eastern Alps (e.g. Lein 1987; Gawlick 2000). It further resembles the Felsötárkány Limestone Formation in the Bükk Mountains (Kozur 1991; Less et al. 2005), as well as coeval deep-water limestones in the Korabi-Pelagonian zone of Albania (Gawlick et al. 2008). A paleogeographic derivation of the Kopaonik Formation close to the Meliata-Maliac-Vardar branch of the Neotethys is also suggested by the similarity with the Adhami Limestone that occurs in the distal part of the internal Pelagonian continental margin in the Argolis area of Greece and separates the shallow-water platforms (Pantokrator Limestone) of the more proximal margin from the oceanic realm (Baumgartner 1985).

Almost all the occurrences of Middle to Upper Triassic chert-rich deep-water limestones occur on the distal parts of the continental margin facing the Meliata-Maliac-Vardar Ocean. Towards the more proximal areas of the margin, the sites of hemipelagic deposition were linked to coeval carbonate platforms (Wetterstein, Dachstein platforms). The depositional area of the Kopaonik Formation must also have been connected to one or more Middle to Upper Triassic rimmed carbonate platforms, like those preserved in the more external parts of the Dinarides, whereby the grain size and amount of the redeposited material decreases distally as can be observed from the Durmitor area across the Drina-Ivanjica zone to the Kopaonik area. Other carbonate platforms may have been present along the ocean–continent boundary, the deeper areas forming embayments like the modern Tongue of the Ocean. However, there seems to exist a general trend from the external to the internal Dinarides from shallow-water to pelagic near-oceanic environments. Applying Occam's Razor (Thorburn 1918), we opt for a simple continental margin model. In fact, the paleogeographic location of the Jadar-Kopaonik thrust sheet is analogous to that of the Hallstatt facies of the Eastern Alps and to that of the depositional areas of similar facies in Albania or Greece adjacent to oceanic units attributed to the Meliata-Maliac-Vardar branch of the Neotethys and may represent the most distal parts of the Adriatic continental margin. Our data are consisted with the one-ocean-hypothesis and an origin of all ophiolites, including the so-called Dinaridic ophiolites, from east of the Drina-Ivanjica and Kopaonik units.

Conclusions

The metamorphic sedimentary succession of the Jadar-Kopaonik thrust sheet in the most internal Dinarides of southern Serbia includes a succession from the Upper Paleozoic terrigenous sediments to the Upper Jurassic ophiolitic mélange and the Western Vardar ophiolites obducted in the Late Jurassic. Lower Triassic siliciclastics and limestones are overlain by Anisian shallow-water carbonates. A drowning event during the latest Anisian resulted in the deposition of a grey hemipelagic limestone succession characterized by fine-grained redeposited and often silicified calcarenites, shed by low-density turbidites from a carbonate platform. New conodont faunas date this hemipelagic sequence as Late Anisian to Norian, possibly extending into the Early Jurassic, which makes it to an equivalent of the grey Hallstatt facies of the Eastern Alps. The younger sediments overlying the Kopaonik Formation are red hemipelagic limestones and radiolarites of probably Middle–Late Jurassic age; they suggest that deep-pelagic conditions preceded the obduction of the Western Vardar Ophiolitic Unit.

Sedimentation of the hemipelagic Kopaonik Formation was contemporaneous with shallow-water carbonate production in nearby carbonate platforms that were part of the same passive continental margin. Most of these platforms were located on the more proximal parts of the Adriatic margin, whereas the distal margin was dominated by pelagic and distal turbiditic sedimentation, facing the evolving ocean to the east. Our data are in line with a continental margin model in which the facies belts are arranged in a logical order from the proximal margin to the Neotethys Ocean. In our interpretation the Drina-Ivanjica and Kopaonik thrust sheets expose the most distal portions of the Adriatic margin, emerging in tectonic windows below one and the same ophiolite nappe referred to as the Western Vardar Ophiolitic Unit (including the so-called Dinaridic ophiolites) derived from the east and overthrusting the Durmitor zone.

We see no evidence for one or several independent Triassic oceans between the Adria, the Drina–Ivanjica and/or the Kopaonik areas. The sedimentological and stratigraphic evolution of the different areas reflects the transition from a proximal to a distal continental margin.

Acknowledgments: We thank S. Kovács and S. Kövér (Budapest) who participated in the field campaign for their valuable discussions and support, and J. Charvet and J. Michalík for thoughtful reviews. This project was financed by the Swiss National Funds, Project No. 200020-109278 to S.M. Schmid, B. Fügenschuh and S. Schefer. The research of M. Sudar and D. Jovanović was supported by the Ministry of Science and Technological Development of the Republic of Serbia, Project No. 146009.

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