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# Microstructures of the Lim Zone along the contact with Dinaridic Ophiolite nappe

Aleksandar Ilić[1] & Luka Pešić[2]

**Abstract.** The Lim Zone is a part of the low-grade metamorphic core complex called the Lim Palaeozoic Unit, overlain by detached Triassic sedimentary successions. The Lim Unit is located in the footwall of overriding Dinaridic Ophiolite nappe. In general, three major ductile deformation phases could be observed on the boundary between the Lim Unit and the overriding Dinaridic Ophiolite nappe. In both, the Lim Unit and the Dinaridic ophiolite nappe, the major deformation event was related to the SSW-directed, oblique thrusting along the Dinaridic ophiolite thrust. The same orientation of the stretching lineation in both units is related to the predominant top-to-the-south shear, which suggests, therefore, oblique thrusting during the emplacement of the ophiolites over the Lim Unit. This paper deals with the results of microstructural analysis of Palaeozoic rocks of Lim Zone along the contact with Dinaridic ophiolite nappe.

**Key words**: microstructure, shear zone, shear bends, transpression, oblique thrusting.

**Абстракт**. Лимска зона је део ниско-метаморфисаног комплекса званог Лимски палеозоик, који је прекривен тријаским седиментима. Лимски палеозоик се налази у подинском блоку Динарске офиолитске навлаке. Генерално, главна фаза деформација, како у Лимском палеозоику тако и у Динарској офиолитској навлаци је везана а ЈЈЗ-дно навлачење дуж Динарске офиолитске навлаке. Иста оријентација “streaching” линеације у обе јединице је везана за смицање у правцу југа што стугерише косо навлачење офиолита преко Лимске зоне. Овај рад приказује резултате микроструктурне анализе палеозоијских стена Лимске зоне дуж контакта са Динарском офиолитском навлаком.

**Кључне речи**: микроструктуре, зоне смицања, клизне зоне, C–S склоп, транспресија.

## Introduction

The working area is part the East Bosnian–Durmitor Unit of the Central Dinarides in westernmost Serbia and easternmost Montenegro, located in the footwall of overriding Dinaridic Ophiolite nappe (Figs. 1A, B). The Dinaridic Ophiolite nappe is correlated with the Mirdita Zone of Albania (Shallo 1990) and the ophiolites of the Pindos and Subpelagonian Zones of Greece (e.g., Jones & Robertson 1990). The East Bosnian–Durmitor Unit represents a composite pile of nappes (Dimitrijević 1982) and is considered to be the eastern passive continental margin of an Apulian plate (Robertson & Karamata 1994). The outcrops to the south–west of the Dinaridic Ophiolite nappe show mainly Palaeozoic successions, which are overlain by partly detached Triassic sedimentary and sub-volcanic rocks. Within the working area, this is represented by the Lim Zone, part of East Bosnian–Durmitor Unit (“Zone de Lim” of Rampnoux 1970). The Lim Unit was overthrusted by Dinaridic Ophiolite nappe (Figs. 1A, B) during the Late Cretaceous time, associated with low-grade metamorphic conditions. This led to the formation of brittle-ductile and ductile fabrics along the thrust zones (Ilić *et al*. 2003).

## Geological and structural settings

The Lim Zone is characterized by molasse-type deposits, including metaconglomerate, metasandstone and

[1] Caspian Wireline Services, Baku, Azerbijan. E-mail: alexandar.ilic@gmail.com
[2] Department of Geology, Faculty of Mining and Geology, University of Belgrade, Kamenička 6, P.O. Box 227, 11000 Belgrade, Serbia. E-mail: gorgf@rgf.bg.ac.yu

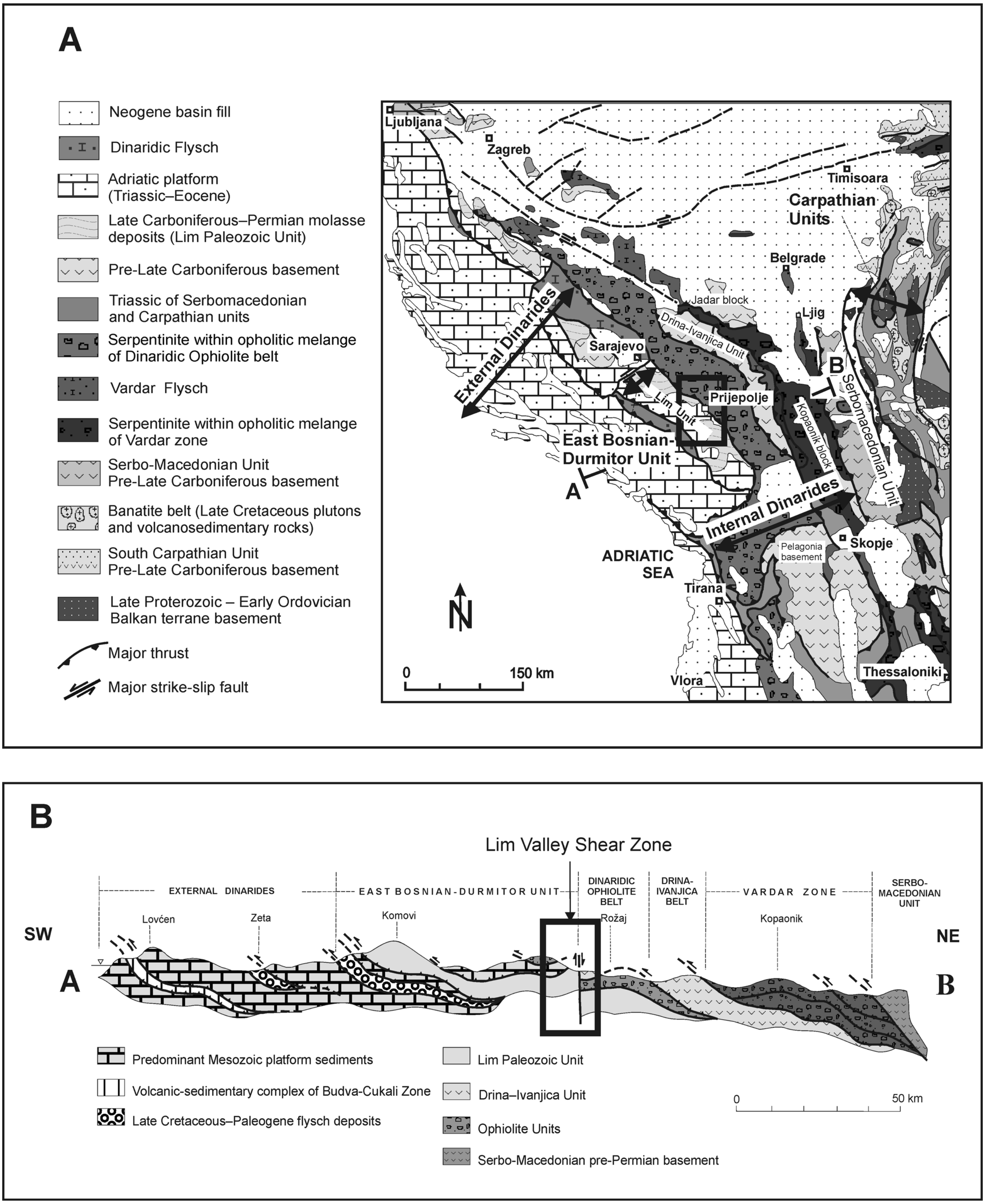


Fig. 1. **A**, Simplified tectonic map of the Dinarides; **B**, Section across the Central Dinarides.

metasiltstone of Early and Late Carboniferous age, which are overlain by Early Triassic clastics, Middle Triassic reef and pelagic carbonate deposits and volcanic successions (PAMIĆ 1984). The north-western part of the Zone ("Paleozoic of Prača" in SE Bosnia) is represented by Early Carboniferous flysch deposits and large, Late Devonian olistostromes (KRSTIĆ *et al*. 1988; EBNER 1991), overlain by Permian and Triassic sequ-

Table 1. Correlation table showing the different ductile deformation phases in the Lim Unit and Dinaridic Ophiolite nappe; DOT, Dinaridic Ophiolite Thrust. (ILIĆ *et al.* 2006).

| | **Lim Unit** | **DOT** | **Dinaridic Ophiolite nappe** | **Age** |
|---|---|---|---|---|
| **$D_3$** | Crenulation, kink bands and kink folds with NW-trending fold axes | ? | NW-trending extensional veins in serpentinites<br>Kink bands and SW-vergent kink folds | 52–58 Ma (ILIĆ *et al.* 2003) |
| **$D_2$** | Top-to-the west shearing in Triassic cover and EW extension<br>Updoming of Palaeozoic rocks<br>Open folds with strongly developed axial plane foliation and NS trending fold axes | ? | EW trending extensional veins | Late Cretaceous |
| **$D_1$** | Formation of metamorphic foliation and N-trending stretching lineation<br><br>Top-to-the south shearing | SSW-thrusting | Formation of pressure solution foliation and NS stretching lineation<br>Internal W and SW-directed thrust structures | 78–80 Ma (ILIĆ *et al.* 2003) |

ences. The Central and southern part of the Unit (Prijepolje–Brodarevo area in south-western Serbia, the Bijelo Polje area in north-eastern Montenegro, respectively) consists mainly of low-grade molasse-type sediments with Late Carboniferous fusulinide limestones (ĆIRIĆ 1980), covered in some places in the south with Early to Middle Permian clastic and volcanic rocks (ŽIVALJEVIĆ 1980). The whole complex of Paleozoic rocks is overlain by partly detached slices of very low-grade Early Triassic sandstones and shales, Anisian–Ladinian massive, pelagic limestones, volcanic rocks and massive Ladinian–Carnian carbonates. The Triassic magmatism is represented mainly by intermediate and acid plutonic and volcanic rocks of calc-alkaline affinity (PAMIĆ 1984).

ILIĆ *et al.* (2004) reported Variscan $^{40}Ar/^{39}Ar$ ages of detrital white mica from nearly undeformed sandstones exposed within a higher structural level of the Lim Palaeozoic Subunit. The presence of dominantly Variscan ages of the detrital white mica indicates that Alpine metamorphism was not sufficient to reset these ages, which constrain, therefore, variable Alpine, very low- to low-grade metamorphic overprints (ca. 300–350º C) within these structural levels. There is no evidence for Variscan metamorphic overprints on Carboniferous molasse-type deposits.

The study area, represented by the central part of the Lim Unit, forms a NNW trending structural dome with Palaeozoic rocks in the core and Triassic sequences on the limbs (Fig. 2). An ENE trending zone with Triassic rocks separates the north-western, Prijepolje subdome from the south-eastern, Brodarevo subdome.

In general, three major ductile deformation phases could be observed on the boundary between the Lim Zone and the overriding Dinaridic Ophiolite nappe (ILIĆ *et al.* 2006). In both, the Lim Zone and Dinaridic Ophiolite nappe, the major deformation event was related to the SSW-directed, oblique thrusting ($D_1$) along the Dinaridic ophiolite thrust (DOT). The same orientation of the stretching lineation in both units (ILIĆ *et al.* 2006) is related to the predominant top-to-the-south shear, which suggests oblique thrusting during the emplacement of the ophiolites over the Lim Zone.

Table 1 presents a correlation of these tectonic phases between the two tectonic units. A more detailed description of the ductile deformation phases is given in ILIĆ *et al.* (2006).

## Results of microstructural analysis

The structures were mapped in many stations all over the study area. A relative succession of outcrop-scale deformation structures was established on the basis of overprint criteria. Sets of structures belonging to the same deformation phase were correlated within the study area using their style, geometry and orientation as distinguishing markers (e.g. HANCOCK 1985; PRICE & COSGROVE 1990). Shear sense indicators, such as shear bands, *C–S* fabrics or asymmetric pressure shadows, were employed to obtain information on the kinematics of the deformation phases on the macroscopic as well as the microscopic scale. Thin sections, prepared for kinematic analysis, were cut parallel to the stretching lineation and perpendicular to the foliation plane (*XZ* finite strain plane). This paper deals with the results of microstructural analysis of Palaeozoic rocks of the Lim Zone along the contact with Dinaridic Ophiolite nappe. The terminology follows PASSCHIER & TROUW (1996).

### Microfabrics of the Lim Palaeozoic Unit

Based on the compositional types of metamorphic rocks, Palaeozoic rocks of area along the contact with ophiolites can be divided into three main categories:

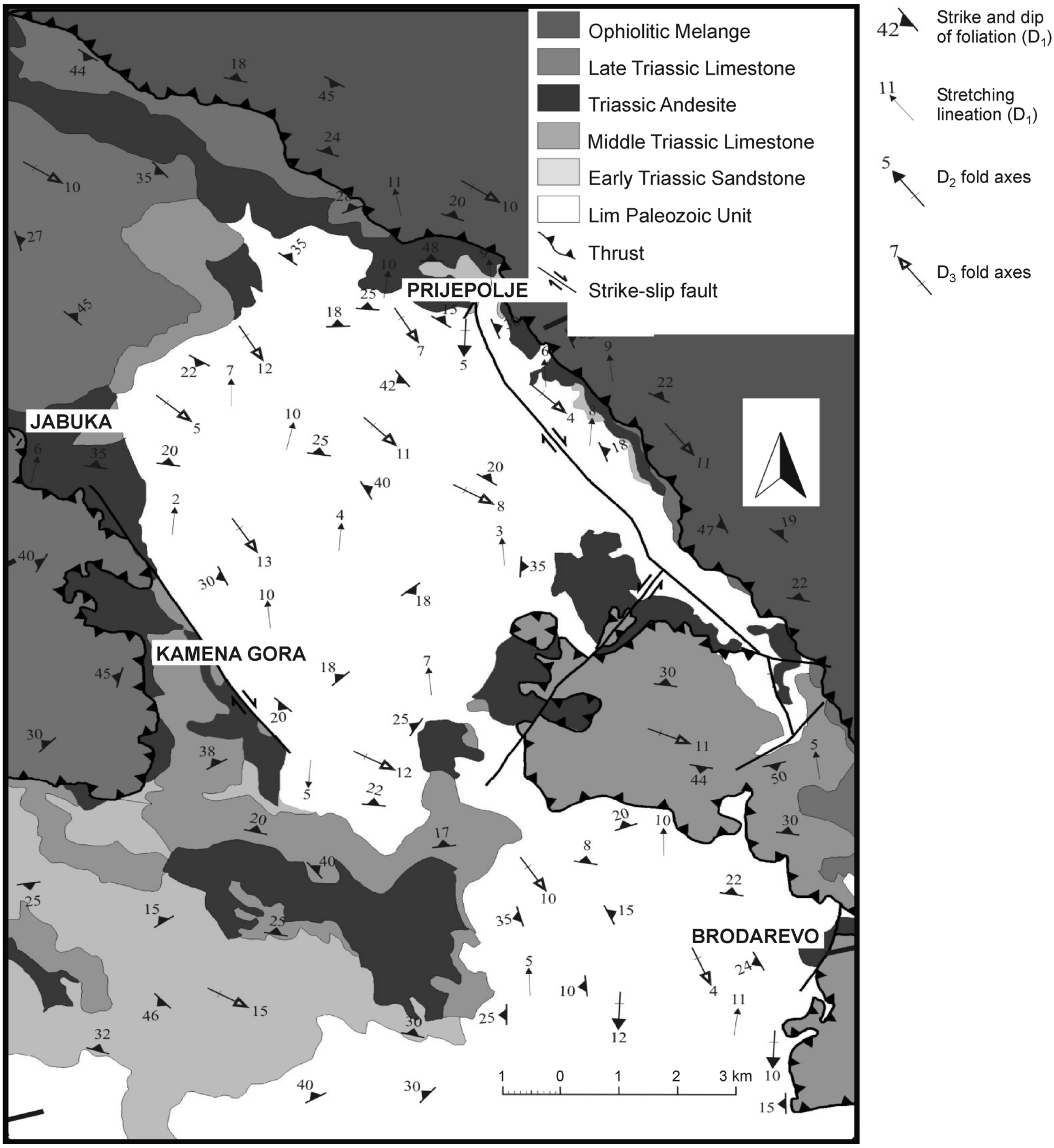


Fig. 2. The central part of the Lim Unit.

– semi-pelitic to pelitic metasediments,

– quartzo-feldspathic-mica rich metasedimentary rocks, and

– metabasites.

Each of thes groups of rocks has its own microfabrics and style of deformation. Semi-pelitic and pelitic metasediments of this area are highly sheared rocks, dominated by phyllosilicates. They show a continuous slaty cleavage ($S_1$) (after the classification proposed by PASSCHIER & TROUW 1996; Fig. 3A). Quartzo–feldspathic–mica rich metasedimentary rocks are characterised by irregular and often curved quartz and feldspar grain boundaries, while mica aggregates dominate the microstructure; i.e., the quartz grains tend to be elongated parallel to the micas. This is indicative for a higher surface energy system (very small degree of stability; PASSCHIER & TROUW 1996). In low-grade slates and schists, undulose extinction is most common (Fig. 3B). It is frequent in pre- and syn-tectonic minerals, especially in quartz.

The main deformation mechanism in quartzo–feldspathic–mica rich metasediments is pressure in the solu-

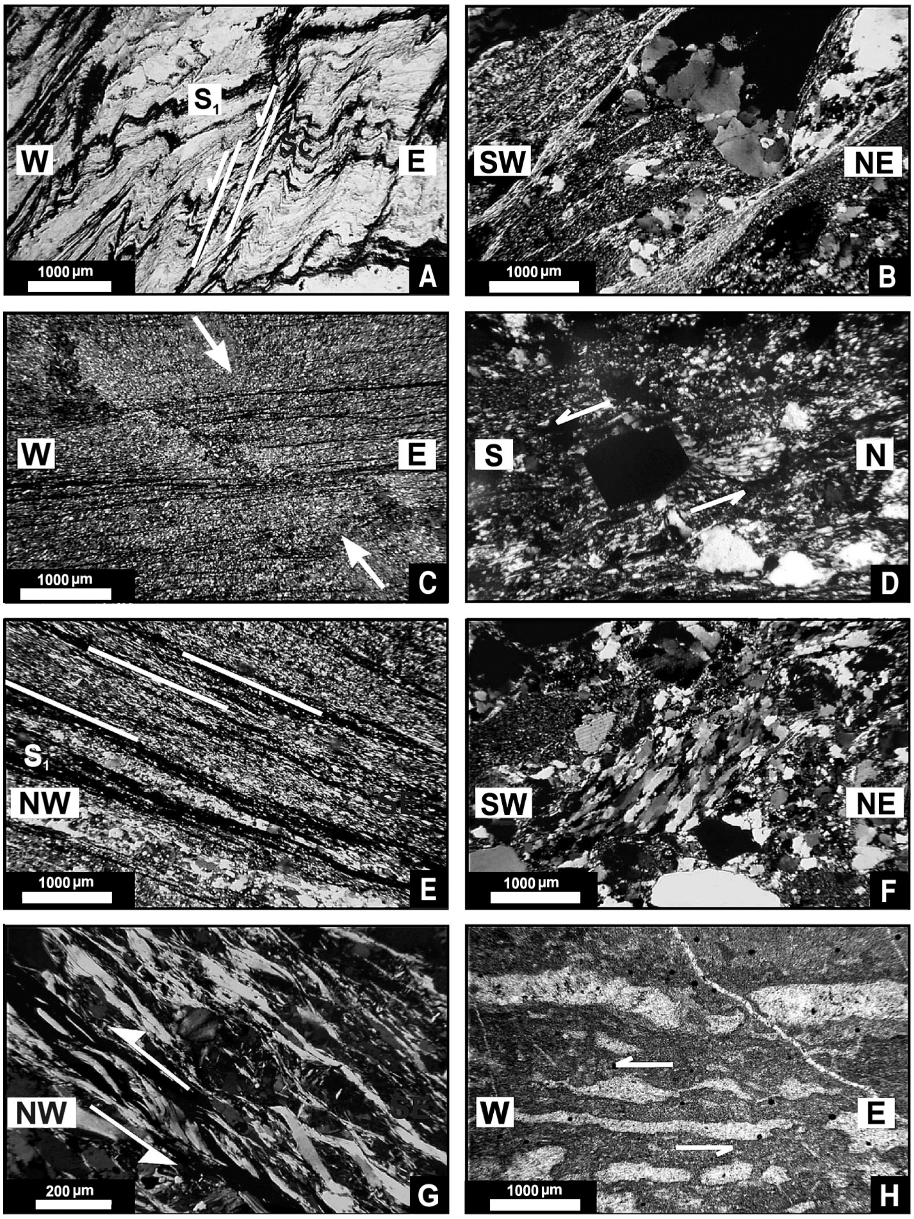


Fig. 3. Microfabrics and shear criteria of the Lim Unit. **A**, Crenulation cleavage developed in phyllonites of the Prijepolje-domain; **B,** Quartzo-feldspathic-mica rich metasandstone; **C,** Apparent slip due to pressure in the solution; **D,** Quartz pressure shadows developed around an euhedral crystals of pyrite in Paleozoic meatasandstone; **E,** Continuous slaty cleavage in metabasites; **F,** Grain-scale faults and undulose extinction of Triassic sandstone; **G,** Mica fishes in Paleozoic siltstones; **H,** Calcite grains recrystallised along the boundary and elongated in the east–west direction in Triassic limestones.

tion (Fig. 3B), localized along the grain boundaries, which are at a high angle to the instantaneous shortening direction. Furthermore, a slip along the contact due to the pressure in the solution can be displayed (Fig. 3C).

Pressure fringes around rigid clasts are another characteristic feature of most quartz-feldspar-mica rich metasedimentary rocks of this area. Pressure shadow developed around pre- and syn-tectonic rigid crystals. These pressure shadows are low strain areas where new minerals preferentially crystallised. They result from strain partitioning around rigid porphyroblast or -clast. In this particular case, quartz pressure shadows developed around euhedral crystals of pyrite (Fig. 3D), show the top-south sense of the shear. According to RAMSAY & HUBER (1983) they represent a pyrite-type of strain shadow.

The pyrite-type of strain fringes involve incremental fibre growth of different mineral species at the interface between porphyroblast or porphyroclast and its pressure shadow. Depending on the mode of growth, fibres of pyrite-type shadows can be sub-divided into two categories: (1) displacement-controlled fibres (Fig. 3D) show consistent geometry of progressive growth of the fibres along the displacement path; and (2) face-controlled type fibres exhibit fibre growth normal to the faces of the rigid object, irrespective of the displacement direction. Depending on the P–T conditions, the fibres may also be deformable or rigid. Pressure shadows asymmetry in the X–Z section (deformable-fibre type). The sense of the shear in this particular case is top-to-the-south (Fig. 3G).

Metabasites are found only in the central part of the Prijepolje subdome. They are generally fine-grained rocks, composed of chlorite, albite and quartz. As with the meta-pelites, they are mostly characterised by the presence of a continuous slaty cleavage and quartz, plagioclase, chlorite and white mica grains elongated in the direction parallel to the stretching lineation (Fig. 3E).

### Microfabrics of Triassic sandstones and carbonates

Triassic sandstones mainly comprise quartz, feldspar, white mica and some lithic components. These sandstones were deformed under very low-grade metamorphic conditions, probably below 300º C (ILIĆ *et al.* 2004) and are less deformed than rocks of the underlying Lim Palaeozoic Unit. The main deformation mechanisms were brittle fracturing and pressure in the solution. The quartz and feldspar grains display irregular grain boundaries, intercrystalline deformation, including grain-scale micro-faults (Fig. 3F) and undulose extinction. Pressure in the solution was localized at the grain boundaries, where stress in the grains was probably high. Compared to similar rocks of the underlying Paleozoic Unit, the deformation style of these sandstones shows that they were deformed under brittle rather than ductile conditions.

Triassic carbonates are represented by recrystallised micrite-type limestones. The large calcite grains (ca. 2 mm) were recrystallised along the boundary and elongated in the east–west direction (Fig. 3H). Deformation by twinning dominates, indicating very low-grade metamorphic conditions (SCHMID *et al.* 1987). Finer grains of the matrix show the same elongation in ca. the east–west direction.

## Discussion and concluding remarks

In both the Lim Unit and Dinaridic Ophiolite nappe, a major deformation event was related to the SSW directed, oblique thrusting along the Dinaridic Ophiolite thrust (DOT) in the Upper Cretaceous times (ILIĆ *et al.* 2006).

This is the time of first ductile deformation phase, $D_1$, formation of flat-lying milonitic foliation $S_1$ and the peak metamorphic conditions in the Lim Palaeozoic Unit (ILIĆ *et al.* 2003). The $L_1$ stretching lineation is marked by elongated quartz grains, preferred orientation of mica flakes and mica-chlorite associations. Consequently, the N–S mineral elongation is seen to be parallel to the direction of the maximum extension due to the major $D_1$ compressional event.

The previous $S_1$ foliation is deformed by E–W compression related structures due to updoming of the Lim Palaeozoic Unit in the second phase of ductile deformations (ILIĆ *et al.* 2006). On the thin-section scale, these structures are represented, by crenulation cleavage within semi-pelitic and pelitic metasediments (Fig. 3A). The metamorphic foliation $S_1$ is folded, sheared and overprinted by close-space crenulation cleavage (Sc). The E–W compressional event was followed by top to the west shearing in the Triassic cover (ILIĆ *et al.* 2006). The structures of this deformation phase are represented by decimetre-scale ductile shear fabrics in Middle Triassic flaser limestones (Fig. 2J).

The third deformation event is probably related to further updoming and it had a brittle-ductile character. In the thin-section, micas deformed by this event are bent without recrystallization in the fold hinges, indicating the brittle-ductile nature of the last deformation event.

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## Резиме

## Микроструктурна анализа елемената склопа Лимске зоне Динарида

Главне фазе деформација у "Лимској зони" и "Динарској офиолитској навлаци" су везане за југ–југозападно траспресионо навлачење "Динарске офиолитске зоне" преко "Лимског Палеозоика" током горње креде. То је уједно и време прве фазе дуктилних деформација везане за стварање првобитне фолијације $S_1$.

Предходна $S_1$ фолијација је деформисана у другој фази дуктилних деформација формирањем набора приближне оријентације север–југ. Набирање првобитне фолијације је праћено формирањем кливажа C и смицањем тријаског покривача у правцу запада.

Трећа фаза деформација је вероватно везана за даље издизање и формирање структурне доме. Она има семи-дуктилни карактер и огледа се у пренабирању мусковита у теменима набора без рекристализације.

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# Paleogene–Early Miocene deformations of Bukulja–Venčac crystalline (Vardar Zone, Serbia)

MILUN MAROVIĆ[1], ILIJA ĐOKOVIĆ[2], MARINKO TOLJIĆ[3], JELENA MILIVOJEVIĆ[4] & DARKO SPAHIĆ[5]

**Abstract.** Low-grade metamorphic rocks of the crystalline of Mts. Bukulja and Venčac, which are integral parts of the Vardar Zone, are of Late Cretaceous age. From the Middle Paleogene to the beginning of the Miocene, they were subjected to three phases of intensive deformations. In the first phase, during the Middle Paleogene, these rocks were subjected to intense shortening (approximately in the E–W direction), regional metamorphism and deformations in the ductile and brittle domains, when first-generation folds with NNE–SSW striking fold hinges were formed. In the second phase, during the Late Oligocene and up to the Early Miocene, extensional unroofing and exhumation of the crystalline occurred, which was followed by intrusion of the granitoid of Bukulja and refolding of the previously formed folds in a simple brachial form of Bukulja and Venčac with an ESE–WNW striking B-axis. The third phase was expressed in the Early lowermost Miocene (before the Ottnanghian), under conditions of NE–SW compression and NW–SE tension. It was characterized by wrench-tectonic activity, particularly by dextral movements along NNW–SSE striking faults.

**Key words:** Serbia, Vardar Zone, Bukulja–Venčac crystalline, structural analysis, tectonics, metamorphic core-complex.

**Апстракт**. Ниско метаморфне стене кристалина Букуље и Венчаца, које су саставни део Вардарске зоне Србије, су горњокредне старости. Оне су од средине палеогена до почетка миоцена биле захваћене интензивним деформацијама током три фазе обликовања. У првој фази, током средњег палеогена, биле су изложене јаком сужењу (приближно правцем И–З), регионалном метаморфизму и деформацијама у дуктилном и brittle домену, када су формирани набори прве генерације са Б-осама пружања ССИ–ЈЈЗ. У другој фази, током горњег олигоцена, до у доњи миоцен дошло је до екстензионог откривања и ексхумације кристалина, што је било праћено утискивањем гранитоида Букуље и пренабирањем претходно формираних набора у једноставну брахиформу Букуље и Венчаца са Б-осом пружања ИЈИ–ЗСЗ. Трећу фазу, која се испољила у раном доњем миоцену (пре отнанга) у условима СИ–ЈЗ компресије и СЗ–ЈИ, тензије карактерише wrench-тектонска активност, посебно декстрална кретања дуж раседа пружања ССЗ–ЈЈИ.

**Кључне речи:** Србија, Вардарска зона, букуљско-венчачки кристалин, структурна анализа, тектоника, метаморфни core-complex.

[1] Faculty of Mining and Geology, Department of Geology, Belgrade University, Kamenička 6, 11000 Belgrade, Serbia. E-mail: marovic.milun@gmail.com

[2] Faculty of Mining and Geology, Department of Geology, Belgrade University, Đušina 7, 11000 Belgrade, Serbia. E-mail: ilija@rgf.bg.ac.yu

[3] Faculty of Mining and Geology, Department of Geology, Belgrade University, Đušina 7, 11000 Belgrade, Serbia. E-mail: tom2@rgf.bg.ac.yu

[4] Geological Institute of Serbia, Rovinjska 12, 11000 Belgrade, Serbia. E-mail: darkogeo2002@hotmail.com

[5] Faculty of Mining and Geology, Department of Paleontology, Belgrade University, Kamenička 6, 11000 Belgrade, Serbia. E-mail: jelena67@eunet.yu

## Introduction

Crystalline of Bukulja and Venčac, with its non-metamorphosed Mesozoic–Cenozoic cover and Oligocene–Miocene granitoid, spatially belongs to the Vardar Zone (Fig. 1). These are terrains with complex geological compositions which have been discussed many times, often with controversial explanations.

There are dilemmas about the age of the crystalline in the first place, which directly influenced different explanations of the tectonics of these terrains. The crystalline has most often been considered to be of Paleozoic age (SIMIĆ 1938; FILIPOVIĆ 1973; FILIPOVIĆ & RODIN 1980; ĐOKOVIĆ *et al* 1995; TRIVIĆ 1998). Such an opinion is mostly based on the fact that these are rocks of different metamorphic grade, while there are no reliable paleontological proofs or even paleontological proofs of any kind. However, according to findings of globotruncana and other fauna and on the base of palynologic data from low-metamorphic rocks of Venčac, BRKOVIĆ *et al*. (1980) and MAROVIĆ *et al*. (2005), respectively, concluded that the Bukulja–Venčac crystalline is of Late Cretaceous age.

According to its age, folding of the area has also been explained in different ways. ĐOKOVIĆ & MAROVIĆ (1985, 1986) separated three generations of folds in these terrains. These authors related the first fold generation to Hercynian deformation, which is marked by NE–SW striking fold axes. In the second phase, during older Alpine tectogenetic events, the Hercynian fold structures were refolded into E–W striking folds. The third generation of folds is the consequence of a pluton intrusion and further refolding of all the existing folds into large domes and brachial synclines.

TRIVIĆ (1998) separated three (? four) generations of folds. According to this author, axes of the oldest, Hercynian structures are oriented in the WNW–ESE direction. These structures were refolded into folds with NNW–SSE striking axes during the first phase of Alpine deformation in the Mesozoic. Later, during the later Alpine phases, the geometry of such folds became more complex due to a pluton intrusion and strike-slip movements along E–W striking faults.

MAROVIĆ *et al*. (2005) considered the metamorphic rocks of Bukulja and Venčac to be of Late Cretaceous age and the authors are of the opinion that there are only Alpine and no Hercynian folds in these rocks.

The relationship between the crystalline and the non-metamorphosed Cretaceous (prevailingly Late Cretaceous) deposits, including tectonically incorporated slices of serpentinite, is unclear and has been explained in different ways. Sedimentary deposits are widespread on the surface, mostly north, east and southeast of the Bukulja–Venčac crystalline, and they were also drilled out under Neogene deposits of the Aranđelovac and Belanovica Basin. There are also isolated and disconnected portions of Cretaceous sediments on the southern rim of the crystalline. All this points to the possibility that the crystalline was completely covered by Cretaceous sediments. The majority of authors is of the opinion that the Cretaceous sediments transgressively overlie the crystalline. According to TRIVIĆ (1998), metamorphic rocks were thrust over Cretaceous sediments in certain parts of the terrain in the South. BRKOVIĆ *et al*. (1980) and ĐOKOVIĆ & MAROVIĆ (1986) mentioned sections where metamorphic rocks gradually transit into non-metamorphosed Upper Cretaceous deposits.

Finally, in accordance with different interpretations of the geologic composition, the geotectonic position of the Bukulja–Venčac crystalline unit is also controversial. Its metamorphic content resembles the Drina–Ivanjica crystalline (ĐOKOVIĆ *et al*. 1995). The Bukulja–Venčac crystalline is located on the eastward extension of the Jadar Block, which is made of Paleozoic rocks. This fact led FILIPOVIĆ (1995), FILIPOVIĆ & JOVANOVIĆ (1998) and FILIPOVIĆ (2005) to include at least a part of it (western part of Bukulja) into the Jadar entity. There is also the opinion that Bukulja–Venčac crystalline is completely different from the metamorphic rocks of both the Drina–Ivanjica and Jadar developments and that it is made of metamorphosed Cretaceous deposits belonging to the Vardar Zone (BRKOVIĆ *et al*. 1980; MAROVIĆ *et al*. 2005).

The above-cited problems concerning the geologic composition of the Bukulja–Venčac crystalline are a challenge for further investigations directed toward new and better documented solutions. The results of one of these studies, which represent a contribution to a better understanding of the Paleogene–Early Miocene tectonics of these regions, are presented in this paper.

## Short Review of The Lithostratigraphic Characteristics of the Terrain

A wider area of the Bukulja–Venčac crystalline is made of rocks of different composition and age (Fig. 1). Four large lithostratigraphic domains can be distinguished: (1) Bukulja–Venčac crystalline, (2) serpentinite, Cretaceous clastics, carbonates and flysch, (3) Paleogene–Neogene granitoid and volcanic rocks and (4) Neogene–Quaternary sediments.

(1) The Bukulja–Venčac crystalline is made of rocks of different degrees of metamorphism, mostly low-grade metamorphics and, to a smaller extent, medium-to-high-grade metamorphics. These are mostly sedimentary rocks which were subjected to regional metamorphism and also to contact metamorphism in the vicinity of the granitoid. The lowest structural position is occupied by gneisses (and also leptynolites in places), which are followed by: micaschists, sericite schists, meta-quartz conglomerates, phyllites and sericite schists, marbles, calcschists, metacalcarenites and metasiltstones. Also epidote-actinolite- and chlorite schists occur subordinately in the low-grade metamorphic complex. Rocks with a higher grade of metamorphism are found in the vicin-

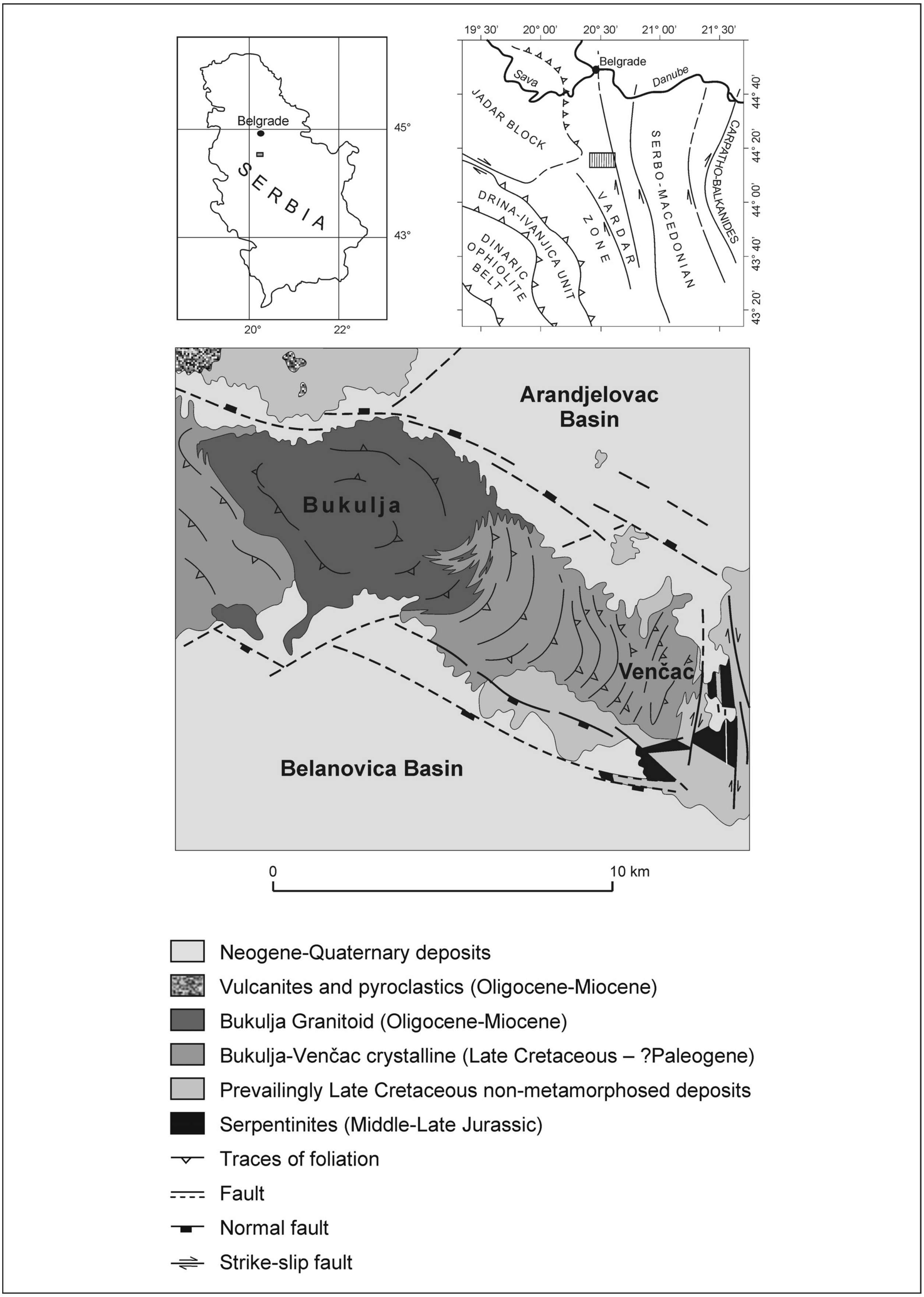


Fig. 1. Geologic sketch of the wider area of Bukulja and Venčac.

ity of the granitoid, while going away from it – towards the Venčac, low-grade metamorphics predominate. The Bukulja–Venčac crystalline is of Late Cretaceous or maybe partly even of Paleogene age. The second author (I.Đ.) is of the opinion that Venčac domain of the crystalline is of Late Cretaceous age, while the rest of it is Paleozoic and resembles the Drina–Ivanjica Paleozoic. During these investigations, rich microfloral association, which indicates Late Cretaceous age, was found in the calcschists and metacalcarenites of Venčac. This is in full agreement with the results on the crystalline age based on globotruncanas (BRKOVIĆ *et al.* 1980). However, this age most probably does not refer to the whole crystalline. Based on a lithostratigraphic correlation, FILIPOVIĆ (2005) is of the opinion that the metamorphic rocks west of Bukulja are similar to the Jadar Paleozoic, thus that they are Devonian and Carboniferous in age.

(2) Cretaceous sequence of non-metamorphosed deposits and serpentinite are exposed on the northern, eastern and southern slopes of the Bukulja–Venčac morphostructure. The Cretaceous sediments are represented by reefal and stratified limestones, rarely also by Early Cretaceous clastites and, for the largest part, by various types of carbonates, clastites and Late Cretaceous flysch (BRKOVIĆ *et al.* 1980). Smaller tectonic slices of serpentinite of Jurassic age occur locally near the Cretaceous sediments.

(3) Oligocene–Early Miocene granitoid was intruded into the Bukulja crystalline (KARAMATA *et al.* 1994; KNEŽEVIĆ *et al.* 1994). It induced also contact metamorphism of the surrounding rocks. The granite intrusion was followed by volcanic rocks, prevailingly phenoandesites, latites and their pyroclastics.

(4) A Neogene–Quaternary cover is represented by loosely bound coarse-grained, gravely-sandy, clayey-sandy and clayey deposits. These are mostly fresh-water equivalents of the Ottnangian–Karpatian and, to a lesser extent, also marine deposits of the Badenian and Sarmatian. The highest stratigraphic level is represented by different types of Quaternary deposits.

## Tectonic Setting

### Methodology of research

Geologic mapping of the Bukulja–Venčac crystalline (including the granitoid) and its non-metamorphosed cover of Late Cretaceous age provided information relevant for solving the tectonic setting of the area. These were data on bedding, foliation, folds of different scale and faults. They were analyzed within different scale ranges and homogeneous domains and the obtained data were incorporated in a tectonic synthesis, together with knowledge on the lithostratigraphic units.

Particular attention was paid to the determination of the orientation of fault planes and associated slip direction, which was used for the reconstruction of paleostress and deformation phases manifested from the middle Paleogene to the beginning of the Miocene.

Reconstruction of faulting succession and displacement was based on the criteria given by PETIT (1987) and GAMOND (1983, 1987). Reduced deviatoric paleostress tensors were computed for a cogenetic fault population which was separated from polyphase sets, based on field observations and kinematic compatibility. The method of numerical and graphical inversion proposed by ANGELIER & MECHLER (1977), ANGELIER (1979, 1989) and method of numerical dynamic analysis (NDA) by SPERNER *et al.* (1993) were used. Computation of the data for paleostress analysis was performed using Tectonic FP software (ORTNER *et al.* 2002).

### Structural features

In a structural sense, three large homogeneous domains can be distinguished within the research area: (1) Bukulja–Venčac crystalline, (2) the thrust-fold sequence of non-metamorphosed Cretaceous deposits with tectonically incorporated slices of serpentinite and (3) Neogene basins. The first two structural domains are discussed in this paper, because they resulted from Paleogene–Early Miocene deformations, which were the subject of the research.

The structural setting of the Bukulja–Venčac crystalline is very complex with a polyphase-deformation history and at least two phases of folding. The area is dominated by a large (Dkm) brachial-antiform structure, the hinge of which plunges toward ESE. The best-developed fabric element is foliation, which actually makes this antiform (Fig. 2A). Foliation is unevenly developed: it is best-developed in gneisses and micaschists, less present in phyllites, sericite schists and calcschists, while it is poorly developed in metacalcarenite, metasiltstone and "massive" marble.

The foliation is probably the result of flattening perpendicular to the foliation planes. Isoclinal intrafolial folds of cm and dm scale are indicators of shearing along foliation. They are particularly well-visible in the metacalcarenites of Venčac, and locally, also in quartz-sericite schists (Fig. 3). The Folds are mostly rootless and represent thickened hinge zones, while their limbs are strongly flattened and sheared. These folds are west–northwest-vergent with fold axes plunging toward NNE and SSW (Fig. 2B). Crenulations of foliation are noticed locally. The crenulation axes plunge toward south–southeast to, southeast and northwest and they are genetically related to the formation of the brachial antiform (Fig. 2C). Foliation and intrafolial rootless folds could have been formed in an almost horizontal position. All this indicates refolding in the Bukulja––Venčac crystalline.

Foliation is developed in the granitoid as well. It has a periclinal distribution (Fig. 2D) compatible with foli-

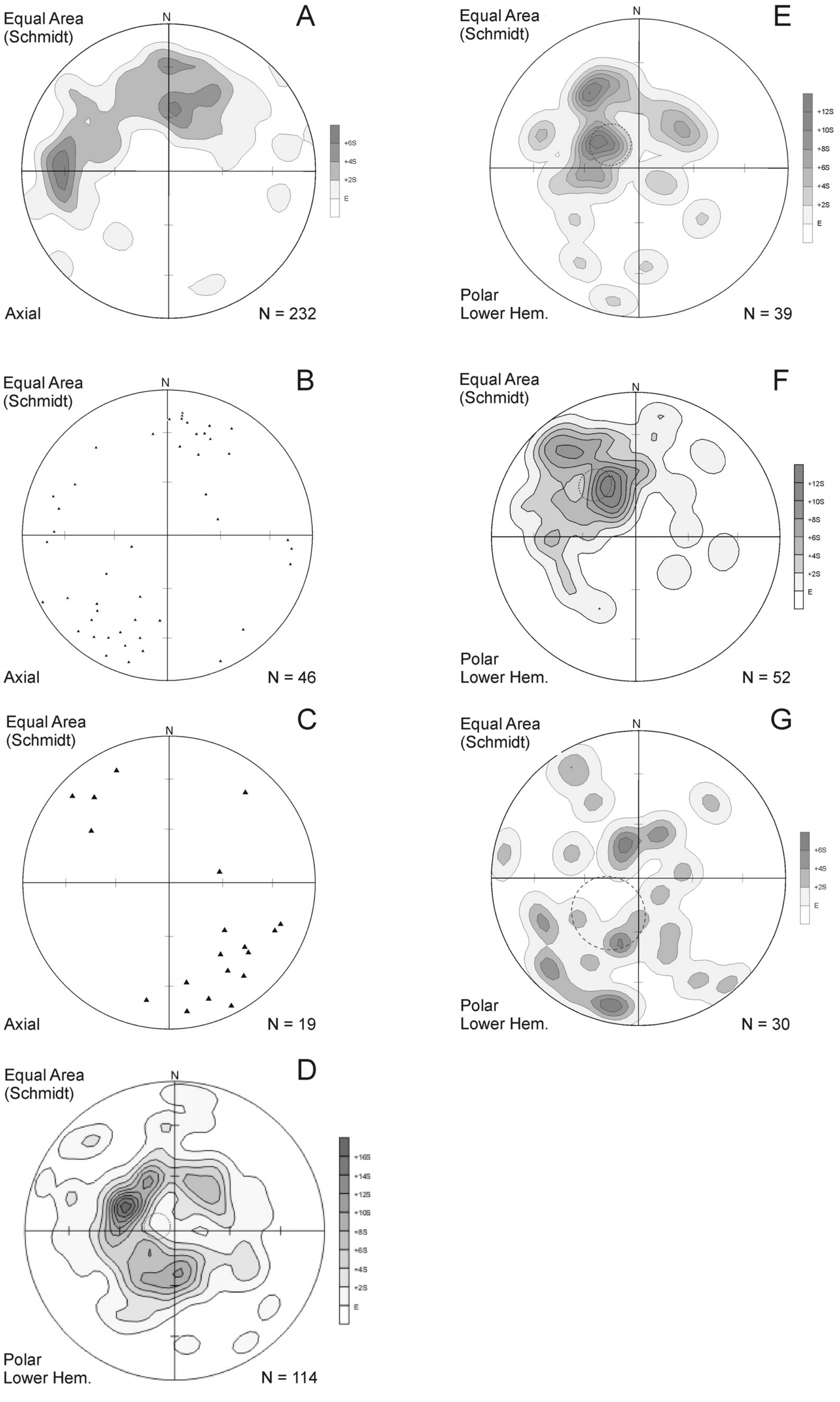


Fig. 2. Equal – area Lower hemisphere stereograms of: **A,** foliations in the crystalline; **B,** B-axis intrafolial folds; **C,** crenulation lineation; **D,** foliations in the granitoid; **E,** bedding in Cretaceous deposits north of Bukulja; **F,** bedding in Cretaceous deposits northwest of Venčac; **G,** bedding in Cretaceous deposits south of Venčac. Spheristat software was used for the analysis.


Fig. 3. Isoclinal folds in metacalcarenites of Venčac (Venčac quarry).

ation in the Bukulja–Venčac crystalline, which indicates their genetic relationship.

The thrust-fold stack of non-metamorphosed Cretaceous sediments with tectonically incorporated slices of serpentinite also have a very complex structure as well. Today, this unit is preserved within several small, more or less homogeneous structural regions on the northern, eastern and southern rims of the Bukulja–Venčac antiform. The structure is dominated by bedding and faults. The Bedding planes are well-exposed and penetrative.

Terrains on the northern slopes of Mt. Venčac are composed of non-metamorphosed deposits of Cretaceous age. Despite the fact that a large part of the area is covered with deluvium, a lot of information was acquired for fault analyses.

On the diagram F (Fig. 2), poles to bedding are mostly concentrated in the NW quadrant, marking a monoclinal dip toward southeast. However, field investigations showed that the folds in this area are not simple but that it is a folded unit with normal and overturned limbs of NNW (NW) vergent folds, similar to the folds of the first generation in the underlying Bukulja–Venčac crystalline, only less developed with less strain. Cretaceous deposits north of Bukulja are identically deformed (Fig. 2E).

East of Venčac, there is an intensely tectonized zone in the Cretaceous deposits and serpentinite. Unfortunately, this area is mostly covered, with no outcrops of Cretaceous deposits, thus a comprehensive measuremant the of bedding attitude could not be performed. According to the data from the wider surroundings (BRKOVIĆ *et al*. 1980), the area is characterized by a thrust-fold pattern marked by West-vergent recumbent folds and reverse faults, developed under dextral transpressio.

Terrains made of non-metamorphosed Cretaceous deposits on the southern and southwestern slopes of Venčac are mostly covered with deluvium and are unfavorable for structural investigations. The scattering of the bedding data, presented on diagram G (Fig. 2) is probably a consequence of the rotation of faulted blocks, but also of the small number of measurements which are statistically not representative. Field observations showed that the Cretaceous deposits here are also intensely folded, with the occurrence of overturned west–northwest-vergent folds.

## Results of paleostress analysis

Paleostress analysis in the area of the Bukulja–Venčac crystalline, non-metamorphosed Cretaceous deposits and the granitoid show three kinematic stages, the first probably being of Middle Paleogene, the second of Oligocene to Oligocene–Miocene and the third of Early Miocene (Pre-Ottnangian to Karpatian) age. The relative chronology of these events is deduced from cross-cutting map-scale faults in key outcrops.

### *Deformational event ($D_1$) – E–W compression*

This paleostress tensor group comprises a conjugated pair of NW-trending sinistral and NE-trending dextral strike-slip faults (Fig. 4). These faults are overprinted by mainly extensional structures on numerous outcrops.

Folds of the first generation with a NNE (NE)–SSW (SW) striking axes probably originated in such a stress field. Today, they are exposed as intrafolial folds in the Bukulja–Venčac crystalline, as well as in WNW (NW) vergent folds in non-metamorphosed Cretaceous deposits.

### *Deformational event ($D_2$) – N–S-to-NE–SW extension*

The second paleostress tensor group comprises WNW to NW and NE-trending normal faults (Fig. 5). These faults are probably related to an Oligocene unroofing of the Bukulja–Venčac crystalline and the granitoid intrusion. In this case, WNW to NW trending normal faults often form conjugate sets: synthetic, gently sloping northwards and antithetic, with steeper dips toward the south. They were formed above the brittle-ductile detachment zone along which the extensional unroofing occurred.

### *Deformational event ($D_3$) – wrench tectonic regime, NE–SW compression and NW–SE tension*

The third paleostress tensor group comprises NNW to NW trending dextral and WNW trending sinistral strike-slip faults (Fig. 6). Fault systems with these kinematic characteristics, which originated in the stress field with NE–SW compression and NW–SE tension, can be

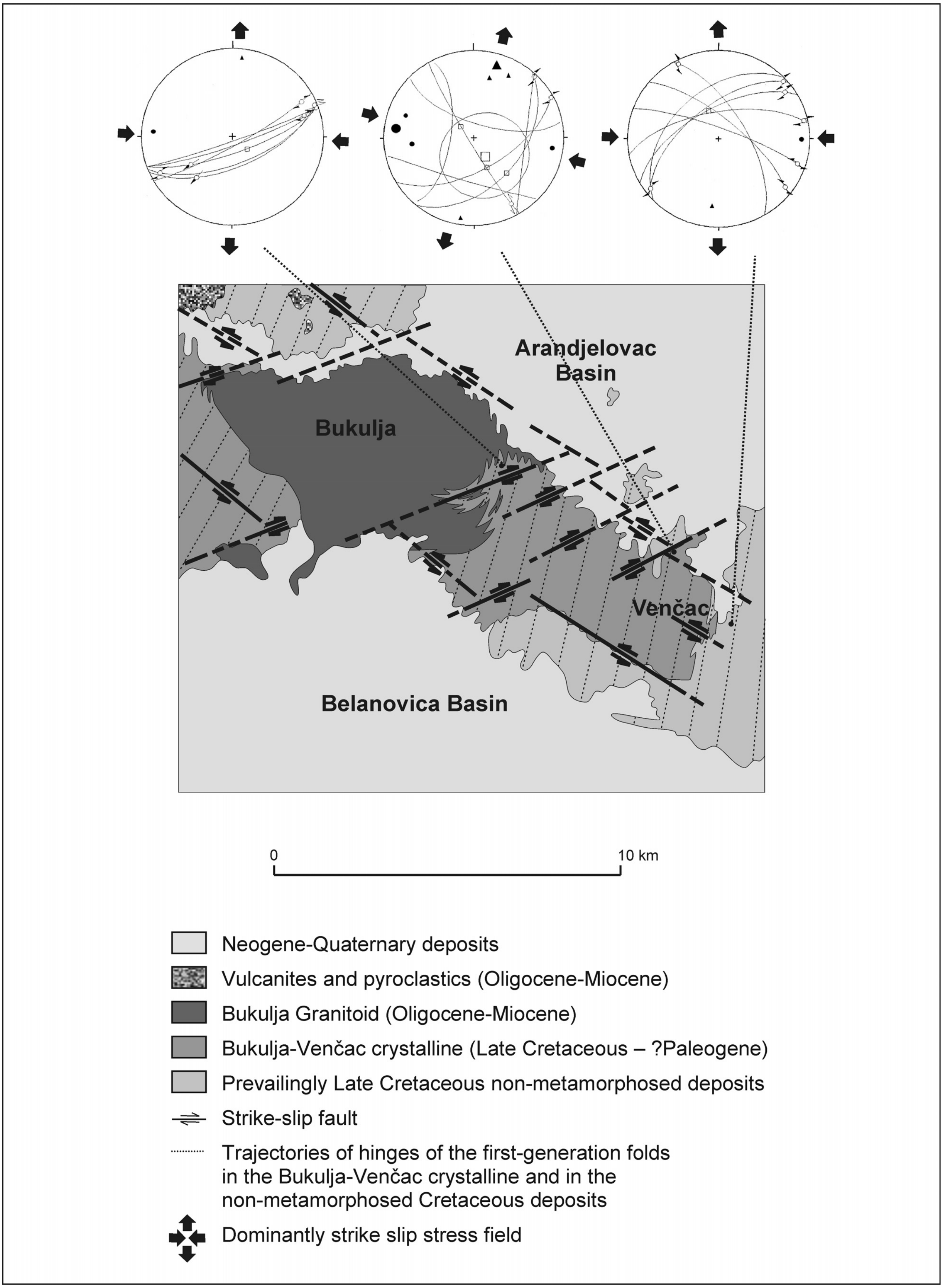


Fig. 4. Distribution of stress states related to a E–W compressional event. Stereographic projection of the measured outcrop – scale faults and calculated stress axes. The circle, rectangle and triangle represent the orientation of the maximum, intermediate and minimum principal stress axes, respectively.

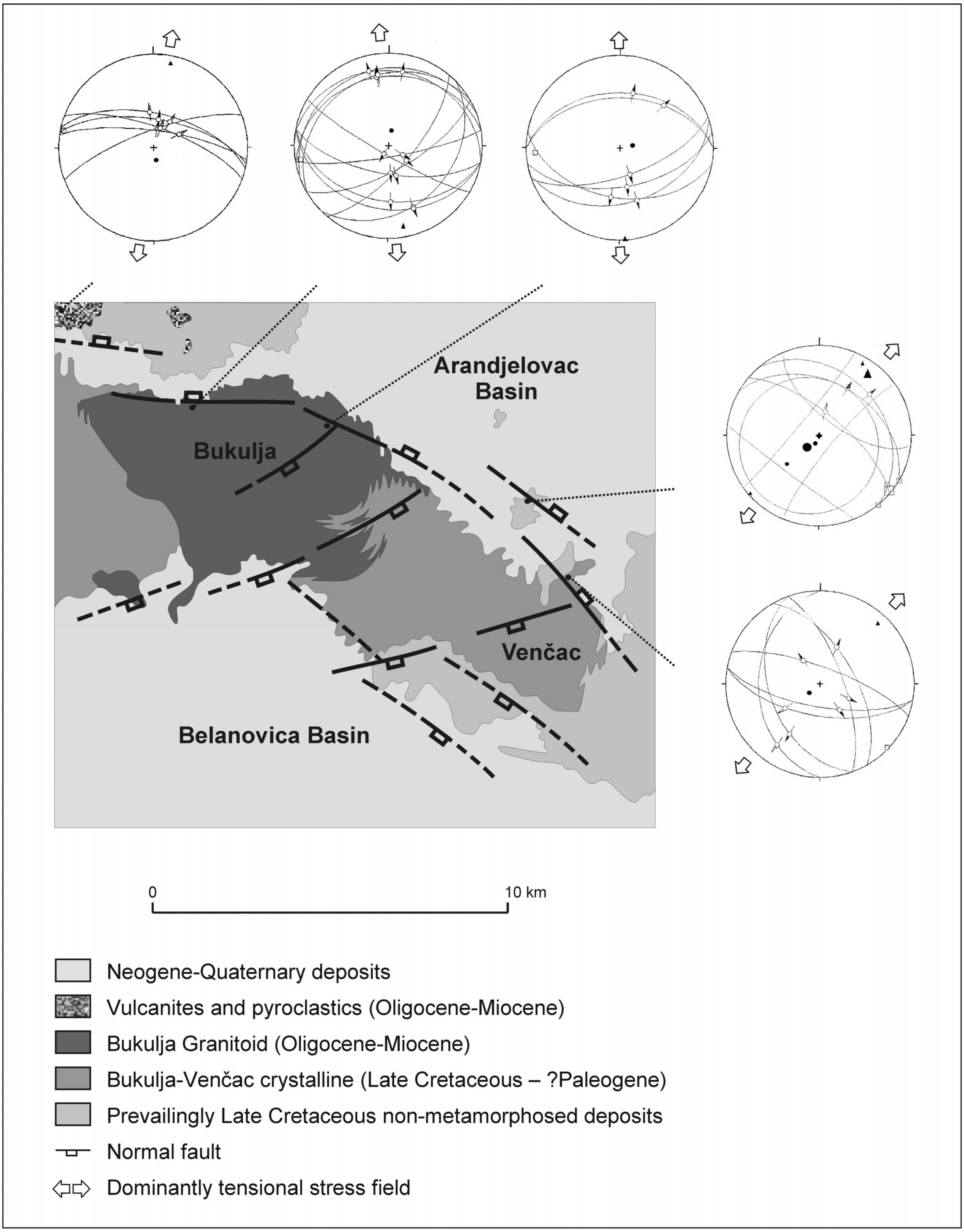


Fig. 5. Distribution of stress states related to an extensional event with N–S to NE–SW trending $\sigma_3$. Explanation the same as for Fig. 4.

related to dextral wrenching. In this case, NNW to NW trending faults could belong to the principal displacement zone (PDZ) with dextral characteristics (Y-faults), while WNW-trending sinistral strike-slip faults could represent X-faults. Such a stress field was generated at the beginning of the Miocene ("Sava phase").

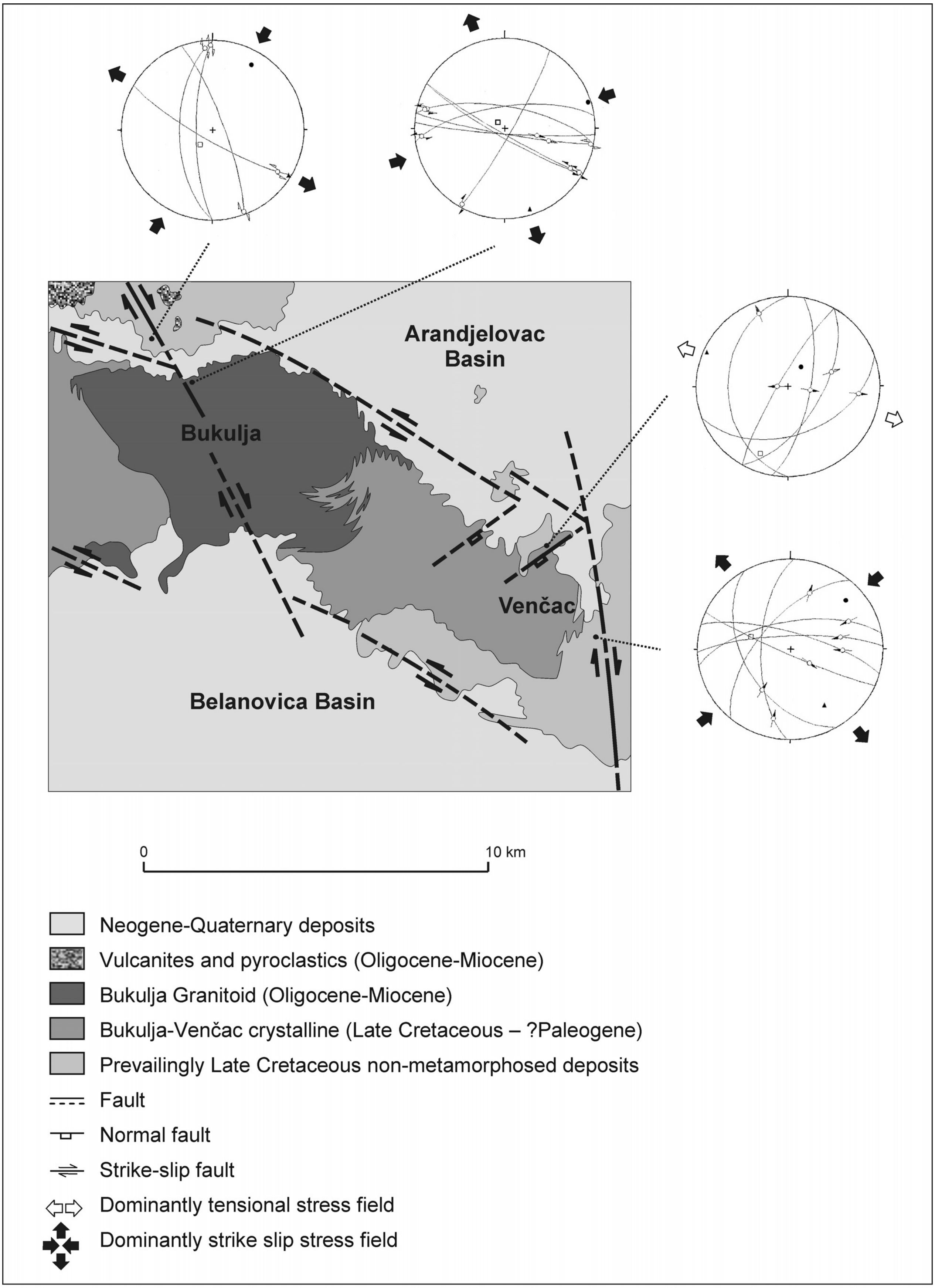


Fig. 6. Distribution of stress states related to a dextral strike-slip regime with $\sigma_1$, trending NE–SW. Explanation the same as for Figs. 4. and 5.

## Discussion and Conclusions

Investigations in the area of the Bukulja–Venčac crystalline showed the following:

• The Bukulja–Venčac crystalline is of Late Cretaceous age, maybe even partly Early Paleogene. It was intruded by an Early Miocene granitoid.

• The crystalline is overlain mostly by Late Cretaceous non-metamorphosed clastic-carbonate rocks and flysch.

• Metamorphic grade in the crystalline decreases from the granitoid to the periphery and toward the upper structural levels, where there is a gradual transition into non-metamorphosed members of the Late Cretaceous.

• There is a similar manner of folding (fold shape, vergences) in both sequences of Cretaceous deposits: the metamorphosed and the non-metamorphosed ones, but deformations in the crystalline is more intense and occurred in the ductile domain. Two phases of folding are noticed.

• Reconstruction of paleostress fields points to three major phases of brittle formation : in the middle of the Paleogene, in the Oligocene–Early Miocene and in the Early Miocene.

The above presented facts point to a unique tectonic-sedimentary environment in this area during the Late Cretaceous (maybe also in the ?Early Paleogene), which was inverted in the middle of the Paleogene. Such an environment is consistent with the model elaborated by PAMIĆ (1993), PAMIĆ *et al.* (2000, 2002), according to which the northern part of the Vardar Zone (Vardar––Sava) is the result of obliteration in the Upper Cretaceous–Paleogene active continental margin of Southern Europe, with well-defined island arc and back-arc basins. This sedimentation area was inverted and included into the Dinaridic orogene by collisional processes in the Eocene. According to PAMIĆ *et al.* (2000, 2002), this phase was followed by intense deformation of the Jurassic ophiolitic mélange, metamorphism and magmatism.

The Bukulja–Venčac sedimentation and deformation area (Fig. 7) was probably generated in a similar tectonic setting. In the middle of the Paleogene, the Bukulja–Venčac area was subjected to shortening in the approximate E–W direction, when a thick WNW vergent thrust-fold sequence was formed. The second author (I.Đ.) is of the opinion that these structures were formed only in the Venčac domain of the crystalline, while, in its other parts, the Hercynian structures were refolded by a Mesozoic–Cenozoic tectonic event. The lower parts of the sequence reached the zone of ductile deformations and underwent regional low- to medium-grade metamorphism. The whole process was followed by the formation of tight and isoclinal folds with hinges striking NNE (NE)–SSW (SW) with strong axial plane cleavage, and subsequent transposition of bedding along the cleavage, the formation of foliation. Remnants of these folds are preserved today as intrafolial folds.

In the brittle-ductile and brittle domain, above the metamorphites, this phase of tectogenesis resulted in the formation of distinctly WNW (NW) vergent overturned, sometimes also recumbent, folds with axes striking NNE (NE)–SSW (SW) and the formation of conjugated NW trending sinistral and NE trending dextral strike slip faults.

Extension, probably ductile, followed by intrusion of granitoid, volcanism and exhumation of the Late Cretaceous metamorphics (metamorphic core complex) is characteristic for the second phase, which that was expressed in the Late Oligocene and up into the Early Miocene.

The process of exhumation metamorphism and emplacement of the granitoid was marked by refolding of the foliation and the previously formed folds, when the distinct brachial-antiform of the Mts. Bukulja and Venčac (with an ESE plunging axis) was formed. There are certain indications that a shallow synform), rim synform, which is presently mostly burried with Neogene–Quaternary deposits, was formed northeast of the antiform.

Unfortunately, the detachment zone along which the ductile extension occurred has not been defined, which certainly does not mean that it does not exist. Further detailed investigations are necessary for its determination.

In the brittle domain in the area of extensional allochthon, WNW to NW and NE trending normal faults were activated, often as pairs of synthetic and antithetic sets.

After the exhumation of the metamorphic core complex of Bukulja and Venčac, tectonic shortening affected the area. It is expressed through dextral transpression with NE–SW compression and NW–SE tension. Activation of the NNW–NW trending dextral and WNW trending sinistral strike-slip faults is characteristic for this phase. In the domain of the first system, small NE-trending normal faults (probably "pinnate" faults) were activated. Under transpressional conditions, west-vergent folds and thrusts were formed, particularly on the eastern periphery of Venčac. This transpressional event affected the Vardar Zone, the Serbian–Macedonian Unit and the Carpatho-Balkanides, all the way to the Moesian Plate (wrench corridor, MAROVIĆ *et al.* 2001).

The process of destruction of the previously formed structures, related to the shaping of the Pannonian Basin and its periphery, commenced after the transpressional events, already from the Ottnangian.

The performed investigations stress the problem which demands more detailed research and application of new methods in order to obtain more reliable and precise solutions. This refers, in the first place, to the necessity of performing detailed structural investigations and registering kinematic indicators of extensional processes and stress fields in general. Particular attention should also, be paid to an explanation of the

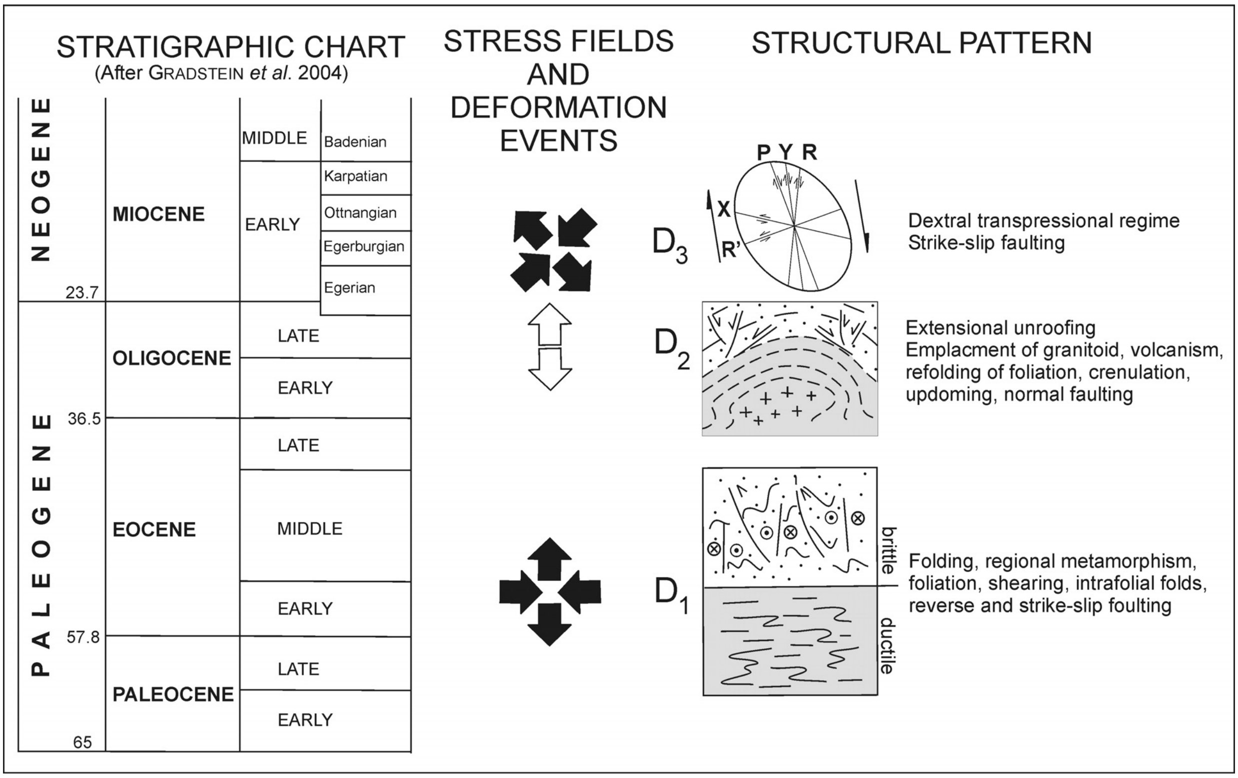


Fig. 7. Scheme of the Paleogene–Early Miocene tectonic evolution of the Bukulja–Venčac domain.

manner of extensional unroofing, transpressional tectonics and related phenomena.

In order to date the tectonic events, it will be necessary to apply methods of thermogeochronology, e.g., Ar/Ar on mica and fission-track analyses.

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## Резиме


### Палеогено-доњомиоценске деформације Букуљско-венчачког кристалина (Вардарска зона, Србија)

Нискометаморфни кристалин Букуље и Венчаца са својим неметаморфисаним мезозојско-кенозојским покровом је део Вардарске зоне. Сложене је геолошке грађе, посебно тектонског склопа, који је резултат вишефазног обликовања. Предмет овог рада су палеогено-доњомиоценске деформације које су најодговорније за формирање најмаркантнијих структура у овом региону.

О геолошкој грађи букуљско-венчачког кристалина постоје бројне контроверзе, почев од његове старости, наборног склопа, односа према неметаморфисаним кредним творевинама, све до геотектонске припадности.

Ова истраживања су показала, односно потврдила, да је кристалин горњокредне (можда делом и палеогене? ) старости. Сагласно томе не поседује херцинске наборе, већ само алпске, који су резултат палеогено-доњомиоценских обликовања. Утврђене су три главне фазе формирања палеогено-доњомиоценског склопа.

У првој фази, средином палеогена, у напонском пољу И–З компресија, стене букуљско-венчачког подручја биле су изложене јаком сажимању, регионалном метаморфизму и деформацијама у дуктилном и brittle домену (формирани су изразито ЗСЗ-вергентни набори који су у дуктилном домену претпели још и транспозицију, формирање фолијације и shearing).

У другој фази, током горњег олигоцена до у доњи миоцен обављено је екстензионо раскровљавање и ексхумација кристалина, што је било праћено утискивањем гранитоида и пренабирањем претходно формираног наборног склопа у једноставну брахи-антиформу Букуље и Венчаца.

За последњу фазу испољену у доњем миоцену (пре отнанга), у условима СИ–ЈЗ компресије и СЗ–ЈИ тензије, карактеристична је wrench-тектонска активност.

Током све три тектонске фазе, активирани су раседи који су имали кинематска обележја сагласно напонском пољу у коме су формирани.

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# Extensional Unroofing of the Veliki Jastrebac Dome (Serbia)

Milun Marović[1], Ilija Đoković[2], Marinko Toljić[3],
Darko Spahić[4] & Jelena Milivojević[5]

**Abstract.** This paper presents the basic structural elements of the dome of Veliki Jastrebac, as well as the chronology and mechanisms of the deformational events responsible for its formation. It was determined that the dome of Veliki Jastrebac consists of two large sequences which are, in the vertical section, in the inverse position. The lower part is made of Late Cretaceous and Cretaceous–Palaeogene low-grade to medium-grade metamorphic rocks, which are intruded by Paleogene granitoid (probably the Vardar Zone), which are covered with a large overthrust consisting metamorphics of the Serbian-Macedonian Mass. The low-grade to medium-grade metamorphosed complex of Veliki Jastrebac, with the granitoid, represents a metamorphic core complex, exhumed by mechanisms of extensional tectonics in the Paleogene.

**Key words:** Serbia, Veliki Jastrebac, tectonics, syntectonic intrusion, extension, unroofing.

**Апстракт**. У раду су приказани основни елементи грађе Великојастребачке доме и хронологија и механизми деформационих догађаја одговорних за њено формирање. Утврђено је да дому изграђују два крупна навлачно-наборна ентитета која су, у вертикалној сукцесији, у инверсном положају. Доле леже горњо-кредне и кредно-палеогене ниско до средњометаморфисане стене у које је утиснут палеогени гранитоид (вероватно Вардарска зона), горе је као крупна навлака, кристалин Српско-македонске масе. Ниско до средње метаморфисан комплекс Великог Јастрепца са гранитоидом представља метаморфни core complex, ексхумиран механизмима екстензионе тектонике у палеогену.

**Кључне речи**: Србија, Велики Јастребац, тектоника, синтектонска интрузија, екстензија, раскров-љавање.

## -Introduction

The geological setting of Veliki Jastrebac and its immediate surroundings, particularly its tectonic setting, is very interesting and insufficiently defined. According to all previous concepts, this area was considered to be a part of the Serbian–Macedonian Mass. In the spatial sense, this is apparently correct. However, according to geological characteristics of the terrain of Veliki Jastrebac, this opinion should be revised. Namely, there are deposits in the area of Veliki Jastrebac which are, regarding their lithology and structural-tectonic characteristics, exotic in the Serbian–Macedonian Mass. Grubić (1999) was the first to suggest that the Serbian–Macedonian Mass is not a homogenous structure but is composed of several thrust-fold stacks with units in inverted stratigraphic positions (double window). The uppermost level of this pile is made of high-grade metamorphics, while the lower parts are made of Paleozoic, Mesozoic and Mesozoic–Palaeogene rocks, and medium to low-grade

[1] Faculty of Mining and Geology, Department of Geology, Belgrade University, Kamenička 6, 11000 Belgrade, Serbia. E-mail: marovic.milun@gmail.com

[2] Faculty of Mining and Geology, Department of Geology, Belgrade University, Đušina 7, 11000 Belgrade, Serbia. E-mail: ilija@rgf.bg.ac.yu

[3] Faculty of Mining and Geology, Department of Geology, Belgrade University, Đušina 7, 11000 Belgrade, Serbia. E-mail: tom2@rgf.bg.ac.yu

[4] Geological Institute of Serbia, Rovinjska 12, 11000 Belgrade, Serbia. E-mail: darkogeo2002@hotmail.com

[5] Faculty of Mining and Geology, Department of Paleontology, Belgrade University, Kamenička 6, 11000 Belgrade, Serbia. E-mail: jelena67@eunet.yu

metamorphics. The geological setting of the area of Veliki Jastrebac has hitherto been explained: the Serbian–Macedonian Mass (gneiss and low-grade metamorphics) in the lower part and discordant Upper Cretaceous–Paleogene low-grade metamorphics with intruded Palaeogene granitoid of Jastrebac in the upper part (RAKIĆ *et al.* 1974, 1976; KRSTIĆ *et al.* 1978, 1980).

The model of the geological relations in the area of Veliki Jastrebac introduced by GRUBIĆ (1999), GRUBIĆ *et al.* (1999, 2005), has opened new problems related to the geology of the area:

a) more detailed division of the low-grade metamorphic formations;

b) reconstruction of the exhumation of the mechanism of the Veliki Jastrebac Dome (by surface erosion or by tectonic denudation?).

This paper is focused on solving these problems. For this purpose, a number of new data on the lithology, age and fabric of this terrain were collected. Preliminary results were obtained by these investigations, but detailed structural analysis and application of geochronology and thermochronology, the fission track method in the first place, are necessary for more reliable conclusions. Despite this, it is still possible to assume, on the basis of the obtained results, that the Veliki Jastrebac Dome was unroofed by tectonic denudation during the Palaeogene, coevally with an intrusion dome of the granite of Jastrebac.

## Basic characteristics of the main tectono-stratigraphic units of Veliki Jastrebac

The structural setting of the Veliki Jastrebac Dome is a product of polyphase deformation, beginning with the Baikalian, through the Caledonian and Hercynian to the Alpine orogen. The Alpine Mesozoic–Cenozoic structural content is dominant today (Fig. 1). Two major tectono-stratigraphic units are recognized: the Jastrebac Unit and the Morava Unit, which are divided into several smaller subunits each of which being itself a complex thrust-fold pile. These units have different lithostratigraphic characteristics and structural pattern, which were the criteria for the tectono-stratigraphic divisions (GRUBIĆ 1999). He suggested that the Morava Unit is thrust over the Jastrebac Unit.

### Jastrebac pile of nappes

The Jastrebac pile of nappes – Jastrebicum makes the central part of the area of Veliki Jastrebac. It lies beneath the Morava pile of nappes, while its footwall remains unknown (GRUBIĆ 1999). He distinguished the following three subunits within the Jastrebicum: Lomnica, Boljevac and Vukanja. Detailed investigations showed that the Boljevac and Vukanja Subunits cannot be easily distinguished, because the formations from which these consist of are intercalated, particularly in the border area. Thus, these two subunits are thus presented as one unit.

*The Lomnica subunit* consists mostly of Cretaceous––Palaeogene low-grade metasediments, anchimetamorphosed rocks and, in places, also of non-metamorphosed rocks (PANTIĆ *et al.* 1969; RAKIĆ *et al.* 1972, 1974, 1976), Palaeogene granitoids and granodiorite-porphyrite and aplite (RAKIĆ *et al.* 1974, 1976). The Cretaceous––Palaeogene deposits are represented by psammites, psephites and most often by pelites, which are regionally metamorphosed up to greenschist facies ("black phyllite"). These rocks were subjected to contact-metamorphism (hornfels, dotted phyllite and micaschists) in the immediate surroundings of the Paleogene granitoid.

The granitoid of Jastrebac intruded into the Cretaceous–Paleogene deposits at 37 Ma (ČERVENJAK *et al.* 1963). Its periphery is made of fine-grained varieties, while coarse-grained varieties are in the central part.

The Cretaceous–Palaeogene deposits of the Lomnica subunit are intensely folded. At least two phases of folding can be distinguished. According to GRUBIĆ (1999), the older phase is characterized by intense folding accompanied by transposition and formation of axial-plane cleavage, therefore the primary sedimentary fabric can only be assumed in hinges of the intrafolial rootles folds (cm-dm, rarely of meter scale). The hinges of these folds plunge to NNW and SSE (Fig. $1D_1$).

The cleavage planes became the dominant S-surfaces which were deformed during the second phase of folding in such a manner that they periclinally encircle the Jastrebac granitoid, forming a rather symmetrical dome (GRUBIĆ 1999). Poles to the axial plane cleavage clearly mark such folds (Fig. $1D_2$).

The initial vergences of I phase old folds and therefore the tectonic transport could not have been determined because of the strong transposition and intense folding and subsequent refolding. According to the intensity of folding, the Lomnica Subunit could not be autochthonous, but it was most probably thrust over an unknown footwall. GRUBIĆ (1999) believes that transport in this unit was toward the east.

*The Boljevac–Vukanja* Subunit extends over the immediate periphery of Veliki Jastrebac and, in an arch shape, it surrounds the deposits of the Lomnica Unit and in places the Jastrebac granitoid. The Boljevac–Vukanja Subunit is made of two sequences of metamorphosed rocks of "greenschist facies" (Fig. 1).

The lower sequence is made up of epidote-actinolite, albite-chlorite and rarely chamosite schists with certain amounts of transposed rocks of the upper sequence. In the lower sequence of the crystalline schists, there are large and small lenses of metagabbro, particularly in the southern and southeastern parts of the Veliki Jastrebac Dome (RAKIĆ *et al.* 1974, 1976).

The upper part consists of albite-sericite schists, calcschists and marble with certain amounts of transposed rocks from the lower sequence (mostly in their bordering area) (RAKIĆ *et al.* 1974, 1976; KRSTIĆ *et al.*

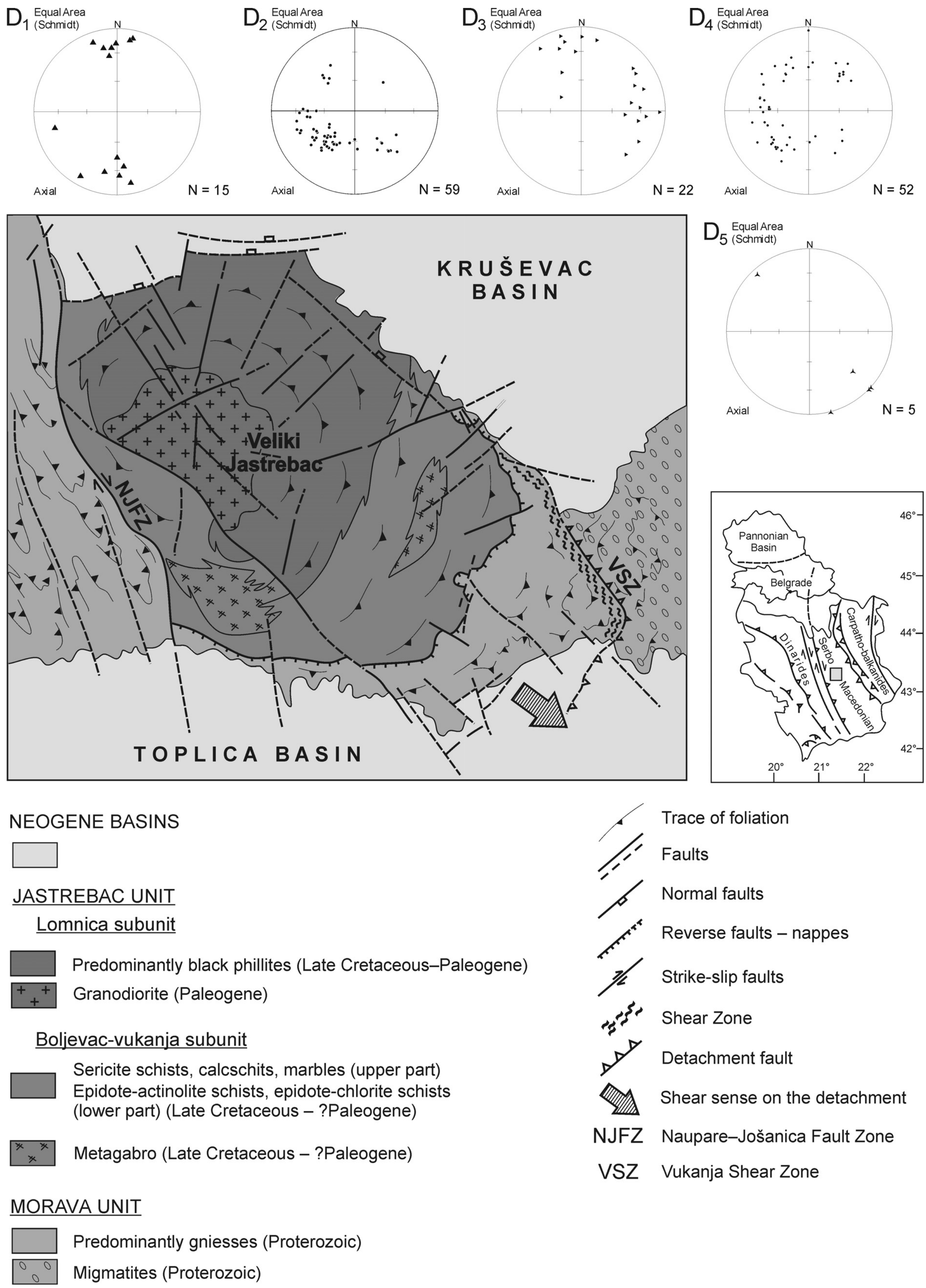


Fig. 1. Structural sketch of Veliki Jastrebac and an equal area lower hemisphere stereograms of: **$D_1$,** intrafolial folds of the Lomnica Unit; **$D_2$,** foliation of the Lomnica Unit; **$D_3$,** intrafolial folds of the Boljevac–Vukanja Unit; **$D_4$,** foliation of the Boljevac–Vukanja Unit; **$D_5$,** extensional lineation in the Boljevac–Vukanja Unit. Geological map (modified and simplified) after RAKIĆ *et al*. 1974; KRSTIĆ *et al*. 1978.

1978, 1980). The presence of calcschists and marble is rather conspicuous and it represents a criterion for the easier recognition of the upper package of metamorphites in the Boljevac–Vukanja Subunit.

The deposition age of the protolith of the metamorphic rocks of the Boljevac–Vukanja Subunit is the crucial question and the final explanation of the tectonic relations and events on these terrains depends on its solution. On the Basic Geologic Map, sheet Kruševac (RAKIĆ *et al*. 1974), these deposits were determined as Paleozoic, with the possibility of being younger. On the sheet Aleksinac (KRSTIĆ *et al*. 1978), these rocks were considered to be of Riphean–Cambrian age.

The palynological analysis performed during these investigations showed that the sericite schists, calcschists and marble are Late Cretaceous or maybe even Palaeogene. Less reliable data were obtained for the lower sequence, but they also imply Late Cretaceous age. These two sequences are probably of the same age because they are often interfingered and have similar structural characteristics.


Fig. 2. Intrafolial folds in calcshists of the Boljevac–Vukanja Unit.

The greenshists facies metasediments of the Boljevac–Vukanja Subunit were also folded during at least two phases, in a similar way to the Lomnica Unit. The first phase of folding is indicated by parts of the hinges of intrafolial rootless folds preserved to different degrees and, in places, by the whole folding sequences (Fig. 2). Hinges of these cm-dm and even meter-sized folds plunge generally to the east and NNW (Fig. $1D_3$). The bedding is transposed along the axial-plane cleavage; the primary fabric is mostly unrecognizable. The foliation along the axial plane cleavage of the first-generation folds is probably the result of flattening perpendicular to the planes. Foliation represents the dominant planar element. Foliation fabric is particularly well developed in the lower metamorphic sequence of this unit. It may be rather the strain than the rheology.

There are indications that folds on the eastern slopes of Veliki Jastrebac are west-vergent. Sericite schists, calcschists and marble appear in the cores of synforms, while epidote-actinolite and albite-chlorite schists appear in the cores of antiforms.

The cleavage and foliation of the Boljevac–Vukanja Subunit were folded into a dome structure during the second phase, similarly to the case of the Lomnica unit. This is clearly shown by the distribution of poles to foliation (Fig. $1D_4$).

## Morava pile of nappes

The gneiss which surrounds the Veliki Jastrebac Dome, except in the southeast where it is probably covered by Neogene deposits, is considered to be a part of the Morava Unit (GRUBIĆ 1999).

On the western slopes of Veliki Jastrebac, along the Naupare–Jošanica Fault Zone (NJFZ), the gneiss is in tectonic contact with metasediments rocks of the Jastrebac Unit. In this part, it is mainly represented by fine-grained gneiss, mica-quartz-plagioclase schists, lenses of amphibolite and amphibolite-schists, as well as by small portions of quartzite. The composition of the rocks on the southern slopes of Veliki Jastrebac is similar. In the eastern part of Veliki Jastrebac, there are two groups of high-grade metamorphic rocks. From the tectonic contact between the gneiss and the Boljevac–Vukanja Subunit to the Vukanja Shear Zone (VSZ), there are mostly andesine gneiss, amphibolite and amphibolite gneiss. East of the VSZ, there is mostly migmatite with smaller portions of gneiss. The structure of the gneiss complex is extremely complex and in it was not studied during these investigations. Foliation, as the most distinct structural element is in the western part folded into cylindrical antiforms and synforms with the hinges trending in NNW–SSE, while it forms gentle open fold forms on the eastern side (Fig. 1).

The Morava Unit most probably consists of two nappes: the lower, consisting of various gneisses, overlays the Jastrebicum and the upper, represented by migmatites and subordinate gneiss, lays over the gneiss crystalline from which it is separated by the VSZ.

## Exhumation Mechanism of Origin of the Veliki Jastrebac Dome

At the end of the Cretaceous and at the beginning of the Palaeogene, during the final phases of convergence between the Serbian–Macedonian Continental Plate and the Vardar Basin, intense folding of the deposits from the Vardar domain occurred. These deposits are exposed in the core of the Veliki Jastrebac Dome, overlain gneiss and schists of the Morava Unit. The complex fold-thrust sequence with an inverse succession of deposits was formed in the following manner:

Mesozoic–Cenozoic deposits are in the lower parts, while the Serbian-Macedonian Mass, i.e. the Morava Unit is in the upper part.

These deposits have been metamorphosed to greenschist facies grade and were folded during this metamorphic event at the end of the Paleogene. According to the lithological characteristics and by analogy to the certain parts of the Vardar Zone (north Bosnia and Croatia; PAMIĆ 1993; PAMIĆ *et al.* 2000, 2002), this could be a Vardar–Sava island-arc-back-arc-basin system.

During the final phases of convergence between the Serbian-Macedonian Continental Plate (as above) and the eastern part of the Vardar Zone, the Mesozoic–Palaeogene rocks were folded into tight, isoclinal folds, with the formation of an axial-plane cleavage with transposition. The hinges of the intrafolial folds in the Boljevac–Vukanja Subunit are generally plunging to the east, north-northwest and southeast.

The granitoid of Jastrebac originated in the Paleogene, at about 37 Ma (ČERVENJAK *et al.* 1963), by the melting of the crustal material which was buried into the deeper levels of the convergent Serbian–Macedonian–Vardar suture and subsequently intruded into the Cretaceous–Palaeogene complex.


Fig. 3. Extensional lineation in epidote-actinolite schists.

The emplacement mechanism of the granitoid into the higher levels and finally exhumation is still unknown. The explanation involving simple diapirism and erosion is hardly acceptable. The following indicators of extension, noticed in the gneisses and schists of the Jastrebicum, point to such events in the area of the Veliki Jastrebac Dome: stretching lineation (Fig. 3), s-type porphyroclasts (Fig. 4) and the wide mylonitic zones in the domains of the Naupare–Jošanica and Vukanja shear zones (particularly in the domain of the Vukanja fault) (SPAHIĆ 2006). The Vukanja Shear Zone (VSZ), which extends along the northeastern rim of Veliki Jastrebac, is bent toward south and southwest. The shear zone, marked by a several hundred meter-wide mylonite zone could represent a low-angle detachment normal fault along which extensional unroofing occurred. The stretching lineation (Fig. 1$D_5$), shows the top-to-the south and southeast shear sense (SPAHIĆ 2006). It is also confirmed by the shape and orientation of the s-type porphyroclasts in the calcschists of the Boljevac–Vukanja Subunit (Fig. 4).

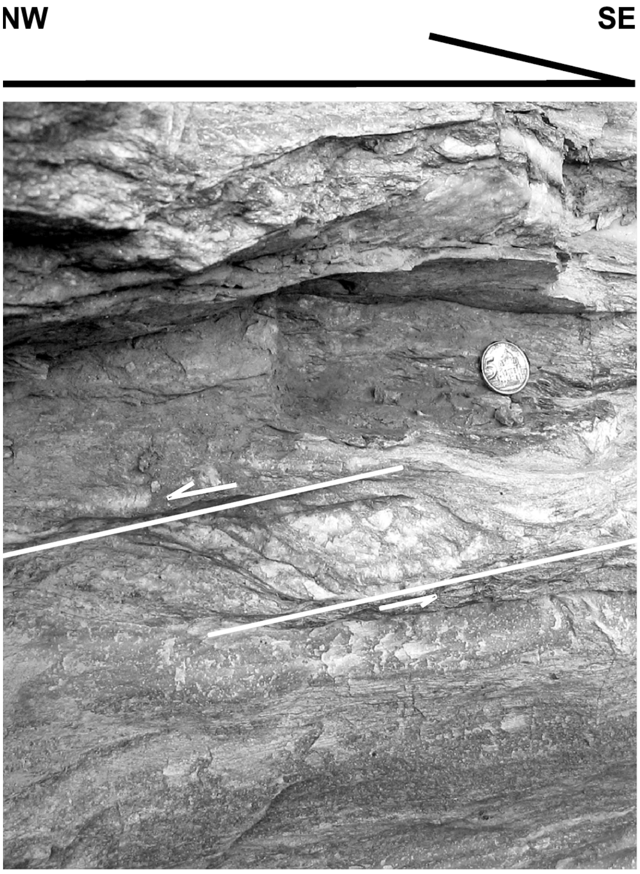


Fig. 4. Sigma -type porphyro clast in calcshists of the Boljevac–Vukanja Unit.

The process of extensional tectonic denudation probably induced decompression, uplift of geotherms and rock uplift of the granitoid body (isostatic adjustment?). Accompanied with erosion, the extension resulted in exhumation of the granitoid, together with the previously deeply seated metamorphic rocks. This resulted in a core complex-type map pattern of the area.

If the action of such an exhumation mechanism of Veliki Jastrebac is accepted, the problem of the tectonic denudation model and timing arise immediately. According to the age of the granitoid, the extension occurred most probably in the Palaeogene, during transtensional activity in the domain of the Naupare–Jošanica Fault Zone. In this case, there are two possibilities of activation of these extensional mechanisms:

- The Naupare–Jošanica and Vukanja shear zones represent a conjugate pair (NJFZ – dextral strike-slip, and VSZ – sinistral strike-slip) under conditions in which the axis of the maximum horizontal stress (SH) is

NE–SW oriented. In this case, the area between these two faults could escape towards the southeast and induce the extension and exposure of the deeper parts of the Jastrebicum. Such a lateral, crustal extrusion raises the problem of free space for the tectonic escape toward the south and southeast. However, in this particular case, no such space existed during the time of the extension.

• The extension could have occurred in the domain of the dextral strike-slip of the Naupare–Jošanica Fault Zone in the area of the releasing band (Fig. 5). In this case, the Vukanja Shear Zone was activated as a major, low-angle normal detachment fault.

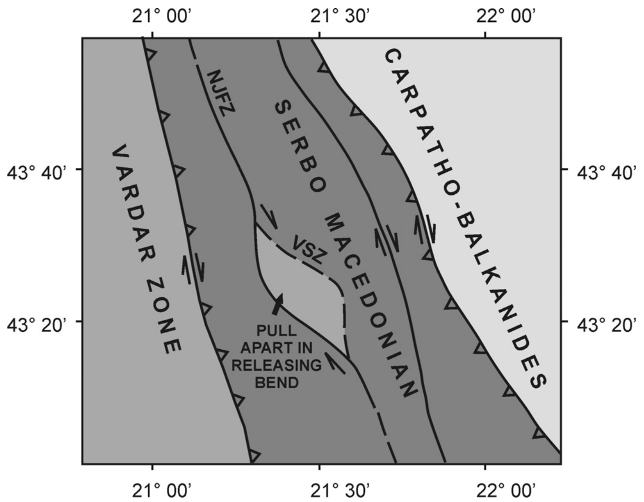


Fig. 5. Schematic diagram of extensional unroofing of the Veliki Jastrabac Dome.

The extension was probably followed by a quick uplift of the granitoid, accompanied by the consequential folding, i.e., refolding of the Mesozoic–Palaeogene folds of the first phase and development of the Veliki Jastrebac Dome (the second phase of folding of the Mesozoic–Palaeogene deposits).

## Conclusion

The geological setting of Veliki Jastrebac, which was presented during the last several years and which have been partly obtained by investigations, point to the possibility that this area is a metamorphic core complex exhumed by extensional processes, i.e. by tectonic denudation during the Palaeogene. The extension could be related to the dextral transtension along the Naupare-Jošanica fault in the domain of the releasing band, with the Vukanja Shear Zone acting as a low-angle normal fault detachment. It remains necessary to obtain additional data for a more precise confirmation of this assumption. In this sense, data should be documented by structural and thermochronological analyses.

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## Резиме

### Екстензионо откривање доме Великог Јастрепца (Србија)

Дому Великог Јастрепца изграђују две крупне тектоностратиграфске целине које су у инверсном положају и у тектонском контакту. У доњем делу су горњокредне и кредно-палеогене нискометаморфне стене (вероватно Вардарске зона), преко којих су навучени кристаласти шкриљси високог степена метаморфизма Српско-македонске јединице. У мезозојско-палеогени метаморфни комплекс утиснут је палеогени гранитоид.

У склопу Великог Јастрепца доминира структура доме. Централно место у њој заузима гранитоид около којег су елиптично распоређене остале формације: прво, мезозојско-палеогене и на крају кристаласти шкриљци Српско-македонске јединице.

Истраживања су показала да су мезозојско-палеогени метаморфити претрпели две фазе убирања. У првој фази, крајем креде и почетком палеогена са навлачењем кристалина Српско-македонске масе преко горњокредних и кредно-палеогених творевина, ове стене су деформисане у дуктилним условима. Овакав догађај означен је регионалним метаморфизмом, формирањем изоклиних набора и кливажа аксијалне површи дуж којег се одвијала транспозиција и генерисала фолијација. Други деформациони догађај је последица испољене екстензионе активности и тектонске денудације у палеогену. То је омогућило рађање и премештање гранитоида ка површини, ексхумацију ниско до средње метаморфисаних горњокредних и кредно-палеогених творевина и пренабирање доњег и горњег навлачно-наборног пакета у дому Великог Јастрепца. Екстензија је обављена у условима декстралне wrench-тектонске активности раседа Наупаре–Јошаница и са Вукањском дислокацијом као главним low-angle detachment гравитационим раседом.

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# A new view on the structural pattern of the Metohiya Basin and its margin: a preliminary note

Milosav Simić[1] & Antonije Antonović[2]

*Never before could our imagination be*
*measured with the inventiveness of nature.*
*(Никада до сада наша машта није се*
*могла мерити са инвентивношћу природе)*
*Richard Miller, In "Nemesis", 1994*

**Abstract**. The region of the Metohiyan depression and its complex geological margin is a morphotectonic entity formed over the complicated structures of the basement. The first glance of the orographic-geological map or satellite image shows the hexagonal shape of the depression, in clear contrast to the linear structure of the Vardar Zone. Sedimentation of Neogene deposits began in a trough, the "main shape of which was finished" and the depression itself had been formed and modified over a long period of time. This is indicated by the slight deformations of the Miocene deposits, somewhat stronger along the rim of the basin, and the relatively great thickness of the Neogene in general, uniformity in lithological composition and other characters of deposits.

This region in the south of Serbia was much explored during the last (20th) century, in the latter half in particular, when abundant and interesting information was collected on the geology, structural pattern and mineral resources. Some of the newly collected information has been published and threw new light on the geology of the Metohiyan depression and its margin. Other data, also important, have remained unpublished in numerous documentation funds.

Gaps in the geological knowledge of the Metohiyan depression and its margin, viewed through reference data, account for the missing links of many facts and fragmentation. Also, for some reason, a more comprehensive and reliable idea of the geological relationships or evolution is difficult to conceive.

This work will present the idea of the Metohiya Basin as a ring structure like one resulting from a meteorite impact. In view of its form (morphology) and some indirect indications, there are few conclusive indications that it is an impact structure of about 50 km in diameter. Why? "Sometimes one should know what to look for to be able to see it". From this standpoint, so far actual facts of a certainly strong impact have neither been viewed nor their evidence searched for from any aspect (atomic-molecular, mineralogical, crystallographic, petrochemical, geoelectrical, structural, etc.). Structures in the marginal parts of the Metohiya Basin, which have different strike directions (NW–SE, NE–SW, ENE–WSW, E–W, N–S), may be well interpreted should it be accepted that they border an impact ring structure.

**Key words**: Metohiyan impact, impact structure, Metohiya, Serbia.

**Апстракт**. Метохијска котлина, у ширем смислу, са својим геолошки веома сложеним ободом, представља посебну морфотектонску целину формирану изнад врло компликованих структура "основног горја". Већ на први поглед на орографску – геолошку карту или сателитску слику, уочава се шестоугаона структура ове котлине, која јасно одудара од линеарне структуре Вардарске зоне. Седиментација неогених наслага започета је у рову чији је "основни облик био готов", а сама котлина настала је и бивала модификована постепено и кроз дуже геолошко време. На ово нас упућује мала поремећеност наслага миоцена, нешто већа уз обод басена, као и релативно велика дебљина наслага неогена уопште, уједначеност литофацијалног састава и других особина наслага.

[1] "Dundee plemeniti metali", Makedonska 30, 11000 Belgrade, Serbia. E-mail: m.simic@dundee.co.yu
[2] Gogoljeva 132, 11000 Belgrade, Serbia.

Ово подручје на југу Србије је у прошлом (20-ом) веку, а нарочито у другој половини, било интензивно истраживано. При тим радовима прикупљен је многобројан и интересантан материјал о геолошком саставу, структурном склопу и минералним сировинама овог подручја. Један део тих нових геолошких података објављен је у више публикација, многи од њих бацају нову светлост на геологију Метохијске котлине и њеног обода. Многи други, такође значајни подаци остали су, међутим, необјављени и налазе се у многобројним фондовским материјалима.

Због тих празнина геолошко познавање Метохијске котлине и њених ободних терена карактерише се, посматрано кроз податке из литературе, неповезаношћу многих чињеница и фрагментарношћу. Због тога се истовремено, тешко може добити прегледнија и поузданија слика о геолошким односима и геолошкој еволуцији тих терена.

У овом раду изнећемо идеју о Метохијском басену, као прстенастој структури која би одговарала метеоритском импакту. Ако изузмемо њен облик (морфологију) и неке посредне индиције, за сада, имамо мало материјалних доказа да је то импактна структура пречника око 50 km. Зашто? “Понекад је потребно знати шта тражите да би то и видели” каже РИЧАРД М. писац “Nemeze” (1994). До сада, са тог становишта, нису посматране реалне чињенице нити су тражени материјални докази на ниједном нивоу (атомско-молекуларном, минералошком, кристалографском, петрохемијском, геохемијском, структурном итд.) о једном свакако великом судару. Можда структуре у ободном делу Метохијског басена, које имају различите правце пружања (СЗ–ЈИ, СИ–ЈЗ, ИСИ–ЗЈЗ, И–З, С–Ј) моћи ће сасвим добро да се интерпретирају ако прихватимо, да је ово једна импактна прстенаста структура.

**Кључне речи**: Метохијски импакт, импактна структура, Метохија, Србија.

## Introduction

The Methohiyan Basin in the shape of a huge amphitheater of about 2000 km$^2$ in surface area is situated in the southern and southwestern parts of Serbia bordering on Albania. This depression, for its complex tectonic pattern, especially on its margin, has been the subject of interest of many geologists and other natural scientists from ancient times. Opinions about the origin of the depression, age of faults and Tertiary deposits and other aspects are controversial.

Thus, CVIJIĆ (1901, 1913, 1924) maintained that Metohiyan depression was formed and modified (the phase of faulting of the Dinarides) over a relatively long geologic time and is a typical example of an intermontane depression – tectonic valley filled with terrestrial deposits with coal. The same author explained the formation of the depression by subsidence resulting from a large-scale orographic convergence of the Prokletije and Shar Mountains, or the convergence of the Dinaric and Shar-Pind systems, and the numerous marginal faults on the northern, western and southern sides as “formed by abrupt bending of folds from the Dinaric into Metohiyan (system), giving the impression that the ground was fractured. Sedimentation of Neogene deposits began in the graben, the “main shape of which was finished”. If the “ground was fractured” and “the main shape was finished” does this not suggest certain doubts of CVIJIĆ in the formation of the depression by “convergence”? The hypothesis of convergence of two systems is still prevailing with minor variations.

Important information on the presence and historical evolution of the depression is contained in KOBER (1952) that reads: “Peć depression, almost 100 km wide, divides the Dinarides and the Hellenides and is a tectonic line of the first order. It strikes transversally to the Dinarides direction short of Prishtina in the east. At the present time it is covered by younger and Upper Cretaceous formations.” It may be deduced that KOBER assumed faulting of pre-existing structures even before the Upper Cretaceous.

Old alpine orogenies led to large structural deformations and subsidence along longitudinal and transversal dislocations in the convergence zone of magmatic and sedimentary rocks. MOŽINA *et al*. (1961) wrote: “folding and faulting were the strongest in the Laramian, less strong in Pyrenean and Savian orogenies”.

Each phase, according to the same authors, was characterized by disjunctive movement that led to subsidence of masses “along intermittent and newly formed dislocations and to the formation of basins in which Tertiary sediments were deposited”. However, the movements could have been older.

VIDOVIĆ (1965) refers to the Peć faulting feature as “a deep fault through the Earth’s crust” associated in time with “the earliest differentiation of the Dinaric geosyncline – the Caledonian phase”. Vidović, like CVIJIĆ, describes that geotectonic zones and directrices converge to the Peć fault, which is the boundary “of the Dinaric and Shar-Pind systems”.

ĆIRIĆ (1967) refers to the Metohiya depression as “a large molasse basin particular in its position”. He takes it to be a typical example of “an inherited depression that was formed at the point of convergence of Dinaric and Bosnia–Raška Zone of the Inner Dinarides”. It is classified into the “central molasse depressions”.

A contribution in the collective authorship of a Zagreb Industroprojekt (1969) hypothesizes that during the Mesozoic, the Metohiyan basin was part of a relatively narrow “eugeosyncline” extending from Albania to this area. They describe the depression as a “grabenform” most likely in the “continental phase – without sediment filling” in the time interval $K_2$–$Ol_1$.

A note of interest (BOGDANOVIĆ 1976) is that “intrusion of the huge Mirdita peridotite massif in the late Triassic and early Jurassic led to the bending of Triassic and Paleozoic strata that surrounded the Mirdita pluton”. He states that the Mirdita peridotite massif “had a crucial effect on the deviation of folds from the NW–SE to NE–SW or even E–W direction”. This fold deviation and the depression formation occurred, according to Bogdanović, “before the Upper Cretaceous, but after the Triassic”, and the diagonal Peć and Prizren faults were certainly older than the “Lower Miocene volcanogenic series near Trepča and on Kopaonik, but younger than the Lower Cretaceous”.

According to MAKSIMOVIĆ (1978), the study area of the Peć part of Metohiya belongs to “central ophiolite, which is the most distinctive zone, the membership in the Dinarides of which has never been disputed”.

PETKOVIĆ & SIKOŠEK (1976) argue that the period of Neogene tectonics is characterized by the following: “Savian-phase orogeny activated old and formed new vertical structures, along which land was dissected, depressions formed and filled with Tertiary waters from which molassic sediments deposited.”

BOKČIĆ (1983) does not consider the Metohiyan Basin a “static basin” predisposed for filling. It was a highly dynamic depression where tectonic movements, though frequent, were not abrupt or variable. Tectonic events influenced the formation of relatively thick deposits of different types: Lower Pliocene coal to about 60 m or a “group” of deposits of uniform grain size. This is particularly true of lake deposits of the Middle Miocene and Lower Pliocene.

HADŽI *et al*. (1974) associate tectonic events in the region with plate rotation, in detail the collision of plates and the growing pressure of the Arabian–African plate on Eurasia. To quote: “under the growing pressure of the Arabian platform from SE to NW in the late Eocene, the entire southeastern Europe and southwestern Asia began to move through the section from the style platform to the south Budva–Ionian–Tauride margin”. As the movements to the west and northwest were soon retarded by resistance met by the northern part of the Karnic–Apulian massif, individual plates deviated in the Oligocene to SW, or to the oceanic region of the present-day central Mediterranean. From variations in the paleodeclination and paleoinclination, it may be inferred that the events which disturbed the earlier paleomagnetic balance, or the pre-existing distribution of plates, occurred between the Eocene and the Middle Miocene.

All these large-scale displacements (which have continued to the present day) had a great influence on the youngest structural relationships established through the Neogene and the Quaternary. In modern views, the neoalpine structural relationships are marked by continental subduction of the Adriatic plate under the Dinaric orogen during the Neogene and the Quaternary (MAROVIĆ & ĐOKOVIĆ 1993; MAROVIĆ *et al*. 1998; PETKOVSKI 1990). Structures, such as basins, troughs, and even true basins (Aegean Sea), formed in the post-collision phases and/or under some particular circumstances within the perimeter of the Dinaric orogen. Movements manifested in the border belt of the Adriatic plate and the Dinaride–Hellenide orogen had a direct effect on the neostructural plan of the study area. The littoral belt is a zone of marked level difference. Subsidence was a consequence of the Adriatic lithosphere deflexion during its subduction under the Dinaric orogen, and the rising of the Dinaric orogen was a result of contraction caused by the interaction of African (Adriatic) and European (Mesian) plates and of the relative thickening of the Earth’s crust.

Younger Neogene basins in the region may be genetically associated with extension processes, or explained as the result of tectonic activities during most of the Neogene and through the Quaternary, formerly differentiated (rising and sinking) and later epeirogenic rising. However, the formation of the initial depression structures is directly related to the closing movements of the second formational phase (during the Paleogene to the earliest Neogene), when contraction was marked by reverse slipping, imbrication, thrusting over and transcurrent shearing along intermittent dislocations of N–S, NW–SE and NE–SW directions (MAROVIĆ & ĐOKOVIĆ 1993; PETKOVSKI 1990).

A new neotectonic (geodynamic) process that evolved through two phases: from the Middle Miocene to the Quaternary and reached the paroxysm in the Pliocene, represented by the clockwise rotation of the Hellenides and the Dinarides pushed by the Asia Minor plate, could have influenced the evolution of neoalpine (neotectonic) structural relationships in South Serbia, Macedonia and a larger area (KRSTIĆ *et al*., 1977). The rotation resulted from the formation of the western and northwestern parts of the Aegean island arc; its effect reached the Skutari–Peć transverse, known as the Mirdita Zone (BILIBAJKIĆ *et al*. 1979; MAROVIĆ & ĐOKOVIĆ 1995). It was along the Skutari–Peć transverse that the Dinaric–Hellenide orogen arcuated and formed, on its convex side, trough structures, the most conspicuous of which is the Metohiyan trough. Spreading in the transverse zone must have reflected, to a lesser extent, on the west, deep into the Mediterranean. The eastward extension bent to Sofia and passed the southern Sredna Gora trough boundary to southern Bulgaria. Within this transverse fracture, differential displacements influenced the formation of many faults of NE–SW strike direction and relatively narrow Tertiary basins normal to the Dinaric ones (NE–SW). Similar events also occurred along the transversal fractures Elbasan–Kyustendil, Joannina–Plovdiv and on the Aegean geofracture (PETKOVSKI 1997).

A zone of more frequent earthquake events extends south of and parallel to the formed boundary (Skutari–Peć). The earthquake epicentral depths were about 10 km (KRSTIĆ *et al*. 1997). The seismic activity indicates movements of more recent history. Active seismotectonic levels are associated mainly with young systems, faults of neotectonic manifestation.

As described above, views on the origin and age of the Metohiyan Basin and its structures are controversial. The depression could not have been formed in a lineament structure, eventually initiated by rotation, though it is hard to imagine a homogeneous geological body to be moved by conjugate forces. It seems more likely that an impact body (impactite, asteroid) formed the circular crater which was modified by other tectonic movements. The very beginning of the formation of the depression is difficult to determine from the present stage of our knowledge and on the available information.

## Geology and Structural Pattern

The Metohiyan Basin and its margin are made up of Paleozoic, Mesozoic and Cenozoic sedimentary and various types of igneous rocks (Fig. 1).

Paleozoic sedimentary rocks build up the basal parts of the Shar Mountain and southeastern, eastern, northeastern and northwestern parts of the Metohiya depression. The Lower Paleozoic is represented by Silurian and Devonian, and the Upper Paleozoic by Carboniferous and Permian. The Silurian–Devonian complex consists of two series: lower, dominantly greenschist of high crystallinity and upper rocks of lower metamorphic grade. The complex equivalent to the Upper Paleozoic consists in the lower part of lustrous foliated phyllite, greenschist, slate and slate clay, and of various sandstones, marbleized limestones and conglomerates in the upper part.

Mesozoic sedimentary rocks are widespread in the eastern, northern and western areas of the Metohiyan depression.

Triassic sedimentary rocks constitute large parts of the northwestern and northern Metohiyan depression and much of the marginal Prizren Polje and Shar Mountain, in the form of east–west lands. These rocks are light-grey, whitish or white limestones, occasionally dolomite.

Jurassic is characteristic for typical diabase-chert formation and serpentinite where Triassic and partly Upper Cretaceous rocks prevail.

Upper Cretaceous is dominantly in the calcareous facies in the Paštrik area and largely in flysch facies in the eastern margin of the Metohiya Basin.

The Tertiary is represented by Neogene formations – freshwater Miocene and Pliocene deposits of large thickness and relatively complex lithology. There is no paleontological evidence of Lower Neogene deposits in the deepest part of the basin.

Miocene sedimentary rock**s** have a small distribution as compared to Pliocene, around Peć and in the northeastern part of the depression (Rudnik, Banja, Crkolez, Rakoš), known in the literature as the Peć Series. It is made up of sands with gravel lenses, whitish ostracod marls, a few tuff layers, coarse green sands and small-grained conglomerates, and a few coal seams. The series is deformed and inclined to the west, northwest and north at different angles (from 10º to 45º). Coal seams are thin (between 0.1 m and 1.2 m). Also thin beds and coaly clay interbeds occur in the upper part of the series. The age of the Peć Series is most likely Middle Miocene and Upper Miocene (Sarmatian). Its thickness is about 450 m. All this is indicative of a long lake phase with shallowing episodes (MILOŠEVIĆ 1966; ANTONIJEVIĆ *et al*. 1969; BOKČIĆ 1983).

Interstratal tuff emplacements suggest volcanic activity during the deposition, along dislocations on the margin of the basin. Distinct lower and upper tuff boundaries indicate rapid deposition of ash. In the views of many investigators, volcanic activity occurred in the Middle Miocene. Identical or very similar volcanic evidence is identified in the underlying Kosovo Series. Most references describe Kosovo tuff interbedded in white marls of the northern basin as Miocene (ATANACKOVIĆ, 1959).

Pliocene rocks have a large distribution in the Metohiyan depression and form two horizons: (a) Lower Pliocene deposits and (b) Middle and Upper Pliocene deposits.

(a) Lower Pliocene deposits. The principal characteristic of the Lower Pliocene, which has a fairly large coverage in the northern Metohiyan depression, is its large coal deposit. The unit is divided the underlying strata and coal measures and overburden.

The underlying strata are widely exposed and transgressive over the Peć Series. They consist of conglomerate and sandy green clay with $CaCO_3$ concretions and knots. Fossils have not been found. These strata are identical with those underlying the coal measures in Kosovo. The estimated thickness of the underlying strata is between 200 m and 300 m.

The coal measures and the overburden are exposed in the Peć area of the depression. The coal measures, about 35 m thick, and the overlying barren rock material, clay-marl deposits with some red burned are Upper Pontian. The entire overlying sequence is highly fossiliferous and resembles Kosovo deposits, which indicates a wide communication of Kosovo and Metohiya lakes (MILOŠEVIĆ 1976; ATANACKOVIĆ 1959).

(b) Middle and Upper Pliocene. Younger Pliocene deposits of sand and sandy marl conformably overlie the coal measures. Their distribution is relatively small in northern Metohiya, but is more widespread in the Đakovica–Prizren part of the depression, where they are the only Neogene deposits. These deposits, abounding in molluskan fossils, primarily unionids and viviparids, have a total thickness of about 300 m.

The Quaternary is represented, among others, by rocks that indicate glaciation, which must have preceded the formation of the large pre-Mindel fluvio-glacial terrace of Orno Brdo.

The territory of Metohiya is a part of the Inner Dinarides geotectonic entity that extends from Serbia into

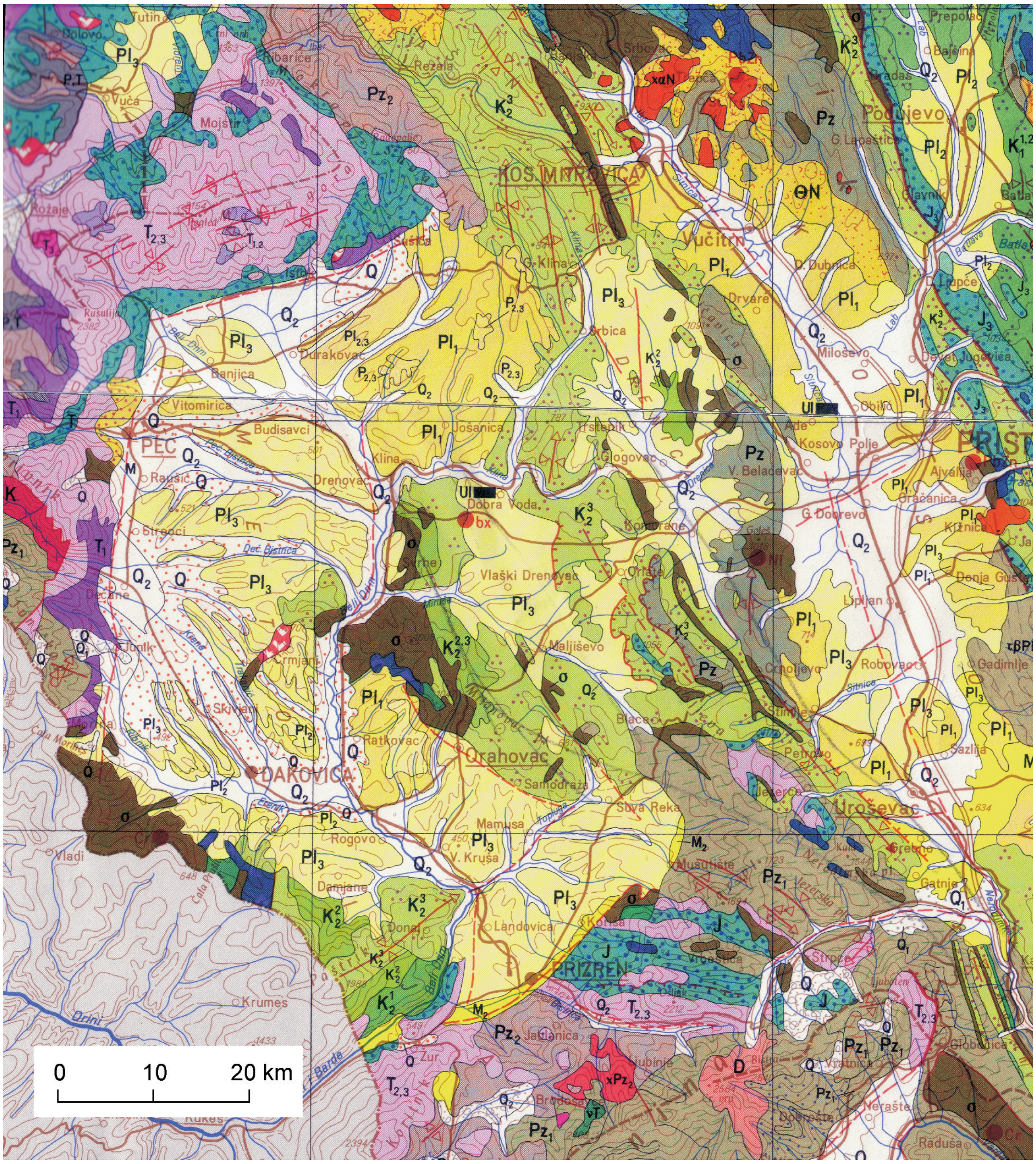


Fig. 1. Geological map of the Metohiyan Basin and its margin (Geological map of Yugoslavia 1:500 000, Federal Geological Survey, Belgrade, 1970). GSm, Gneiss and mica-schist; Pz, Paleozoic metamorphite; xPz, Paleozoic igneous rocks; PT, Permo–Triassic; T, Triassic; vT, Triassic igneous rocks; J, Jurassic; ββJ, Jurassic diabase; Se, Serpentinite; K, Cretaceous; E,Ol, Eocene–Oligocene; θN, Neogene pyroclastics; M, Miocene; Pl, Pliocene; ααqN, Neogene dacite andesite; xαN, Neogene quartz latite; θτβPl,Q, Pliocene and Quaternary pyroclastics and feldspar leucite basite; τβPl,Q, Pliocene and Quaternary feldspar leucite basite; Q, Quaternary; Ul, coal.

Bosnia in the NW and Macedonia and Albania in the SE. The tectonic depression of Metohiya is radial in form and has a complex tectonic pattern on its periphery. Rock strata are tightly folded, faulted and imbricated. Fold axes have different trends, Dinaric or Metohiyan, and strike the direction north–south on the eastern margin of the depression. Major tectonic units in this area, which control the tectonic depression, are: a marginal system of faults, the river Klina fault system and the Ćićavica thrust-sheet (PETKOVIĆ & SIKOŠEK 1976) (Fig. 2).

The view so far prevailing is that the Metohiyan depression was formed by the stepwise subsidence (about 1000 m) along the system of bounding faults as they strike today. The system of faults of ENE–WSW strike, probably Pontian in age (CVIJIĆ, 1913), bound the Metohiyan tectonic depression on the north and south. On its western rim, there are two faults: one almost N–S from Peć to Dečani, and the other NW–SE from Dobroš to Damnjan, forming its southwestern boundary (Fig. 2). The thus-shaped depression was filled with Miocene terrestrial sediments, with the central occurrence of tectonically controlled Cretaceous deposits and serpentinite. The tectonic depression of Metohiya is located in the "migration" area of the strike directions Dinaric orogen structures, where during the neotectonic events, the pressure release was the greatest.

The term "Metohiyan direction" was introduced by CVIJIĆ (1924). He noted in the extreme south that the Dinaric Mountain ranges curved from NW–SE to E–W or NE–SW, locally N–S, while the outer folds nearer to the Adriatic Sea retained the Dinaric direction (NW–SE), sank to the level of the Drim and Bojana Rivers backland and converged "at an obtuse angle with Albanian folds of the Mediterranean direction". However, "internal directrices bent right behind Skutari, in Tarabaš and Rumija to the NE, the direction presently referred to as Metohiyan, because it is best marked around the Metohiyan depression".

Similar curvings are noted on the other side of the Metohiyan depression in the Shar Mountain system (Shar, Koritnik and Paštrik), where the meridian direction changes into the Metohiyan direction (NE). CVIJIĆ (1901, 1924) tried to explain the phenomenon by tectonic control. His hypothesis was that the curving of the folds and directrices in Prokletije and further westward caused the orographic bending.

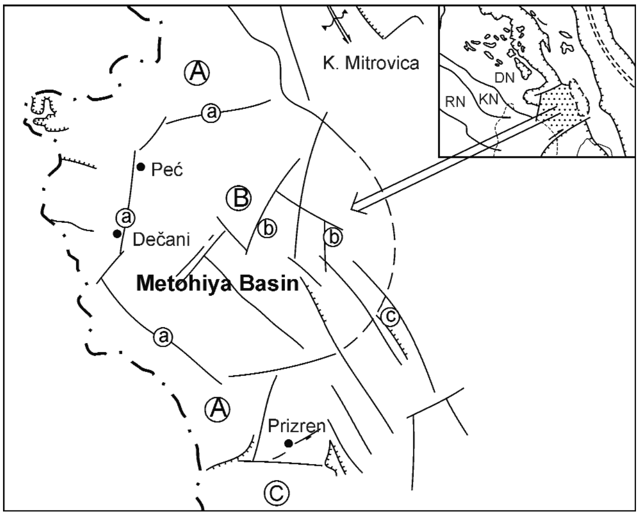


Fig 2. Tectonic map of Metohiya and its margin (modified after PETKOVIĆ & SIKOŠEK 1976). DN, Durmitor nappe; KN, Kuči (Žijovo) nappe; RN, Rumija nappe. Geotectonic units: A, Central Paleozoic and ophiolite belt; B, Tectonic depression of Metohiya (a, Metohiya depression marginal fault system, b, the Klina system of faults, c, the Ćićevica thrust sheet); C. Korab nappe.

## General Impact Effect and Product (Impactite)

It is interesting to note that not one of geologists or other researchers who studied this region ever thought of the impact of an extraterrestrial body, though images of such bodies from artificial satellites have become available (ANTONOVIĆ & SIMIĆ 2006).

As a result of cosmic explorations in the late 20th and beginning of the new century, an abundance of information has been obtained on the composition and structure of planets in the solar system, what led to new knowledge and a new scientific discipline, Comparative Planetology.

Studies of the surface geology of the family planets of the Earth (Mars, Mercury, and Venus) and their satellites the Moon, etc.) have shown that many characteristic features of their surface configuration and deeper structures are controlled by ring (circular) structures of various dimensions. It has been noted that most of the ring structures were impact craters and that no more than 20% of all the ring structures were volcanic craters (MARKOV 1984; ANTONOVIĆ & SIMIĆ 2006). Estimates have shown that intensive meteorite showers were dominant in the early phases of their evolution, from 4 to 3.8 milliard years, and before two milliard years had decreased 200 to 300 times (it was calculated that in the early stages of the Earth's evolution, $10^3$–$10^4$ bodies between 10 km to 100 km in radius should have fallen on its surface at a velocity rate between 10 km/s and 20 km/s; *in*: MARKOV 1984). Intensive bombardment of planets in the early stage of their evolution should be considered as a universal process of substance transformation for any solid body of the solar system. The geochemical effect of this impact transformation has been inadequately evaluated and studied, or little is known about the proportions of the events, their effects and influences on the evolution and transformation of the continental crust.

If the Earth's nearest neighbours were exposed to meteorite showers in different stages of their history, there should be hardly any doubt that meteorites fell on the Earth surface as well. As mentioned earlier, many specialists in Earth geology have given little consideration to or ignored impact occurrences as a geological process on the Earth, even if they were obvious and should have been taken into consideration both in the early geologic history and the latest evolution of the plant Earth. It is understandable, because endogenic processes have done much in erasing the traces of impacts. Moreover, at the present time, about a hundred impact structures, some of 140 km or more in diameter have been identified on the Earth (BARSUKOV & BAZILEVSKIY 1984; MARKOV 1984; GRIEV & PARMENTE 1984; GLUHOVSKIY & PAVLOVSKIY 1984; MASAITIS *et al.* 1984; ENGELGARDT 1984; FELDMAN 1984; ANTONOVIĆ & SIMIĆ 2006).

The study of tectonics and magmatism in the early stage of the Earth's evolution is very important in itself, because it affords insight into the origin of the geological history of our planet, and a view on the sources of the formation of its upper mantle. This is equally interesting for tectonists and petrologists, geochemists and sedimentologists, or, in other words, for many disciplines of geological science.

Principal bombardment effects are the following: (1) essential contribution to the planet is energy on the account of rapidity of the strikes, transformation of kinetic into thermal energy, (2) initiation of volcanism, the products of which mostly fill craters and (3) meteorite bombardment on the Earth's surface, which led to essential redistribution and mixing of material, and to changes of its chemical composition.

Nevertheless, it is interesting to learn and explain the character of basalt volcanism on different planets, because basalt is one of the essential constituents in the crusts of planetss. It is well known that in the Phanerozoic history of the Earth, the primary mass of basalt formed in contemporary oceans and their paleoanalogues. May this pattern of an early stage of the geological history of Earth be applied to other planets of the Earth's family? The question is still obscure because the moon "seas" and "continents" are not analogues, in the strict sense of the word of similar structures on the Earth.

Craters more than 2 km across in sedimentary and more than 4 km in crystalline rocks have a characteristic depth-to-diameter ratio of less than 1/10 and an elevated central area of shock-metamorphosed rocks, which form a central peak and/or inner ring (ANTONOVIĆ & SIMIĆ 2006).

A brief review of the geology and geophysics of many Earth's craters can be found in the works by DENCE *et al*. (1977) and MASAITIS *et al*. (1980). In some examples of extraordinary geological circumstances, the formation of large impact structures influenced the precipitation and emergence on the ground of surface ore deposits (e.g. Ni-sulphides in the Sudbury structure; MORRISON 1982). In some impact structures, appreciable reserves of hydrocarbon were also formed, as in the Boltish depression (YURK *et al*. 1975) and Viewfield (SAWATZKY 1977). An impact exerts deep effects on the local geology, disturbing the physical and chemical balance in rocks, which in particular cases leads to the formation of a structure of much larger horizontal scale than the largest volcanic product.

The effects that indicate a large-scale impact on the early Earth's crust may include the following: landform of a few km in amplitude, thermal gradient rise in the lithosphere and the atmosphere directly beneath the shock site, controlled ascension to the surface of deep material, some potential energy for the next eruption of basalt on account of adiabatic expansion, endogenic mineralizations (Pb–Zn and the like), geomagnetism and other relevant indications (ANTONOVIĆ & VUKAŠINOVIĆ 1989/1990).

In case of the relatively thin lithosphere of the Earth, which probably was even thinner in the early history of the planet, large-scale impacts could have supplied asthenosphere material to the ground surface, which caused volcanic events over a large area (GRIEV & PARMENTE, 1984).

An impact is followed by the transformation of the large impact basin. The transformation processes include contraction and expansion after heat loss, subsidence and rise after the shock, degradation of landforms on account of erosion and rapid relaxation, the filling of basins.

During the hypervelocity impact of a relatively solid body onto the hard planetary surface, there follows a rapid succession of phases:

a) penetration of the impacting body and consequent compression, compaction of material;

b) excavation – caving and formation of a crater;

c) transformation of the transient crater and its filling both underneath (rapid replacement of dislodged and crushed socle) and above (numerous settlings and emplacement of ejected, broken and molten material of target rocks).

The shock wave spreads from the shock zone in concentric rings and is manifested in: (a) evaporation, (b) complete melting, (c) partial melting and plastic deformation, (d) crushing and fissuring. In crater structures only relics have remained, formed in the zone of partial melting and plastic deformation, and complete in the zone of crushing and fissuring. According to current estimates, the area of complete destruction in an impact crater (zones a, b and partly c) is characterized by high pressure (about 25 GPa).

Rock and structure transformation, during a collision, may be considered at several levels:

1. On the atomic/molecular level, the shock wave causes atom compaction, or destruction of atomic or molecular bonds. The high temperature rise leads to dehydration of water-bearing minerals, carbonate decomposition and moisture evaporation.

2. On the crystal lattice plane, fine mosaic cracking of crystal structure and lattice rearrangement or complete destruction at a higher or lower level.

3. On the mineral level, transformation evolves through several successive stages: (a) propagation of the shock wave (progressive shock metamorphism), (b) heat effect from the impact melt source (pyrometamorphism) and its cooling (crystallization, glass formation, neocrystallization, recrystallization, polymorphic transitions, etc.), and (c) during the action of aqueous solutions that flow through the cooled rock mass.

The processes, due to high temperature and pressure generated within the short time of the collision, lead to different structural transformations and formation modes of the group of crystal and glass phase: crystals under high pressure, monomineral and polymineral impact glass, grassy condensate, glassy products of pyrometamorphic melt and glassy products of thermal decomposition. The glassy formations or tektites are small, rounded, spherical or uniform-surface bodies found in groups. Tektites have high silica (70%–80%), aluminium oxide (11%–15%) and alkalis ($Na_2O$+$K_2O$ from 3.34%

to 4.04%), and very low water contents (RIKA & MALYSHEVSKAYA 1989).

## Impact structure

The Metohiyan depression in South Serbia is a large geotectonic unit of complex structure. Major tectonic units in the region, which control the depression, form a system of marginal faults, the fault system of the River Klina and Ćićavica overthrust nappe.

The geological-structural map of this Serbian region clearly shows its principal features:

1. Distinct bending of deep-seated structures in the southern, western, northwestern and northern parts of the Metohiyan depression is manifested in sharp changes of the strike directions, from E–W to NW–SE to NE–SW to N–S (Figs. 1 and 2). An impact or a vestige of its edge may explain the abrupt changes in the strike direction, or almost circular pattern of the structures. The western margin is formed by two faults: one, extending from Peć to Dečani, almost N–S, and the other, bounding the basin on southwest, strikes in the NW–SE direction from Dobroš to Damnjan. The eastern border of the Metohya Basin is similarly curved. The morphology of the bent structures and abrupt change in their strike directions on the edge of the Metohiyan depression can be satisfactorily explained neither by the convergence of the Dinaric and Shar-Pindus systems nor by plate rotation or gravitational sliding. The best explanation is that it was produced by an impact.

2. Another feature suggesting its impact structure is the recognizable circular depression, almost a thousand metres deep, filled with Neogene sediments, including thick coal deposits, bounded by fractured and deformed rocks of "the central Paleozoic and ophiolite belt" (Fig. 2). The base under the depression fill (clastics) is the some rock as those building up the sides of the depression. Also, subsidence is manifested (DRAGAŠEVIĆ 1974), in the then thinner Earth's crust in the structures, by a lower common thermal gradient.

3. More evidence of the likely impact character of the structures is provided by some geophysical data, foremostly the agreement of positive geomagnetic anomalies with the circular structure (VUKAŠINOVIĆ 2005).

4. A supportive evidence of the circular structure is the distribution of Oligocene/Miocene intermediate igneous rocks, which frequently bear large and locally Pb–Zn rich deposits (NE of Metohiya depression, Trepča, etc.).

The time when Metohiyan depression was formed is difficult to determine. It probably occurred before the Upper Cretaceous, after the Triassic (possibly also in the Paleogene). Some references (BOGDANOVIĆ, 1976) associate the fold deflections with the Mirdita peridotite massif. Could not a meteorite impact cause synchronous deviations of folds and the formation of Orahovac peridotite? The answers to this and many other questions may be searched for in the sediments of the Metohiyan depression and rocks building up its edges. The search must be multidisciplinary and comprehensive to include geological-structural, atomic-molecular, crystallographic, mineralogical, petrological, geochemical, and geophysical studies.

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## Резиме


### Нови погледи на структурни склоп Метохијског басена и његовог обода

Метохијска котлина представља једну од крупних и у структурном погледу сложених геотектонских јединица у јужној Србији. Значајне тектонске јединице, које се у том простору јављају, односно које условљавају појављивање те саме депресије су ободни систем раседа и систем раседа реке Клине и краљушт Ћићавице. И летимичним погледом на геолошко-структурну карту овог подручја Србије неке особености избијају у први план:

1. Оно што је одмах уочљиво је необично савијање дубинских структура у јужном, западном, северозападном и северном делу Метохијске котлине, што се манифестује наглим променама правца пружања од И–З, СЗ–ЈИ, СИ–ЈЗ, С–Ј и др, (сл. 1, 2). Ове ненадне и нагле промене правца пружања структура, њихов скоро кружан (прстенаст) облик може бити објашњен импактом, односно може бити наслеђен од обода импакта. На западном ободу постоје два раседа, који се пружају: један од Пећи до Дечана, скоро у правцу С–Ј, а други, који чини југозападну границу басена, протеже се у правцу СЗ–ЈИ, од Доброжа до Дамњана. Нешто слично имамо и у источном ободном делу Метохијског басена. Оваква морфологија структура са великим повијањем и наглим променама правца у ободном делу Метохијске депресије, не може се задовољавајуће објаснити, тектонским сутоком Динарске и Шарско–пиндске системе, као ни евентуалном ротацијом пложа или гравитацијским колапсом, већ импактном структуром.

2. Следећа особеност која указује на импактну структуру је седиментолошки препознатљива готово 1000 метара дубока кружна депресија испуњана неогеним седиментима са великим наслагама угља, ограничена разломљеним и деформисаним творевинама "централног палеозојског и офиолитског појаса" (сл. 2). Заправо основу седимената (кластита) који испуњавају котлину чине стене које изграђују ободни део депресије. Исто тако је евидентно тоњење (види ДРАГАШЕВИЋ 1974), мања дебљина Земљине коре у овим структурама, као и нижи температурни ток (градијент) од убичајених.

3. Следећи доказ у односу на могуће импактне карактере структура нуде неке геофизичке чињенице. У првом реду је сагласност позитивних геомагнетских аномалија са овом кружном прстенастом структуром (ВУКАШИНОВИЋ 2005).

4. Идеју о прстенастој структури поткрепљује дистрибуција олигомиоценских интермедијарних вулканита, који су жесто носиоци великих и местимижно богатих Pb–Zn лежишта (североисточо од Метохијске котлине – Трепча и др.).

Формирање метохијске депресије, тешко је временски тачно одредити. Највероватније да се то десило пре горње креде, а после тријаса (могуће и у палеогену). Неки аутори (БОГДАНОВИЋ 1976) скретање набора везује за Мирдитски перидотитски масив. Није ли скретање бора и настанак ораховачког перидотита временски повезано и узроковано метеоритским ударом, односно импактом. Одговор на ово питање и, многа друга, крије се како у седиментима Метохије, тако и творевина његовог обода и захтева студиозно проучавање. Та проучавања морају да буду мултидисциплинарна и свеобухватна од геолошко-структуролошких, атомско-молекуларних, кристалографских, минералошких, петролошких, геохемијских, геофизичких и других испитивања.

| ГЕОЛОШКИ АНАЛИ БАЛКАНСКОГА ПОЛУОСТРВА<br>ANNALES GÉOLOGIQUES DE LA PÉNINSULE BALKANIQUE | 68 | 39–51 | БЕОГРАД, децембар 2007<br>BELGRADE, December 2007 |
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# *Neomeris mokragorensis* sp. nov. (Calcareous alga, Dasycladales) from the Cretaceous of Serbia, Montenegro and the Northern Calcareous Alps, (Gosau Group, Austria)

RAJKA RADOIČIĆ[1] & FELIX SCHLAGINTWEIT[2]

**Abstract.** The new species of the genus *Neomeris* – *Neomeris mokragorensis* sp. nov. described in this paper from western Serbia originates: from the Albian of Mokra Gora (the succession transgrading on the serpentinite) and from the Turonian of the Skrapež–Kosjerić area (the succession transgrading on the Carboniferous). The presence of this species has been noted in the Turonian of the Kukes and in the Santonian of the Metohija Cretaceous Unit (Mirdita Zone). In the surrounding of Podgorica (Dinaric Carbonate Platform, Montenegro), the same species previously was presented as *Neomeris* cf *cretacea* STEINMANN. Well preserved *Neomeris* specimens from the Turonian to the Santonian strata of the Northern Calcareous Alps (Gosau Group, Austria) previously described as *Neomeris circularis* BADVE & NAYAK, is assigned to *Neomeris mokragorensis* sp. nov. *Neomeris mokragorensis* is characterized by a thin loosed skeleton formed only around ampullae, by which, besides the form of the ampullae, this species is clearly distinct from *Neomeris cretacea* (Steinmann).

**Key words:** Dasycladales, genus *Neomeris*, new species, Middle and Late Cretaceous, Serbia, Montenegro, Austria.

**Апстракт.** Из кредних слојева западне Србије описана је нова врста дасикладалеса *Neomeris mokragorensis* sp. nov. до сада нађена у албу Мокре Горе (типски локалитет) и турону долине Скрапежа. Осим у западној Србији, наласци ове врсте познати су у Мирдита зони: из доњотуронских слојева Кукеске и сантонских слојева Метохијске кредне јединице. У околини Подгорице (Динарска карбонатна платформа, Црна Гора) неомерис раније приказан као *Neomeris* cf. *cretacea* STEINMANN сада се приписује новој врсти. За разлику од релативно масивног карбонатног скелета такође албске врсте *Neomeris cretacea*, скелет нове врсте формиран је калцификацијом појединачних ампула те је стога слабо везан и ограничен само на дио око репродуктивних органа (ампула). Ове двије врсте се разликују и по облику ампула које су овоидно-субсферичне код нове врсте, насупрот издужено елиптичним ампулама врсте *Neomeris cretacea.*

**Кључне ријечи.** Dasycladales, род *Neomeris*, нова врста, средња и млађа креда, Србија, Црна Гора, Аустрија.

## Introduction

*Neomeris mokragorensis* sp. nov. is described from the Cretaceous of western Serbia. The today living genus *Neomeris* LAMOUROUX (dasycladalean alga) is known since the Early Cretaceous (Valanginian). Following the compilation of GRANIER & DELOFFRE (1993) only two species of *Neomeris* (excluding the subgenus *Larvaria* DEFRANCE, and *Drimella* RADOIČIĆ) are knouwn from Cretaceous strata: *Neomeris cretacea* (STEINMANN) (Albian of Mexico) and *Neomeris circularis* BADVE & NAYAK, 1993 (?Cretaceous of India). *Neomeris cretacea* was throughly described and well illustrated from the type-locality area by BARATTOLO (1990), whereas *Neomeris circularis* was introduced by one single poorly preserved fragment. GÉNOT (1994) did not list this species in valid Cretaceous *Neomeridae*. Well preserved representatives of *Neomeris* from the Late Cretaceous of the Northern Calcareous Alps, ascribed by SCHLAGINTWEIT & EBLI (1995) to *Neomeris cirularis,* is assigned, in this paper, to *Neomeris mokragorensis*. sp. nov.

[1] Kralja Petra I. 38, 11000 Belgrade, Serbia. E-mail: rradoicic@sezampro.yu
[2] Lerchenauerstrasse 167, München. E-mail: EF.Schlagintweit@t-online.de

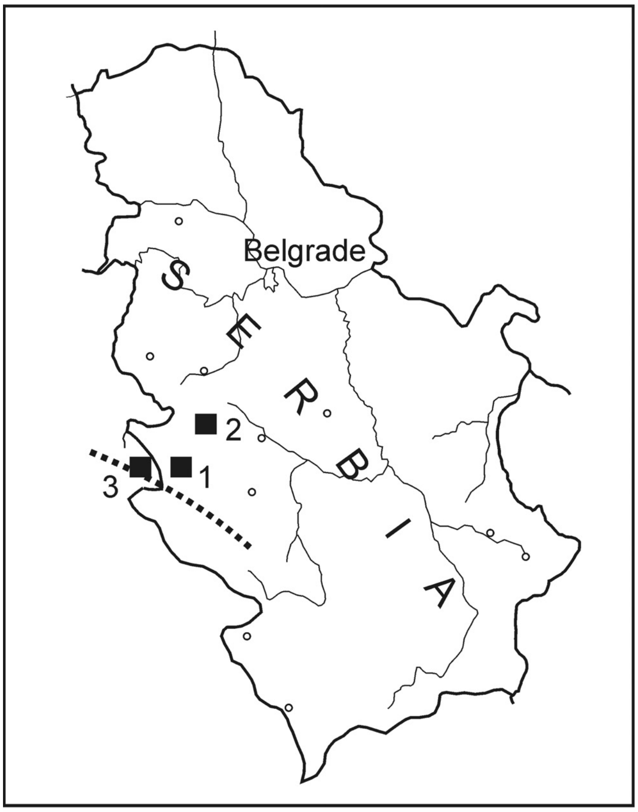


Fig. 1. Location map of the studied sections. 1, Mokra Gora; 2, Skrapež Valley; 3, Vardište; Dotted line: Drina Cretaceous Unit.

## Geological setting

### Western Serbia

In western Serbia, *Neomeris mokragorensis* sp. nov. has been found in two regions: in the Albian sediments of Mokra Gora (Figs. 1, 1) and in the Turonian of the Skrapež Valley (Figs. 1, 2).

#### *Mokra Gora (cf. Mirdita Zone)*

The Cretaceous succession of Mokra Gora is part of the Drina Cretaceous Unit (RADOIČIĆ 1995). In western Serbia, this unit crops out in the Zlatibor–Tara–Zvijezda Belt, from where it stretches further to the area of Višegrad in eastern Bosnia (Fig. 1, dotted line). Large ophiolite massifs, basinal Diabase-chert Formation and shallow water Triassic carbonates are transgressively and diachronously overlain by Albian to Turonian–Lower Senonian sediments. The Albian, Early–Middle Cenomanian, Middle Turonian and Early Senonian ages of Mokra Gora successions were documented by rich micro and macrofossil associations (ŽIVKOVIĆ 1905; LÓCZY 1924; MILOVANOVIĆ 1934; PEJOVIĆ & RADOIČIĆ 1971; BANJAC 1994) and also by Albian–Cenomanian palynolospectra (DULIĆ 1994). Precise stratigraphic data on the interval between the Early–Middle Cenomanian and the Middle Turonian limestone with rudists (on the Ograđenica marly sequence, respectively) are lacking. The Ograđenica marly sequence (Fig. 5) represents a peculiar feature in the paleogeography of the Drina Cretaceous Unit, occurring in the Mokra Gora area only, as a result of Mid-Cretaceous tectonic events. Early Cenomanian slump breccia (Fig. 6), observed in the western periphery of Mokra Gora, was the first announcement of these events.

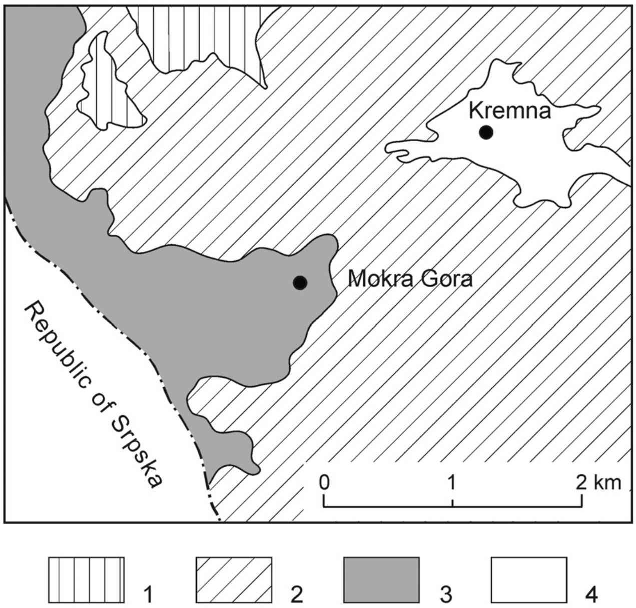


Fig. 2. Simplified geological map of the eastern Mokra Gora area. 1, Triassic; 2, serpentinites; 3, Cretaceous; 4, Kremna Neogene. According “Carte géologique de la R. S. de Serbia”, 1:200 000, by MILOVANOVIĆ & ĆIRIĆ (1968).

In the eastern part of the Mokra Gora (Fig. 2), Cretaceous sediments, represented by some tens of metres of marls and marly limestones, overlying serpentinites with weathering crust, outcropped at places. These freshwater? to brackish deposits without noted microfossils, but in some beds with molluscs (*Glauconia, Acteonella*, *Natica*, *Cerithium*, other different gastropods; *Lucina, Cirena*, *Lopha*, *Gryphaea,* ostreid coquinas at places and other bivalvies) were ascribed to the Albian, although a latest Aptian age of the lowermost beds cannot be excluded. These sediments gradually pass into a sequence of alternating marls and marly-silty, peloidal or bioclastic limestone (Fig. 4), some of them containing benthic foraminifera, *Charophyta* gyrogonites and small molluscs. Within the beds about 10–12 metres below the outcrop in Fig. 4, the presence of *Hemicyclammina sigali* MAYNC indicated an age not older than middle Albian. The hand sample 011541 containing *Neomeris mokragorensis* sp. nov. and marls with *Atopochara trivolvis* PECK (011541a; see LJUBOVIĆ-OBRADOVIĆ 1995) are from the base of this outcrop. Wackestone – p. p. packstone with *Neomeris* contains frequent annelids (prevail-

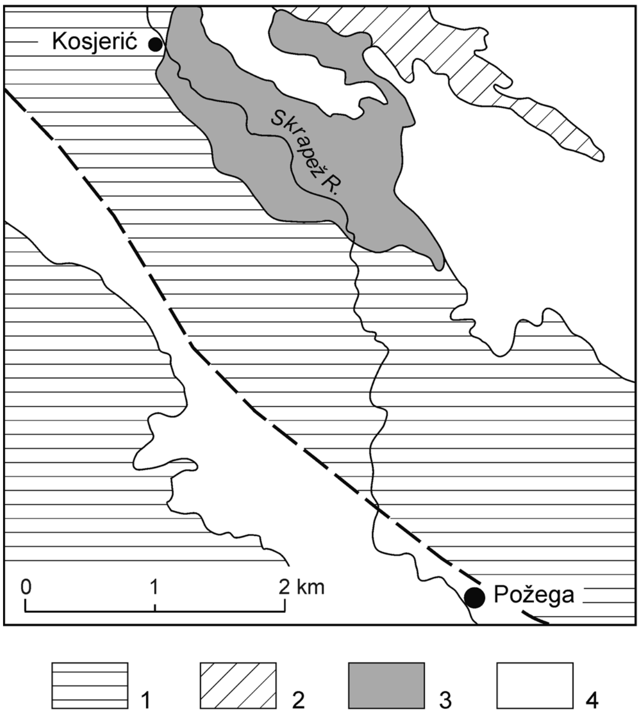


Fig. 3. Simplified geological map of the Skrapež Valley area. 1, Paleozoic (Lower Carboniferous); 2, Diabase-chert Formation; 3, Cretaceous; 4, Neogene. Aaccording "Carte géologique de la R.S. de Serbia", 1:200 000, by MILOVANOVIĆ & ĆIRIĆ (1968).

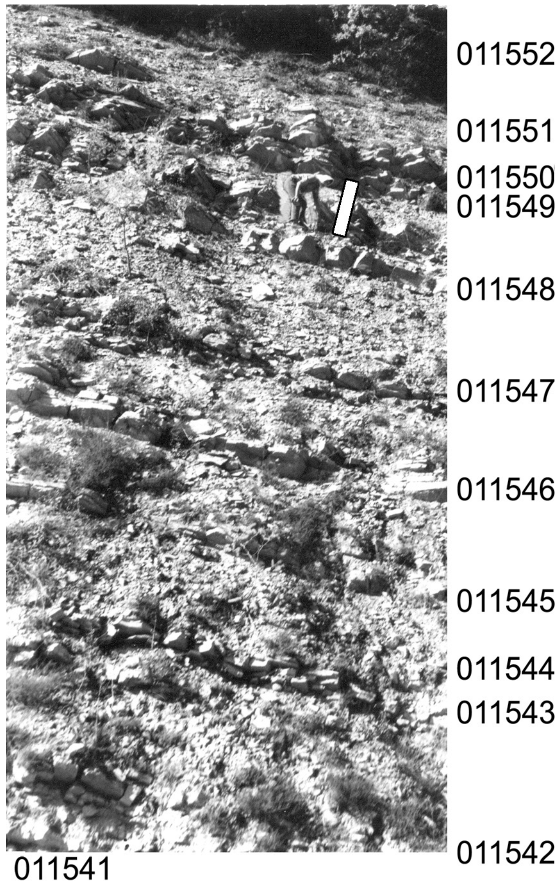


Fig. 4. Outcrop of a part of the Albian (Vraconian) deposits (about 15 metres) in the eastern part of Mokra Gora, at the crossing of the road and the railway (Photo: 1970).

ing fragments), rare *Charophyta* gyrogonites, micromolluscs and few foraminifera (last occurrence of *Hemicyclammina sigali* in this sequence!) In the sample 011545, only few a *Charophyta* gyrogonites were detected (Pl. 3, Figs. 9, 10). Very rare *Ovalveolina maccagnoae* DE CASTRO, associated with minute molluscs and rare ostracods, were found in samples 011546, 011549 and 011551. They became abundant in the topmost beds (Pl. 3, Figs. 7, 8). This sequence is ascribed to the Late Albian–Earliest Cenomanian (Vraconian).

Upward, badly exposed Early–Middle Cenomanian limestone with orbitolinids, *Pseudorhapydionina laurinensis* (DE CASTRO), *Charentia cuvillier*i NEUMANN, *Cuneolina*, nezzatidae and ostracods is present. Further, followed friable deposits, some of them rich in molluscs (e.g. ostreids coquina, those with different gastropods), corresponding to the lower part of the Ograđenica marly sequence (Fig. 5). The succession continues in friable hemipelagic marly limestone with rare and badly preserved ammonites, echinoderms and rare planktonic microfossils (minute *Pithonella*, "*Hedbergella*"). In this part of the sequence, olistostromatic beds and some bioclastic limestone with debris of rudists and other molluscs, halimedacean algae and rare foraminifera were noted. Based on the ammonites, LOCZY (1924) considered a Cenomanian–Turonian age for this deposit, a view accepted by later researches. The Ograđenica marly sequence is discontinuously overlain by Middle Turonian to Early Senonian limestone with rudists (Fig. 5, on the top-arrow). The presence of the Santonian species *Vaccinites oppeli* (DOUVILLE) was mentioned by MILOVANOVIĆ, 1934, probably from the upper part of this limestone sequence. Younger beds of the Santonian are not documented.

It should be mentioned at this point that the Albian sequence of the same Cretaceous Unit at Vardište, westward of Mokra Gora (Fig. 1, 3), have been studied by BORTOLOTTI *et al.* (1971). According these authors "the fossils indicate an Late Jurassic age and an environment of shallow water and anomalous salinity". Between the illustrated microfossils shown in Fig. 6, the specimen "L", assigned with reserve to *Haplophragmoides* sp. is recognized as *Hemicyclammina sigali* MAYNC, a species widely distributed in the Albian of Mokra Gora.

In the basal part of the Drina Cretaceous Unit, fossils are rare and badly preserved. In addition, Albian shallow water facies in this area are different from those in the Albian of the Periadriatic Carbonate Platforms, therefore these deposits were not recognized, by our Italian colleagues, as Albian.

Fig. 5. Ograđenica marly sequence, on the top (arrow) limestone with rudists (Photo: 1970).

Fig. 6. Lower– Middle Cenomanian slump breccia cropped out during road constructions in 1970, Kotroman, Mokra Gora (Photo: 1970).

### *Skrapež Valley (The Cretaceous of Kosjerić, western belt of the Vardar Zone)*

The Late Cretaceous deposits of Skrapež occur in the most eastern part of the Kosjerić Cretaceous area (Fig. 3). The oldest known sediments are Cenomanian in age transgrading over Early Carboniferous strata. The shallow water Cenomanian and p.p. Turonian deposits gradually pass into a basinal succession.

In the Skrapež Vallley, *Neomeris mokrogorensis* sp. nov. was found in two localities. In both cases in the sequences between the *Cisalveolina fraasi* Zone and sediments with hippuritids. In the locality Gradnja (sampled in 1966, the outcrop was 14 m thick), the *Neomeris* was found in the 4 m thick marly limestone (samples in the base and on the top, 07504, 07505) associated with barrel-shaped segments of *Halimeda*, *Terquemella, Nezzazatinella picardi* (HENSON), *Gendrotella rugorensis* (MAYNC), remains of gastropods and rare coral debris. About 10 metres upward (marly limestone, sandy marls and sandstones), Turonian hippuritids where discovered within a conglomeratic bed (data of D. PEJOVIĆ 1966). The other locality with *Neomeris mokragorensis* sp. nov. is on the opposite riverside to Gradnja.

Limestone with *Neomeris mokragorensis* sp. nov. in the Skrapež area was deposited in a low energy, shallow-water, lower?–middle ramp environment.

## Other localities

### Mirdita Zone and Montenegro

*Neomeris mokragorensis* sp. nov. has been recognized in the Turonian and Santonian limestone of the Mirdita Zone, and in the Albian (revised) of the Dinaric Carbonate Platform (Montenegro).

Mirdita Zone, Kukes Cretaceous Unit. A rare prevailing *Neomeris* fragment was found in the Early Turoian (*Helvetotruncana helvetica* Zone) of the Gradište succession, where it was associated with frequent *Halimeda elliotti* CONARD & RIOULT (RADOIČIĆ 1998, Pl. 1, Figs. 1–3). From here originates a unique *Neomeris mokragorensis* specimen with the contour of the central stem preserved and, consequently, the space corresponding to the primary laterals (Fig. 7). Dispersed ampullae and fragments of *Neomeris* in the Santonian limestone of the Metohija Cretaceous Unit (Mirdita Zone, RADOIČIĆ 1997, Pl. 4, Fig. 12) are ascribed to this species.

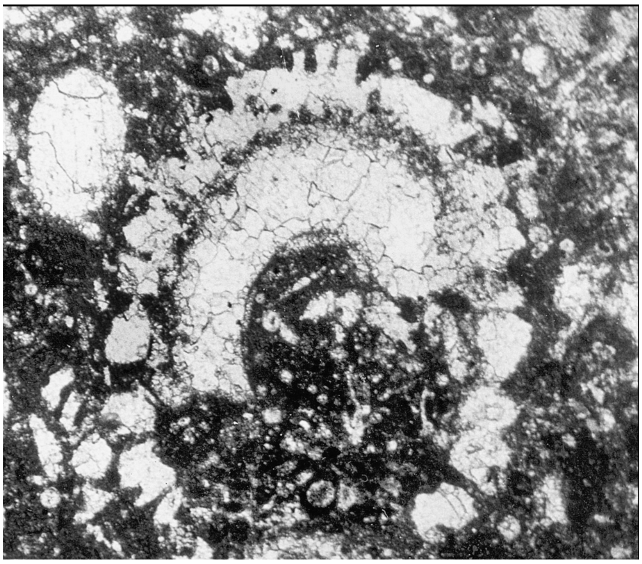

Fig. 7. *Neomeris mokragorensis* sp. nov. with preserved contour of the main stem, Turonian, *Helvetotruncana helvetica* zone, Kukes Cretaceous Unit (Mirdita Zone), thin slide RR2049, sample 015203, ×39.

Dinaric Carbonate Platform Montenegro. From the Albian marly limestone in the surroundings of Podgorica (SE segment of the DCP), previously ascribed to the Cenomanian, this species was presented as *Neomeris* cf. *cretacea* STEINMANN (RADOIČIĆ 1976; Pl. 5, Figs. 1–2). The limestone with *Neomeris mokragorensis* sp. nov. was deposited in a very shallow protected inner platform area, characterized by the presence of beds with Atopochara trivolvis.

## Austria

The Gosau Group of the Northern Calcareous Alps uncoformably overlies the already deformed sediments of the Upper Austroalpine nappe complex. The remants of the neritic Lower Gosau Subgroup comprise different facies associations (continental to shallow marine), which altogether cover a range from the Late Turonian to the Early Campanian (e.g. WAGREICH & FAUPL 1994; SANDERS 1998). The occurring lithologies (marls, limestones, sandstones) comprise a wide range of nearly pure silicoclastic, mixed clastic carbonate and pure carbonate lithologies, including also diverse types of bioconstructions *Neomeris mokragorensis* sp. nov., assigned to *Neomeris circularis* BADVE & NAYAK, has already been reported from various localities of the Lower Gosau Group of Austria:

Pletzachalm, Tyrol, (see SCHLAGINTWEIT & EBLI 1995).

Eisenbach, Salzkammergut area: Brownish lagoonal wackestones with miliolids (*Quinqueloculina*, *Vidalina*), *Thyrsoporella eisenbachensis* SCHLAGINTWEIT & LOBITZER (abundant), *Dissocladella pyriformis* SCHLAGINTWEIT (common) and *Neomeris mokragorensis* sp. nov. (rare) and plant remains (see SCHLAGINTWEIT & LOBITZER 2003). Stratigraphy: ?Late Turonian.

Hofergraben, type area of the Gosau Group: Mixed silicoclastic-calcareous tempestites layers within marls of the Hochmoos Formation with abundant debris of pelycopodes, *Neomeris mokragorensis* sp. nov., *Jodotella koradae*, *Trinocladus tripolitanus* (RAINERI), and *Halimeda paucimedullaris* SCHLAGINTWEIT & EBLI (see SCHLAGINTWEIT 2004).

Summarizing, *Neomeris mokragorensis* sp. nov. occurs in lagoonal, partly marly, wackestones with or without silicoclastic influence of the Lower Gosau Subgroup in strata ranging from Late? Turonian to Late Santonian age.

## Paleontology

Order *Dasycladales*
Family *Dasycladaceae*
Genus *Neomeris* (LAMOUROUX, 1816) DELOFFRE, 1970

***Neomeris mokragorensis*** sp. nov.
Pl. 1, Figs. 1–12; Pl. 2, Figs. 1–3; Pl. 3, Figs. 1–6.

1962 *Neomeris cretacea* STEINMANN – DELMAS & DELOFFRE, 216, pls. 1–2, Albian–Cenomanian of Aquitane, France.

nf 1971 *Neomeris* cf. *cretacea* STEINMANM – PEJOVIĆ & RADOIČIĆ: 138, Cenomanian (revised. Albian), Mokra Gora.

1976 *Neomeris*? cf. *N. cretacea* STEINMANN – CONRAD & PEYBERNÈS: 187, figs. 11b, 14e, Albian of the Spain.

1976 *Neomeris* cf. *cretacea* STEINMANN – RADOIČIĆ: pl. 5, figs. 1–2, Cenomanian (revised. Albian), Montenegro.

1991 *Neomeris* cf. *pfendere* KONISHI & EPIS – SCHLAGINTWEIT: 49, pl. 18, fig. 8, Albian of the Northern Calcareous Alps.

1995 *Neomeris circularis* BADVE & NAYAK – SCHLAGINTWEIT & EBLI: 718, text-fig. 3, pl. 1, figs. 1–10, Late Turonian–Early/Middle Coniacian of the Northern Calcareous Alps.

1995 *Neomeris circularis* BADVE & NAYAK – SCHLAGINTWEIT: 101, pl. 1, figs. 6, 11, Late Santonian of the Northern Calcareous Alps.

1998 *Neomeris* sp. – RADOIČIĆ: pl. 4, fig. 12, Santonian, Mirdita Zone.

*Origin of name*. The species name refers to the type area Mokra Gora in Western Serbia.

*Holotype*. The transversal slightly oblique section with few individually calcified ampullae (Pl. 1, Fig. 12, arrow), holotype (left) and (right) longitudinal section, arrow: primary calcified ampulla. Pl. 2, Fig. 1, thin slide RR4588 (sample 011541), Collection R. RADOIČIĆ, Geological Institute, Belgrade.

*Isotypes*. Different section in thin slides RR4588, 4588/1, 4588/2 and 4588/3 (sample 011541) some of them illustrated in the Pl. 1.

*Type locality*. Mokra Gora, the outcrop along the road, at the crossing of the road with the railway, 43°47’45.80” N, 19°30’41.12’’ E (Fig 4, photo 1970).

**Age.** Albian–Santonian, (in the type locality Middle––Late Albian).

**Diagnosis.** Representative of *Neomeris* with an elongated cylindrical thallus and densely set whorls with laterals set in quincunxes. Calcification formed in distal part of the whorls around fertile ampullae only, resulting in a wide central cavity. Primary laterals, basal parts of the secondaries and their distal swellings (cortex) unknown (not calcified); fertile ampullae ovoidal-subspherical in shape and individually calcified including the membrane and thin sheath around the ampulla, usually overgrown during diagenesis.

**Dimensions**. Data from western Serbia and the Northern Calcareous Alps show good accordance. Minimum values (D, d) from the Alps correspond to a tiny specimen (SCHLAGINTWEIT & EBLI 1995: pl. 1, fig. 5).

| | Austria | Serbia |
|---|---|---|
| D | 0.72–2.32 | 1.28–1.88 |
| d | 0.58–1.68 | 1.05–1.52 |
| d/D | 0.6–0.88 | 0.7–0.86 |
| w | 25–34 | 30–45 |
| L | | 9 (12, on the sample) |

According the specimen *Neomeris mokragorensis* sp. nov. from the Kukes Cretaceous Unit, Mirdita Zone (Fig. 7) the main stem of this species is about one third of the diameter.

**Description.** The variably preserved, simple, thin, loosely connected skeletons (Pl. 1, Figs. 1–6) consist of individually calcified laterally fussed ampullae, alternating in whorls. The skeleton of the primary carbonate sheaths, due to recrysallization and overgrowth sometimes becomes better preserved ( Pl. 1, Fig. 3; Pl. 2, Fig. 2; Pl. 3, Fig. 4) The primary calcified ampullae were preserved in both the studied material – from the Alps (SCHLAGINTWEIT & EBLI 1995, pl. 1, figs. 4, 8, 9) and from Western Serbia (Pl. 1, Fig 11). The ampullae have an ovoidal-subspheric form. Usually, in random sections in thin slides, have a circular form because the axial sections of the ampullae, as those in the fragment shown in Pl. 1, Fig. 11, are extremely rare. In the same fragment (and in some others similarly preserved) are clearly distinct a primary calcified membrane (up to 0.01 mm thick) and a sheath around it (up to 0.02 mm thick). Dimensions of ampullae, in the axial sections (according Pl. 1, Fig. 12): internal diameter 0.1 mm, external with calcareous sheath 0,16 mm Axial dimensions, internal 0.13 mm, external, with primary sheath, about 0.2 mm. Some specimens or a part of them consist only of orthosparite internal moulds of ampullae (about 0.1 mm in diameter) or of subspheric to irregular sparite units, mending both internal moulds and sheaths (Pl. 1, Figs. 2, 6, partly Fig. 1).

The particularly preserved, unique specimen of this species is shown in Pl. 1, Fig. 4. It has a netlike skeleton of fused individual calcified ampullae with micrite filling. Similarly preserved are the oblique sections in Pl. 1, Figs. 5, and 10, both with mixed individually calcified and completely recrystallized ampullae.

The middle part of the secondary laterals, visible in the tangential sections, usually appears as micritic pores (Pl. 1, Fig. 8, d is about 0.025 mm) somewhat in a displaced position.

**Relations.** *Neomeris mokragorensis* sp. nov. differs greatly from *Neomeris cretacea* (STEINMANN) by the skeletal structure and by the form of the reproductive organs (ampullae). The calcareous skeleton of *Neomeris cretacea* is compact and relatively massive, the ampullae are elongated-ellipsoidal in form. The biometric differences between the two species were given by SCHLAGINTWEIT & EBLI (1995).

## Acknowlegments

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## Резиме

### *Neomeris mokragorensis* sp. nov. из кредних седимената Србије, Црне Горе и Сјеверних кречњачких Алпа Аустрије (Gosau група)

Нова врста рода *Neomeris* описана је из кредних седимената западне Србије, из алба Мокре Горе (типски локалитет) и турона долине Скрапежа. Забиљежени су такође налази ове врсте у доњем турону Кукеске и сантону Метохијске кредне јединице Мирдита зоне. *Neomeris mokragorensis* sp. nov. из албских кречњака околине Подгорице (ЈИ сегмент Динарске карбонатне платформе, Црна Гора) био је раније приказан као *Neomeris* cf. *cretacea* STEINMANN (RADOIČIĆ 1976, таб. 5, сл. 1 и 2).

Фамилија *Dasycladaceae*

Род *Neomeris* (LAMPOUROUX, 1816 ) DELOFFRE, 1970

**_Neomeris mokragorensis_** sp. nov.
Таб. 1, сл. 1□12; Таб. 2, сл. 1□3; Таб. 3, сл. 1□6

**Поријекло имена**. по Мокрој Гори гдје се налази типски локалитет.

**Холотип**. попречан мало искошен пресјек са различито очуваним ампулама (таб. 1, сл. 11, стрелица), холотип (лијево) и лонгитудиналан пресјек са очуваном примарно калцифицираном ампулом (таб. 1, сл 12, стрелица). Препарат PP4588, узорак 011541, Колекцја Р. РАДОИЧИЋ, Геолошки институт Београд.

**Иситипови**. Различити пресјеци у препаратима PP4588, 4588/1, 4588/2 и 4599/3 од којих су неки приказани на табли 1.

**Типски локалитет**. Профил (приказан на слици 4, снимљен 1970. године) откривен поред пута у источном дијелу Мокре Горе, на мјесту гдје се укрштају жељезнички и колски пут.

**Дијагноза**. *Neomeris* веома издуженог цилиндричног талуса са густим пршљеновима у којима су огранци наизмјенично распоређени. Калцификација је обухватала само дистални дио пршљена, око фертилних ампула, стога кречњачки скелет карактерише пространа унутарња празнина. Примарни огранци, базални дио секундарних огранака и њихово дистално проширење (кортекс) непознати. Фертилне ампуле овоидно-субсферичног облика, индивидуално су калцифициране (мембрана и спољашњи омотач) и обично секундарно измијењене – прекристалисале и надрастале током дијагенезе.

*Neomeris mokragorensis* sp. nov. веома се разликује од врсте *Neomeris cretacea* по структури скелета и облику репродуктивних органа (ампула).

Према расположивим подацима стратигрфско распрострањење нове врсте је алб–сантон. У типском локалитету старост слоја са *Neomeris mokragorensis* sp. nov. је средњи–горњи алб.

PLATE 1

Figs. 1–12. *Neomeris mokragorensis* sp. nov. from the type locality, Albian of the Mokra Gora.

1–6. Different skeleton preservations:

1. The primary calcification obliterated by recrystrallization; some ampullae preserved as orthosparite moulds (arrow). Longitudinal slightly oblique section, thin slide RR4588/3, scale bar = 0.5 mm.
2. A skeleton in the disintegration stage; note that, notwithstanding a few, the ampullae are in part preserved on primary calcification (arrow). Longitudinal-tangential section, thin slide RR4588/2, scale bar = 0.5 mm.
3. Prevailing recrystallized skeleton, mixed preservation, few ampullae preserved as individually calcified, some as orthosparite moulds (arrows). Longitudinal slightly oblique section, thin slide RR4588/3, scale bar = 0.5 mm.
4. Netlike skeleton. Longitudinal oblique section cat distal part of the ampullae, thin slide RR4588/2, scale bar = 0.5 mm.
5. Mixed preserved skeleton. Oblique section, thin slide RR4588/3, scale bar = 0.5 mm.
6. Oblique section of the skeleton (a frequent type of preservation), thin slide RR4588/3, scale bar = 0.5 mm.
7. A fragment of the oblique section, prevailing preserved individually calcified ampullae, thin slide RR4588/2, scale bar = 0.5 mm.
8. A fragment of a skeleton with micrite filled ampullae and (left) *Charophyta* gyrogonite, tangential section; thin slide RR4588/3, scale bar = 0.5 mm.
9. A fragment of the whorl, few ampullae with well preserved primary calcification, some recrystallized and deformed by overgrowth, thin slide RR4588/3, scale bar = 0.5mm.
10. A fragment of a disintegrated whorl; ampullae filled by orthosparite, membrane and sheath recrystallized, thin slide RR4588/3, scale bar = 0.025 mm.
11. The form of the ampulla characteristic for this species, axial section: well preserved calcified membrane and sheath, detail from Fig. 12., thin slide RR4588/2, scale bar = 0.015 mm.
12. A fragment of the whorl; on the left transversal sections of two ampullae with well preserved primary calcification of the membrane and the sheath, thin slide RR4588/2, scale bar = 0.050 mm.

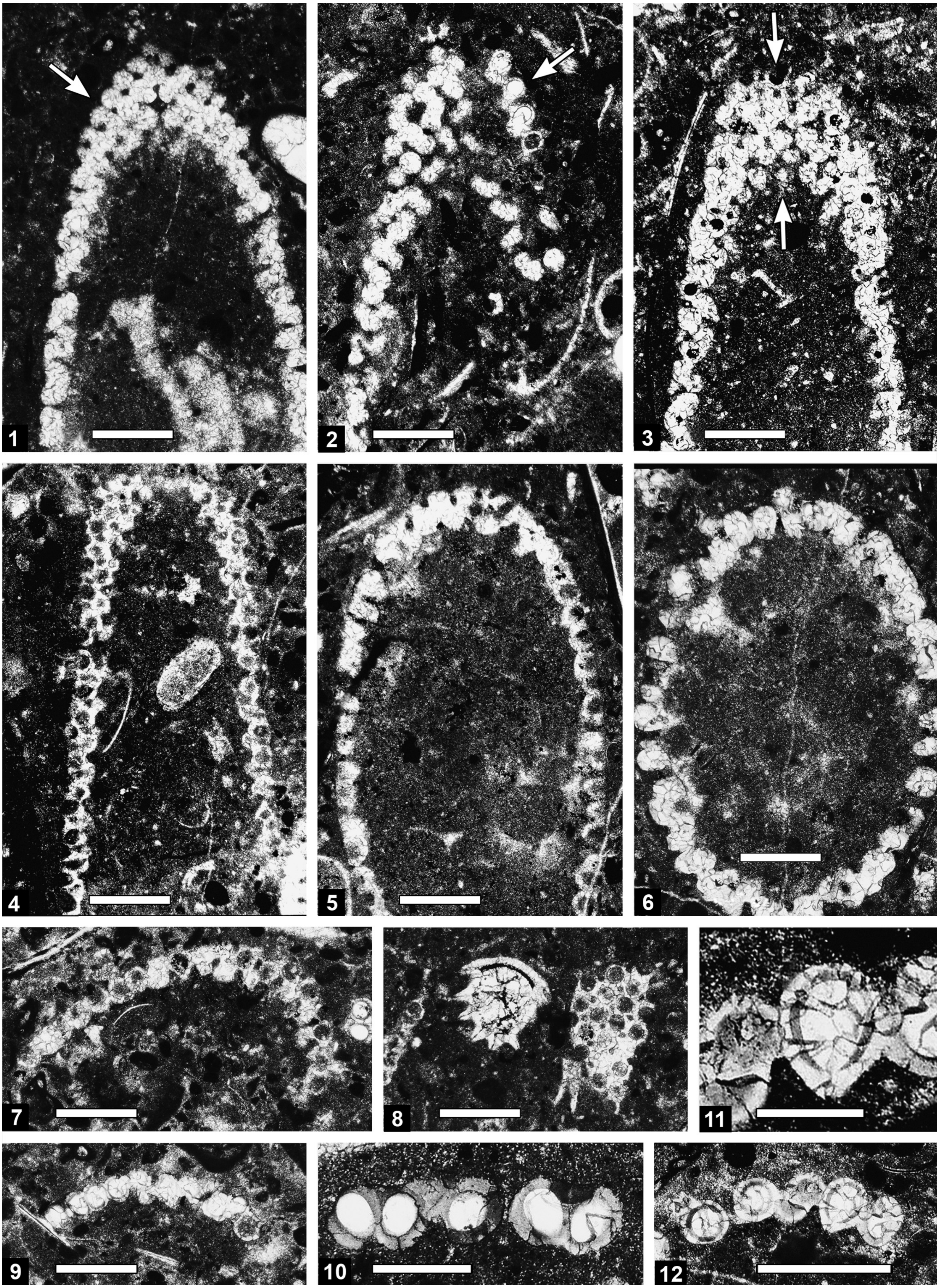
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PLATE 2

Figs. 1–3. *Neomeris mokragorensis* sp nov.

1. Holotype, slightly oblique transversal section (left) showing some individually calcified ampullae (arrow), and (right) longitudinal section with one primary calcified ampulla (arrow). Thin-slide RR4588 (sample 011541); Albian, Mokra Gora (Fig. 4), scale bar = 1 mm.
2. Oblique section of the skeleton with altered primary calcification and orthosparite ampullae moulds, thin slide 4666, Turonian, Skrapež, scale bar = 0.6 mm.
3. Detail from Fig. 2, scale bar = 0.14 mm.

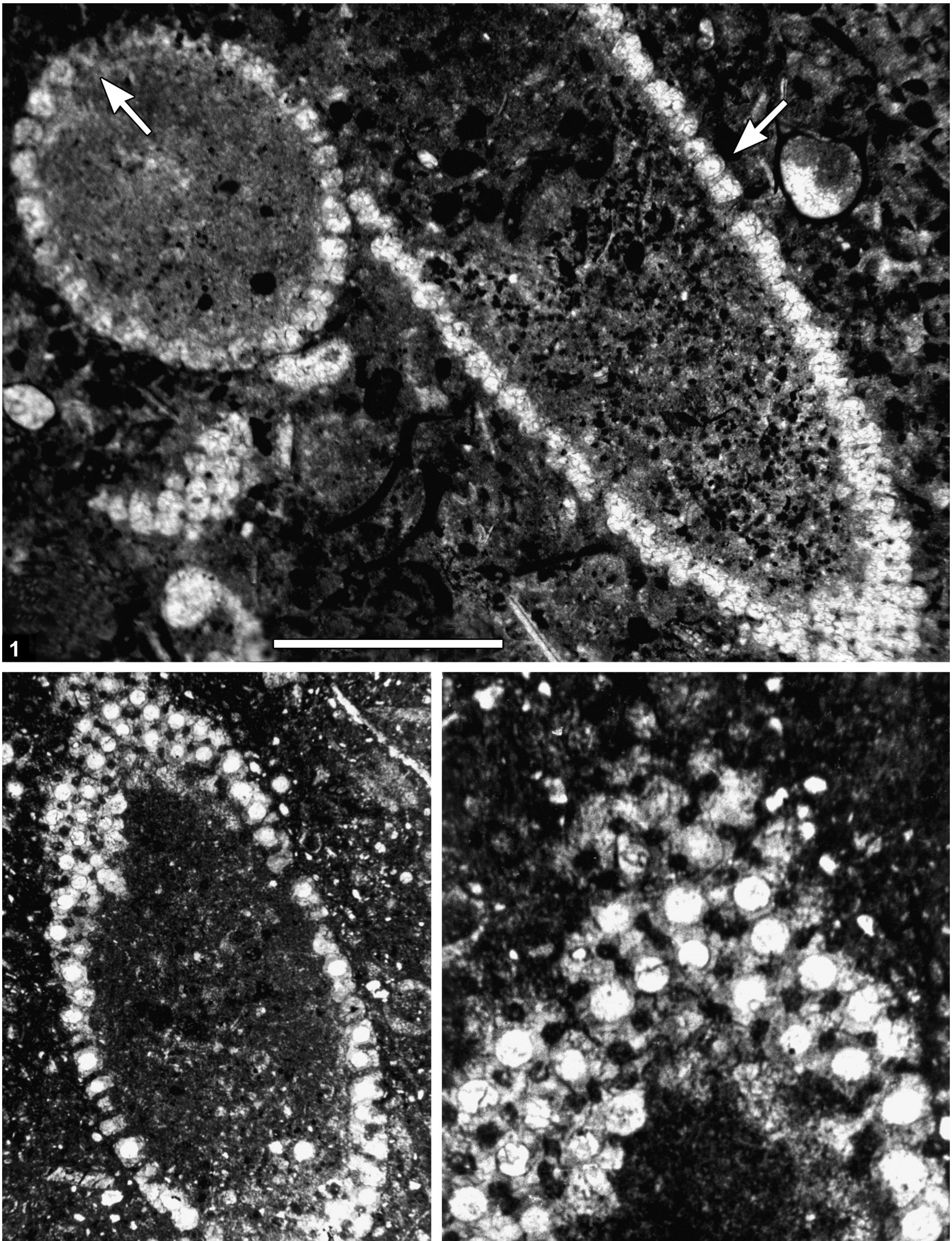
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PLATE 3

Figs. 1–6. *Neomeris mokragorensis* sp. nov., from the Late Cretaceous of the Lower Subgroup of the Northern Calcareous Alps.

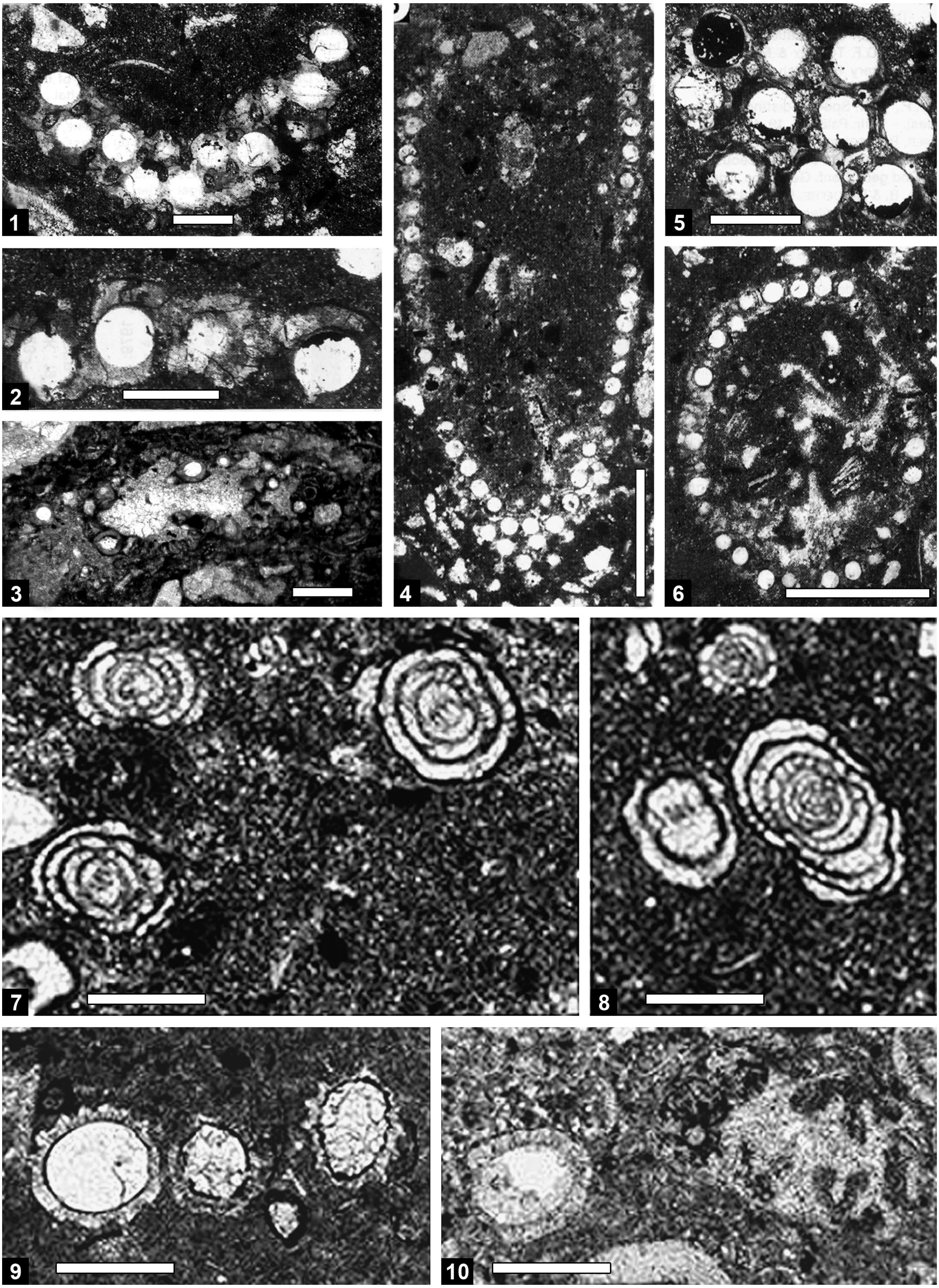
1. Oblique section showing ampullae and sterile laterals, thin-section BSPG 5212-a-93, scale bar = 0.2 mm.
2. A fragment showing spherical ampullae, thin-section BSPG 5214-a-93, scale bar = 0.2 mm.
3. Bentic foraminifer Reophax sp. with agglutinated ampullae of the *Neomeris*, thin-section Pletz 1, scale bar = 0.5 mm.
4. The longitudinal section, slightly oblique, thin section BSPG 5213-a-93, scale bar = 1 mm.
5. A fragmentary tangential section, slightly oblique, thin-section BSPG 5215-a-93, scale bar = 0.2 mm.
6. A transverse section slightly oblique , thin-section BSPG 5213-a-93, scale bar = 1 mm.

Figs. 7–10. Foraminifera and *Charophyta* gyrogonites from the Albian (Vraconian) sequence shown in the Fig. 4.

7–8. *Ovalveolina maccagnoae* DE CASTRO, thin slide RR5226 (sample 011552), scale bar = 0.5 mm.

9. *Charophyta* gyrogonites, thin slide RR5218 (sample 011545), scale bar = 0.5 mm.

10. A fragment of the gyrogonites and the micronerineid fragment, thin slide RR5224 (sample 011551), scale bar = 0.5 mm.



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|---|---|---|---|

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# A mid-Miocene age for the Slanci Formation near Belgrade (Serbia), based on a record of the primitive antelope *Eotragus* cf. *clavatus* from Višnjica

Jan van der Made[1], Slobodan Knežević[2] & Ivan Stefanović[2]

**Abstract.** In a borhole at Veliko Selo near Belgrade in the Miocene lacustrine sediments Slanci, which are locally known as the Slanačka Serija, a mammal tooth was found. The age of these deposits is under discussion. The fossil is here described and attributed with a query to the primitive antelope *Eotragus clavatus* (Gervais, 1850), which is suggestive of a Early Serravallian ("upper Badenian") or Early Middle Miocene age for these deposits, whereas an Aquitalian or Eggenburgian ("Egerian" or "Eggenburgian") (Early Miocene) age can be ruled out.

**Key words:** Miocene, Badenian, Serbia, Belgrade, Slanci Formation, Bovidae, *Eotragus*.

**Апстракт**. У језерским миоценским наслагама Вишњице код Београда, познатим у старијој литератури под називом "Сланачка серија" у истражној бушотини код Великог Села нађен је зуб фосилног сисара *Eotragus* cf. *clavatus* (Gervais, 1850). Налаз фосилних остатака *Eotragus*-а је од значаја за сагледавање развоја сисарске фауне у Европи. Такође, резултати истраживања изнети у овом раду представљају допринос познавању стратиграфије и палеогеографије миоцена околине Београда.

**Кључне речи**: Миоцен, Баден, Србија, Београд, Сланачка формација, Bovidae, *Eotragus*.

## Introduction

The Danube Ključ area near Belgrade is situated on the borderline of the Balkan Mountains and the Pannonian lowlands on the south bank of the River Danube, comprising the villages of Grocka, Višnjica and Veliko Selo. Recent studies into the construction of a canalization basin near Višnjica–Veliko Selo have yielded new data on the geological structure of this area, as well as the first fossil mammal molar from Miocene lacustrine sediments (Slanačka serija, "formation" *sensu* Pavlović (1922). This tooth enables an age assignement for strata from which it was recovered.

Pavlović (1922) described a new lithostratigraphic unit ("formation" *sensu* Pavlović 1922) at Veliko Selo and Slanci, east of the city centre of Belgrade, where sandy clays and marly clays with floral imprints were found. He assumed a "First Mediterranean Age" (the old name for Aquitanian and Burdigalian age used localy) for these lacustrine sediments. These strata referred to in older literature as The Slanačka Serija (or Slanci Sequence; Pavlović 1922; Stevanović & Stangačilović 1954; Stevanović 1975, 1977), are the oldest Neogene sediments in the Belgrade area. The age of these deposits has, however, been the subject of a long debate.

The lacustrine sediments at Slanci were interpreted by Stevanović & Stangačilović (1954) as a sequence of lake deposits, including schistose, laminate clays, bituminous clays, platy marlstone and tuff. Those authors suggested a Burdigalian age because they considered that the sediments were stratigraphically older than Serravallian marine sediments nearby. The thickness of the Slanačka serija sediments was estimated to be in excess of 300 m. They are divided into a lower barren portion, lacking tuff, and an upper portion with fauna, including the last cephalopod to have lived in the area, *Aturia aturi* (Basterot, 1825). Stevanović (1977) again proposed a Burdigalian–Helvetian age.

Luković (1922), Krstić (1978) and Krstić *et al.* (1992) and suggested a Middle Miocene or Badenian age

[1] Museo Nacional de Ciencias Naturales, Consejo Superior de Investigaciones Cientificas, c. José Gutierrez Abascal 2, E-28006 Madrid, Spain. E-Mail: mcnjv538@mncn.csic.es

[2] Department of Geology, Faculty of Mining and Geology, University of Belgrade, Kamenička 6, P.O. Box 227, 11000 Belgrade, Serbia. E-mail: ivstefano@sezampro.yu

of the "Slanačka serija". On the basis of fauna collected from stratigrafically younger transgressive marine sediments, for example ostracods, foraminifera and fish teeth. According to F. Rögl (pers. comm. to KRSTIĆ 2007), the benthic species *Spiroplectinella carinata* (D'ORBIGNY) and planctonic Globigerinidae are present. The age of these younger strata deposited in the Danube Ključ area is estimated to be between 13.25 and 12.9 Ma.

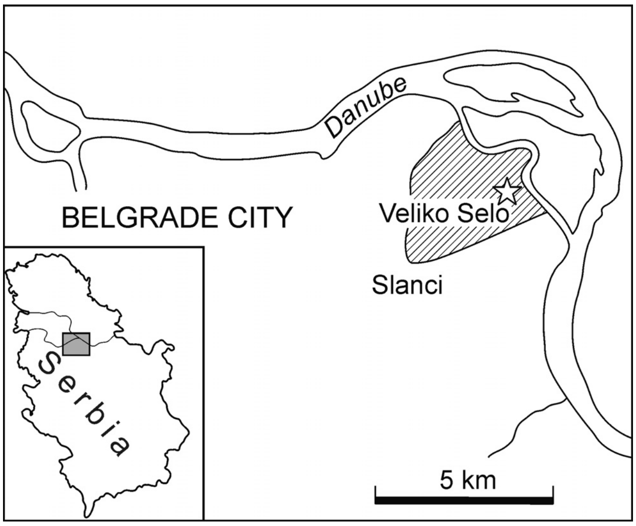


Fig. 1. In the vicinity of Belgrade on the banks of the River Danube, Višnjica, Veliko Selo and Slanci are located. The thickness of the deposits referred to as the "Slanačka serija" in the literature, is estimated to be 350 to 400 m (DOLIĆ 1977). The Slanci Formation is one unit of this series. In borehole VI-4i (indicated with asterisk) (GPS position data: 20°35'50'' E; 44°49'30'' N) at a depth of 8.8 m in the Slanci Formation, a specimen RGFKS31 was found.

Rich macrofloral remains from the village of Slanci were described by MILAKOVIĆ (1956, 1959) and MIHAJLOVIĆ (1978). These fossils, found in grey marls at a few localities in the village, include forms suggestive of a subtropical *Cinnamomum*, *Myrica*, *Engelhartia* and *Libocedrus* or a warm-temperate climate *Populus*, *Salix*, *Zelkova* and ferns. Species characteristic of drier and warm habitats include *Quercus*, *Pinus*, *Celtis* and *Eleagnus* or *Eucalyptus*, while *Metrosideros* and *Sapindos* are also represented. In general, these floral remains are typical of Mediterranean and steppe-savanna associations. Away from the lake, species abundant in a dry and warm climate occur (MIHAJLOVIĆ 1978).

OBRADOVIĆ (1979) described a sedimentary series of "Burdigalian–Helvetian" age and concluded that these were deposited in a shallow-water, lacustrine environment. The size of the lake and its marginal swamps was estimated to have been about ten square kilometres. The maximum depth was assessed to have been 150 m and preservation of organic material suggested anaerobic and stagnant conditions. The rich fossil flora shows that a humid climate existed in this area.

In the G-1 borehole in the village of Grocka, close to Veliko Selo and Slanci, the stratigraphically oldest lacustrine sediments are found at depths between 1300 and 1100 m (KNEŽEVIĆ *et al*. 1994). These are older than the overlying marine Paratethys sediments of Badenian age.

DOLIĆ (1997) described the strata of "Slanačka serija" as part of the "Lake group of the Danube Ključ". In strata exposed between the villages of Višnjica, Slanci and Veliko Selo, he recognised three formations which represent lacustrine sediments. From bottom to top these are (Fig. 2):

1) the Veliko Selo Formation, consisting of sandstone, conglomerate, tuff and tuffite, with an overal thickness between 150 and 200 m (not figured).

2) the Slanci Formation, with a coal horizon of 30 m thickness and lacustrine pelites with laminated shale, marlstone with tuff and tuffite some 50 to 70 m in thickness.

3) the Bučvar Formation, consisting of conglomerate, breccia, laminated shale and marlstone, with a thickness of 100 m.

DOLIĆ (1997) assumed the lake sediments to be of Aquitanian–Early Burdigalian ("Egerian–Eggenburgian" or Early Miocene) age. The contact between the "Lake group of the Danube Ključ" (Veliko Selo, Slanci and Bučvar formations *sensu* DOLIĆ) and the marine sediments of Badenian (Middle Miocene) age, he considered to be discordant.

Thus, the ages proposed for the Slanačka serija vary between Egerian (some 24 to 20.5 Ma; ages according to STEININGER 1999) or Eggenburgian (20.5 to 18 Ma), Ottnangian (18 to 17.2 Ma), Karpathian (17.2 to 16.5 Ma) (all Early Miocene) and Badenian (16.5–13 Ma) or "Helvetian" (Middle Miocene). The antelope molar, found in a borehole core and described herein, permits a more precise indication of the age of the sediments in which yielded it.

## Description of the section penetrated in borehole VI-4i

During the geological research for a construction of the future canalization interceptor, a molar was collected from the core of well VI-4i (Fig. 2). The core was drilled north of Veliko Selo on the elevated right bank of the River Danube at elevation 98 m, in the easterly side of the pit where this canalization interceptor is to be constructed.

The uppermost 1.7 m of the core comprise Quaternary colluvial deposits, while the reminder consists of Miocene sediments of the Slanci Formation. Between 1.7 to 2.7 m, occur clays with coal bands and a number amount of gypsum crystals, while between 2.7 to 8 m, there first are red clays on top with "rusty" siltstone clays with occasional gypsum crystals, and tuff and tuffite below. From 8 to 23.2 m, there are grey clays and

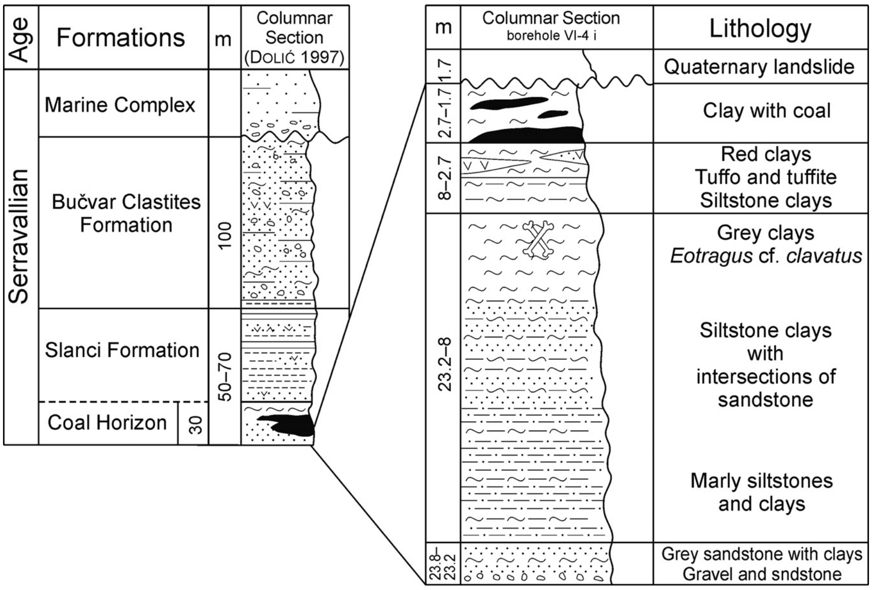


Fig. 2. Section penetrated in well VI-4i at Višnjica north of Veliko Selo on the elevated right bank of the River Danube (at 98 m) composed to a section of the formations of the Danube Ključ (according to Dolić, 1997). The position of *Eotragus* cf. *clavatus* is indicated.

yellowish silty clays with intercalations of sandstones of 2 to 3 cm in thickness. Gradually, to the lowest part of this section, sediments are represented by hard marly siltstone and clays. The molar was found at a depth of 8.8 m. In the lowermost portion of the core, at a depth of 23.8–23.2 m, there are grey siltstone sands with intersections of clays and a bed of sand with gravel.

Core lithology and correlation with other drillhole sections in the vicinity and sediments exposed suggests that the core covers the older portion of the Slanačka serija (see Fig. 1). The appearance of coal and coaly clays, as between 2.7 and 1.7 m, is characteristic of the lower part of the Slanci Formation in the eastern area of the Danube Ključ. The multicoloured sediments found at the base of the core probably represent the transition between the Slanci Formation and the underlying Veliko Selo Formation.

## Palaeontology

### Material and methods

The single molar from Višnjica, is kept in the collection of the Institute for Regional Geology and Paleontology, Faculty of Mining and Geology, University of Belgrade (RGF). It is here compared with *Eotragus* teeth from other localities, as housed at in the following collections: IPS, Institut de Paleontologia, Sabadell; IPUW, Institut für Paläontologie der Universität Wien; MHNT, Muséum d'Histoire Naturelle, Toulouse; MNHN, Muséum National d'Histoire Naturelle, Paris; NMB, Naturhistorisches Museum, Basel; SLJG, Steiermärkisches Landesmuseum Joanneum, Graz.

Measurements are taken as indicated by Van der Made (1989) and descriptive tooth morphology follows Van der Made (1996).

### Description and comparison

The specimen preserves the buccal half of a right upper molar of selenodont morphology (Fig. 3). In the matrix sample contacting it, there is a root of another molar in front, suggesting it to be a second or third molar. The buccal wall extends much further posteriorly at the occlusal surface than at the base, which suggests that it is not a $M^3$, but rather a $M^2$. The selenodont morphology and its low crown show the tooth to have belonged to a ruminant, most probably a bovid or cervid. Although the crown is worn, it is visible that the tooth must have been fairly low, suggesting a Middle Miocene bovid or Miocene cervid, because younger members of these families tend to have higher crowns.

The buccal wall is relatively flat, as in early bovids. Early cervids, like *Procervulus*, *Dicroceros* and *Euprox* generally have a more strongly developed paraexocrista and the style in the centre is much more massive than at the base. In these characters, the tooth is closer to that in low-crowned early bovids, such as *Eotragus* and *Pseudoeotragus*. Of the protocone, only the protoendocrista can be seen. It is well developed, but at the occlusal level, it is not fused to the tetraprecrista or parapostcrista. In early cervids, the protopostcrista is better developed than the protoendocrista, whereas in later cervids the former crest tends to disappear and the latter becomes well developed. Even the earliest bovids have a well-developed protoendocrista and the protopostcrista is absent. The tetraprecrista and tetrapostcrista do not reach the buccal wall at the occlusal surface, leaving the posterior fossa open at both sides. Thus, the tooth represents an early bovid.

The tooth has a very low crown, much lower than in the Hypsodontinae (Köhler 1987), *Protragocerus*/*Miotragocerus* and also lower than a bovid from MN5 in Spain (Puente de Vallecas, Arroyo del Olivar, Valdemoros, etc.; MORALES & SORIA 1985), which was referred to as *Protragoceros* or *Miotragoceros*. In addition, the latter forms generally are larger. *Tethytragus* (*Caprotragoides*) tends to be more hypsodont (AZANZA & MORALES 1994; VAN DER MADE & RIBOT 1999). Although *Tethytragus* from Pasalar, Çandir and La Grive are relatively low-crowned, they still are slightly higher than the molar from Višnjica. *Pseudoeotragus seegrabensis* has a $M^2$ that is slightly more high-crowned (VAN DER MADE 1989). *Eotragus* is a bovid having molars with the lowest crowns and thus is comparable in this respect to the molar from Višnjica.

In Europe, the *Eotragus artenensis* GINSBURG & HEINTZ, 1968 – *E. clavatus* (GERVAIS, 1850) (= *sansaniensis* (LARTET, 1851)) lineage is recognised, characterised by size increase, plus the very small *E. cristatus* (BIEDERMANN, 1873) (VAN DER MADE 1989). The $M^2$ from Višnjica has a length (DAPo = occlusal antero-posterior diameter) of 13.5 mm and a basal length (DAPb = basal antero-posterior) of 12.2 mm. In Fig. 3, the size increase in $M^2$ in the *E. artenensis* – *E. clavatus* lineage is shown. Additional measurements of other teeth show a similar picture (MAZO *et al*. 1998). The large sample from Sansan shows the range of variation. The molar from Višnjica is large compared to the $M^2$ of most samples, but is close to the mean value for specimens from Sansan.

are probably close to the mean of populations which they represent, the tooth from Višnjica probably belongs to *Eotragus clavatus*. The use of open nomenclature reflects these uncertainties.

## The *Eotragus* fossil and the age of the Slanačka serija

As mentioned above, the ages proposed for the Slanačka serija vary between Aquitanian or Early Burdigalian to Early Serravalien. The molar comes from the lower Slanci Formatioin, below the coal horizon.

As is apparent from the description and comparison, the age it indicates lies between the first and last occurrence of *Eotragus*, with a greater probability for a date close to Göriach and Sansan.

The oldest record of *Eotragus*, from Pakistan, is about 18 Ma old (SOLOUNIAS *et al*. 1995; GINSBURG *et al*. 2001). *Eotragus* is the oldest bovid in Europe and its first record is from Artenay (GINSBURG & HEINTZ 1968; GENTRY & HEIZMANN 1996; GENTRY *et al*. 1999) and the youngest probably from Manchones I. Artenay is a locality with *Democricetodon* but still without *Megacricetodon*, *Eumyarion*, *Deinotherium*, *Bunolistriodon* and *Dorcatherium*, and is early MN4 (MEIN 1975, 1977, 1990; DE BRUIJN *et al*. 1992) or zone B of the Aragonian

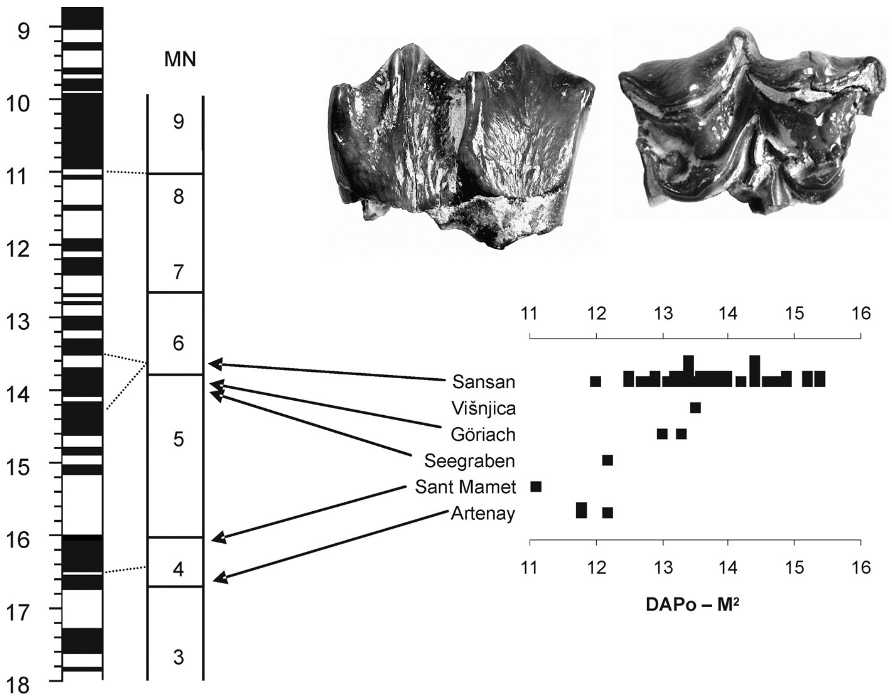


Fig. 3. Molar RGFKS31 of *Eotragus* cf. *clavatus* from Višnjica, buccal (left) and occlusal (right) view. The graph shows the DAPo or occlusal maximum length of $M^2$ of *Eotragus* from different European localities. In approximate stratigraphical order from old to young: Artenay (MNHN), Sant Mamet (IPS), Seegraben (SLJG), Göriach (SLJG, IPUW), Višnjica (RGF), Sansan (MNHN, MHNT, NMB). Correlations with to the MN proposed by VAN DER MADE (2005) (see discussion in text).

## Discussion

Morphological features Višnjica molar best fit *Eotragus*. Accepting the range of variation as indicated by the Sansan sample, the specimen could be a particularly large individual of the small species *E. artenensis*. However, assuming that the small samples for Fig. 3

(DAAMS *et al*. 1999b). Manchones I is placed in MN6 or zone G2 of the Aragonian (MEIN 1990; DE BRUIJN *et al*. 1992; DAAMS *et al*. 1999b). The age of Manchones I is estimated to be 13.25 Ma (DAAMS *et al*. 1999b).

The ages of MN units are still under discussion, especially the MN3-4 and MN6-7 transitions. Higher ages for MN units are suggested by DAXNER-HÖCK *et* *al*. (1998), and REICHENBACHER *et al*. (1998), STEININGER (1999) while younger dates were by KRIJGSMAN *et al*. (1994, 2003), DAAMS *et al*. (1999a, b), AGUSTÍ *et al*. (2001), LARRASOAÑA *et al*. (2006), MONTES *et al*. (2006); see also RÖGL (1999), VAN DER MADE (1996, 2005). The estimated age of the MN 3-4 transition varies between 18 and 16.6 Ma and that of the MN 6-7 transition between 12.5 and 13 Ma. The total range (18 to 12.5 Ma) represents the possible age of the molar from Višnjica. An Egerian or Eggenburgian age can thus be discounted for the deposits which yielded it.

The more likely age of this molar ranges between Göriach and Sansan and possibly also Manchones I. Göriach was placed in MN6 (MEIN 1975, 1977, 1990; DE BRUIJN *et al*. 1992), but its more likely age is very late in MN5, close to the MN5-6 transition, and time equivalent to zone E of the Aragonian (VAN DER MADE 1998; VAN DER MADE & RIBOT 1999; DAXNER-HÖCK *et al*. 2004;). The age of the MN5-6 transition has been estimated to be about 15.1 Ma (REICHENBACHER *et al*. 1998) and 13.75 Ma (DAAMS *et al*. 1999a/b). The age of Sansan is under discussion as well, since its palaeomagnetism has been interpreted in different ways indicating ages of about 15 and 13.6 Ma (SEN, 1997, DAAMS *et al*. 1999a/b). As stated above, the age of Manchones I is estimated to be 13.25 Ma. The more likely age for deposits at Višnjica thus is around 15.1–13.25 Ma. This is more in line with the younger age estimates, which places the Slanačka serija Slanci Sequence in the Middle Miocene.

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## Резиме

### Средњомиоценска старост "Сланачке Серије" (околина Београда, Србија) на основу фосилних остатака примитивне антилопе *Eotragus* cf. *clavatus* из Вишњице

У непосредној околине Београда налазе се седименти Миоценске старости познати у старијој литератури као седименти "Сланачке Серије". Ови језерски седименти, представљени глинцима и лапоцима, са појавом угља, туфа и туфита, истраживани су више пута у прошлости (PAVLOVIĆ 1922; LUKOVIĆ 1922; STEVANOVIĆ & STANGAČILOVIĆ 1954; MILAKOVIĆ 1956, 1959; OBRADOVIĆ 1970; STEVANOVIĆ 1975, 1977; MIHAJLOVIĆ 1978; KRSTIĆ 1978, 1988, 1992; KNEŽEVIĆ 1994; DOLIĆ 1997). Током ранијих истраживања пронађени су остаци флоре и фауне. Сама старост језерских седимената Сланачке формације одређена је на основу суперпозиције и млађих седимената који су таложени у маринској трансгресији која се десила током Бадена (KRSTIĆ 1992). Старост маринских седимената је одређена на основу фауне.

Током истраживања која су обављена приликом копања канализационог колектора у Сланцима, у бушотини VI-4i, пронађени су остаци фосилног сисара који припада еволутивном низу *Eotragus artenensis* GINSBURG & HEINTZ, 1968 — *E. clavatus* (GERVAIS, 1850) (= *sansaniensis* (LARTET, 1851)). На основу палеонтолошке анализе остаци горњег десног молара одређени су као *Eotragus* cf. *clavatus* (GERVAIS, 1850). Поређењем са другим остацима ове линије фосилних бовида, који су пронађени у мноштву европских локалитета, показало се да би наш примерак одговарао врстама које су егзистирале током транзиције NM5 у MN6 јединицу. Одређен је могући интервал, изражен у апсолутној старости, између 15.1 и 13.25 милиона година (сл. 3).

Присуство фосилног материјала који је прикупљен током ранијих истраживања није био довољан да би се одредила тачна старост Сланачке формације. Наласком остататака примитиве антелопе из рода *Eotragus,* може се закључити да је старост седимената Сланачке формације мања него што су то предпостављали неки аутори.

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# Cassiopid gastropods from the Cretaceous of western Serbia

Nenad Banjac[1], Klaus Bandel[2] & Steffen Kiel[3]

**Abstract.** Three species of Cassiopidae (Cerithioidea, Gastropoda) are described from outcrops in the vicinity of the villages Rastište and Mokra Gora in western Serbia. They occur in marly limestones of near shore shallow water deposits. Earlier micropaleontological investigations have indicated an Albian–Cenomanian age. The species encountered are related to those present in deposits of the European margin of the Tethys and closest relationships exist to those of the Armenian and Transcaucasian region. Our species can be placed in the genera *Cassiope*, *Paraglauconia* and *Bicarinella*. A new species *Cassiope kotromanensis* is erected. Assumptions about post-mortem shell transport and size sorting of gastropod shells were examined through statistical analysis.

**Key words:** Gastropoda, Cassiopidae, Cretaceous, Albian, Cenomanian, statistical analysis, western Serbia.

**Апстракт.** У раду су описане три врсте касиопида (Cerithioidea, Gastropoda) које потичу са изданака у околини села Растиште и Мокра Гора у западној Србији. Примерци су нађени у лапоровитим кречњацима насталим у плиткој води, близу обале. Ранија микропалеонтолошка истраживања указала су на алб-ценоманску старост ових стена. Врсте које су описане показују велику сличност са примерцима откривеним у Јерменији и Закавказју. Оне припадају родовима *Cassiope*, *Paraglauconia* и *Bicarinella*. Описана је нова врста *Cassiope kotromanensis*. Претпоставке о постморталном транспорту љуштура испитане су статистичком анализом.

**Кључне речи:** Gastropoda, Cassiopidae, креда, алб, ценоман, статистичка анализа, западна Србија.

## Introduction

Albian to Campanian sediments, resulting from a wide ranging transgression, are commonly encountered in western Serbia. Some of the outcrops are located between the Beli Rzav and Crni Rzav Rivers, with an extent of about 40 km in a NN–SSE direction. These deposits contain many fossils and were previously considered to be of Senonian age (Žujović 1893; Živković 1908; Ampferer 1928; Milovanović 1933). More Recent work on their microfauna point to an Albian–Cenomanian age (Pejović & Radoičić 1971). The fossil assemblages are dominated by cassiopid gastropods, less frequent are bivalves, ostracods, dasycladaceans and foraminifers. The aim of the present study was to describe more closely the cassiopid gastropods, and to discuss their systematic and biogeographic relationships.

## Geological setting

The lithology is represented by terrigenous clastites in the base, covered by bioclastic limestone. A local stratigraphic column was observed at the right bank of the Beli Rzav River at the hamlet Uroševići (coordinates N 43°45'50", E 19°28'30"). Three separate members of the stratigraphic column could be distinguished:

1. The lowermost member consists of dark gray oolitic sandstone and conglomerate with intercalated thin beds of micritic limestone. The coarse sandstone holds particles of different size including fragments of serpentine, glauconite and infrequent quartz. The components are poorly sorted and weakly rounded. Larger particles predominate over smaller ones. Conglomerate pebbles originated from laterites and the peridotitic bedrock of the former islands. This composition of the

[1] Department of Geology, Faculty of Mining and Geology, University of Belgrade, Kamenička 6, 11000 Beograd, Serbia. E-mail: banjac@afrodita.rcub.bg.ac.yu

[2] Geologisch-Paläontologisches Institut, Universität Hamburg, Bundesstrasse 55, 20146 Hamburg, Germany. E-mail: steffen.kiel@gmx.de

[3] Earth Sciences, University of Leeds, Leeds LS2 9JT, United Kingdom. E-mail: klausbandel@yahoo.com

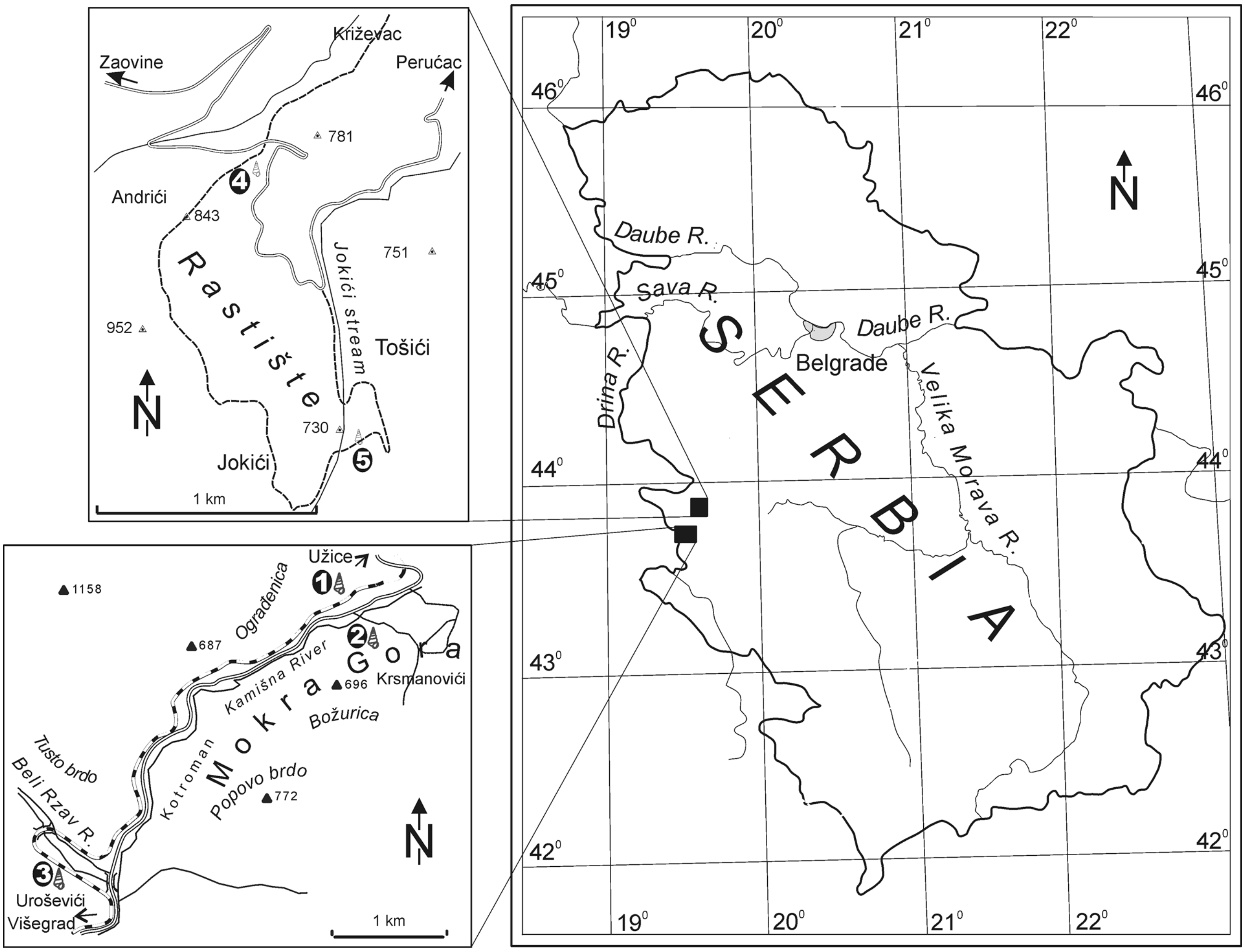


Fig. 1. Topographic map with fossiliferous localities.

beds presents evidence for a deposition in an environment of agitated shallow water, close to a seashore, with strong wave action. Rapid deposition of terrigenious material corresponds with about facial belts 8 and 9 of the classification adopted by WILSON (1975). The total thickness of the lowermost member is about 7 m.

At the beginning of marine flooding of the area, the surface was rugged and the surrounding area mountainous. Due to the composition of the soil formed on peridotites in an arid climate, plant cover on land was thin. Eroded material, therefore, was washed into the area of deposition rapidly and came from nearby. The almost complete absence of fossils in these beds indicates a stressed environment for marine organisms. The presence of oolites point to the presence of strong oscillating currents in shallow water. Intercalated fine beds were deposited in more protected lagoons.

2. The middle member of the stratigraphic column is composed of bioclastic limestones with a fine grained matrix, nodular bedding planes, and thin layers of interbedded marls. Thin sections revealed the composition of a shell coquina with a micro-crystalline calcitic matrix and evenly distributed clay material. Beside minute shell particles of mollusks, fecal pellets and algae are abundant. PEJOVIĆ & RADOIČIĆ (1971) mentioned *Bacinella sterni* RADOIČIĆ, *Nezzazatinella* cf. *picardi* (HENSON) and *Salpingoporella urladanasi* CONRAD, RADOIČIĆ & REY, from the lower part of this member and scarce assemblage with *Nezzazatinella* cf. *picardi* and *Hemicyclamina sigali* (MYNC) from the upper part. In thin-bedded micrites, numerous microscopic mud cracks and birdseye structures are present. These voids are sporadically filled by silico-clastic silt. The sediments were deposited under shallow water conditions, with frequent exposure above sea level. The influx of material from the land was less if compared with the beds of the lower member. The thickness of the middle member is nearly 28 m.

3. The upper member in this stratigraphic column is composed of bioclastic micritic limestone with interbedded thin marl. In thin section fecal pellets, bioturbation, debris of organic material, mollusc shells, and some oogonia and stem fragments of charophytes are noted. The lower part of the member consists predominantly of algal marly limestone with a lot of pyrite and organic material. Here small codiacean pebbles and grains and some *Hemicyclammina sigali* are present.

Higher up in the column the sediments are predominantly marly and contain abundant hematite and limonite particles as well as numerous dasycladaceans, codiacean grains, a few miliolinid foraminifera, shells of small gastropods, sponge spicules, spines of echinoderms and other biogenes. The sediment suggests deposition in warm shallow water, with varying salinity, and without significant water circulation. Frequent charophyte and ostracode debris indicate the temporary influence of brackish water. According to the enumerated characteristics, the sediments were formed on an open or restricted platform, behind an organic reef, about facies belts 7 and 8 of the classification of WILSON (1975). Some charecteristics indicate the environment of slightly deeper lagoons, intermittently connected with the open sea. The thickness of the upper member of the stratigraphic column is about 14 m.

The tectonic characteristics of the Cretaceous deposits are such that the beds form a syncline with Turonian deposits at the axial part, while outcrops of Albian–Cenomanian sediment are wide-spread at the margins of this structure. The syncline became fractured by numerous subsequent faults, forming several vertically displaced blocks.

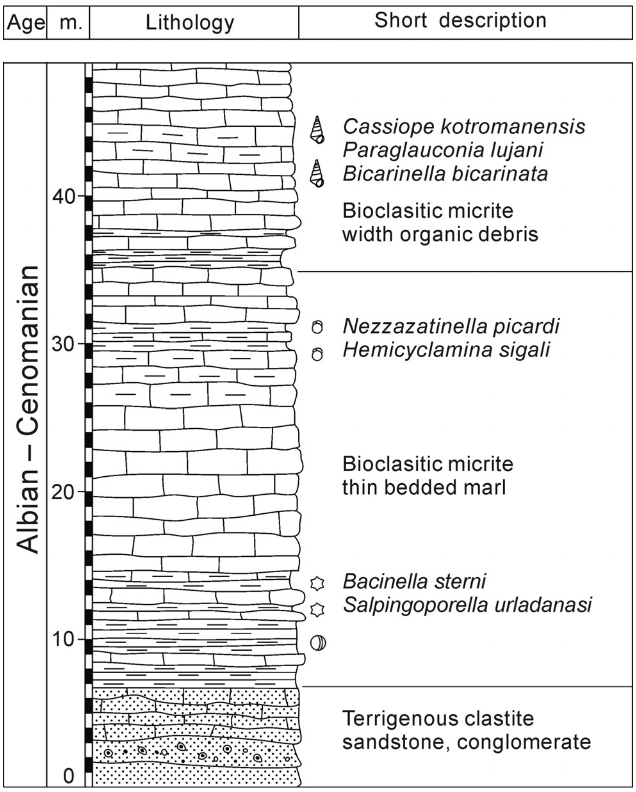


Fig. 2. Local stratigraphic column at Uroševići.

## Material and methods

The majority of the material (84 specimens in total) described below was hand-picked from the bioclastic micritic limestone with interbedded thin marl (upper member of the stratigraphic column). The gastropod assemblage contains *Cassiope kotromanensis, Bicarinella bicarinata* and *Paraglauconia lujani*. Gastropods were collected from outcrops of marly limestone in the vicinity of Mokra Gora, Kotroman and Rastište villages. Fossil bearing localities were numbered 1 to 5 and are indicated at Fig. 1.

The collection is housed at the Faculty of Mining and Geology in Belgrade (registration numbers NB/67/11 to NB/162/97).

Principal components analysis was conducted to examine the possibility of post-mortem shell transport and size sorting within the gastropd assemblage.

Some of the taxa concerned here were introduced and studied by the Armenian paleontologist Vardges Akopyan. In his publications his name was spelled Hacobjan, but is frequently cited as Akopyan. His publications were originally written in Russian, and according to transliteration rules his name would have to be spelled Akopyan, even though it is Armenian. To avoid confusion, we use here the transliteration Akopyan.

## Systematic paleontology

Family Cassiopidae BEURLEN, 1964
(= Cassiopidae KOLLMANN, 1979;
Glauconiidae PCHELINTSEV, 1953)

The family is based on the genus *Cassiope* COQUAND, 1865. which is conical in shape, with wavy spiral ribs and a rounded aperture. The base is angular and the umbilicus open. According to CLEEVELY & MORRIS (1988), the wide conical shell has flattened whorls that are ornamented by spiral ribs that may bear tubercles. The outer lip of the aperture is curved so that there is a posterior lobe. The protoconch morphology has been discussed by KOWALKE & BANDEL (1996, pl. 5, figs. 5, 6) based on *Cassiope kefersteinii* (MÜNSTER in GOLDFUSS, 1844) from the Late Cretaceous of the Gosau (Northern Alps). That protoconch consists of 3 whorls with the embryonic shell about 0.12 mm wide. The ornament of the larval whorls consists of two spiral ribs and a row of tubercles below the suture (BANDEL 1993). The operculum found in the aperture of a half grown individual shows multispiral composition similar to that found in modern Potamididae. It is quite possible that this modern group of coastal Cerithioidea represents the closest relatives to the Cretaceous Cassiopidae, which obviously also lived near shore and was influenced by fresh water run off.

Genus ***Cassiope*** COQUAND, 1865

**Type species.** *Cassiope kefersteini* MÜNSTER in GOLDFUSS, 1844, Gosau Group, Coniacian–Campanian, Austria.

**Diagnosis.** The shell is conical with flattened whorls angled at the base. The ornament consists of spiral threads and rows of nodes. The growth line pattern is sinuous with a shallow bay below the suture. The base is flattened to weakly convex and may have a small slit-like umbilicus. The aperture is simple and of elongated oval shape (WENZ 1938; CLEEVELY & MORRIS 1988). The protoconch consists of three rounded whorls forming a conical shell, ornamented by two spiral ribs in its larval shell portion (BANDEL 1993, pl. 4, fig. 6; KOWALKE & BANDEL 1996). The genotype has an up to 40 mm high shell that consists of about ten whorls with a regular increase in size. Ornament consists of spiral ribs, sometimes increasing in number at latest whorls. In addition to the main spiral ribs, there may be fine spiral threads.

### *Cassiope kotromanensis* sp. nov.
Fig. 3A–E.

? 1949 *Glauconia coquandi* (D'ORB.) – PETKOVIĆ & PAŠIĆ: 141, pl. 1, fig. 1.
? 1952 *Glauconia coquandi* (D'ORB.) var. *velesana* n. var. – ĆIRIĆ: 256, pl. 4. fig. 2, non figs. 3–5.
non 1952 *Glauconia coquandi* (D'ORB.) – ĆIRIĆ: 253, pl. 2, figs. 1–3, 5, 6.
1968 *Cerithium exiguum* ZEKELI – BRKOVIĆ: 127, pl. 1, fig. 1.
1968 *Cerithium distinctum* ZEKELI – BRKOVIĆ: 127, pl. 1, fig. 2.

*Holotype:* NB/67/23, Plate 1, Figs. 1, 2.
*Paratypes:* NB/67/11...NB/162/97.
*Derivation of the name:* After nearby locality Kotroman.
*Type locality:* Uroševići Hamlet, Beli Rzav River.
*Type horizon:* Cenomanian bioclastic micritic limestones (upper part of the local stratigraphic column in Fig. 2).

**Material.** 47 specimens from outcrops at Kamišna, the banks of the Beli Rzav River and Andrići Hamlet, localities 3, 4 and 5 in Fig. 1.

**Diagnosis.** A small cassiopid, variably ornamented with 3–4 tuberculated spiral ribs. The sinus in the opisthocyrt growth lines occurs at the middle part of the whorls, while a shallow sinus occurs at the base.

**Description**. The conical shell consists of about five whorls with flat sides and is up to 35 mm high, with an apical angle of 25–31°. Sutures are V-shaped and narrow, and inclined at about 16°. The juvenile whorls also have this characteristic suture. The whorls are sculptured by three wide, equally spaced spiral cords, which bear 18–20 up to 2 mm wide tubercles on each whorl. The spiral ribs are clearly separated and slightly wider than the space between them. In some specimens, a narrow tuberculated spiral thread positioned between the central and the abapical spiral cords appears. This thread is slightly narrower than the other cords, or it can be a fine, pustulae bearing spiral thread of second order.

The growth lines reflect the broad and shallow sinus of the outer lip. The corner to the base is sharp, the base is convex, has a narrow umbilical slit and bears three or four spiral lines with small tubercles. Besides the main sinus, there is a delicate shallow sinus of secondary order at the basal surface. Longitudinal sections indicate the whorl height as large as the whorl width.

**Remarks.** The significance of the patterns of the growth line in species determination of *Cassiope* had been emphasized by KOLLMANN (1979) and CLEEVELY & MORRIS (1988). One of the characteristic features of the shell of *Cassiope kotromanensis* is the presence of the collabral sinus reflecting the shape of the outer lip, and a second sinus present on the basal surface. Our specimens have an average height of about 23 mm, and, therefore, measure only about half the size of other species of the Cassiopidae. They also have a slightly smaller spiral angle than *Glauconia coquandiana* (D'ORBIGNY) described by AKOPYAN (1976). PETKOVIĆ & PAŠIĆ (1949) described four subspecies of *Glauconia coquandiana*, ornamented by small pustules on some of the spiral cords. Only one of their specimens (PETKOVIĆ & PAŠIĆ 1949, pl. 1, fig. 1) shows some characteristics of *Cassiope kotromanensis* and is tentatively included in the synonymy. Also ĆIRIĆ (1952) described numerous types as different subspecies of *Glauconia coquandiana*. The original specimens are not available, while according to the author's description only *Glauconia coquandiana* var. *velesana* bears tuberculated spiral cords, resembling *Cassiope kotromanensis*. ĆIRIĆ (1952) mentioned a wider apical angle, 34–40°, when compared with *Cassiope kotromanensis,* and the specimen is hesitantly included in the synonymy. Specimens from other nearby localities identified as *Cerithium exiguum* ZEKELI and *Cerithium distinctum* ZEKELI by BRKOVIĆ (1968) also belong to *Cassiope kotromanensis*. The characteristic shape of the growth lines reflecting the sinus of the median and basal part of the outer lip of the aperture was not noted by these authors.

**Occurrence.** Albian–Cenomanian beds in the vicinity of Kotroman, Uroševići, Kamišna and Beli Rzav River banks, western Serbia.

### Genus *Paraglauconia* STEINMANN, 1929

**Type species.** *Paraglauconia carbonaria* (ROEMER, 1836), Wealden (Early Cretaceous), Germany.

**Diagnosis (following AKOPYAN, 1976).** According to it, the shell is of conical shape with concave whorls. Ornament consists of two rows of nodes positioned at the apical corner and the edge to the base of whorls. Spiral rows of secondary order may occur. The growth lines bear a wide sinus which reflects a wide lobe at the middle of the outer lip of the aperture.

CLEEVELY & MORRIS (1988) noted in *Paraglauconia tricarinata* (SOWERBY in FITTON, 1836) a protoconch which is in essential features like that of *Cassiope*

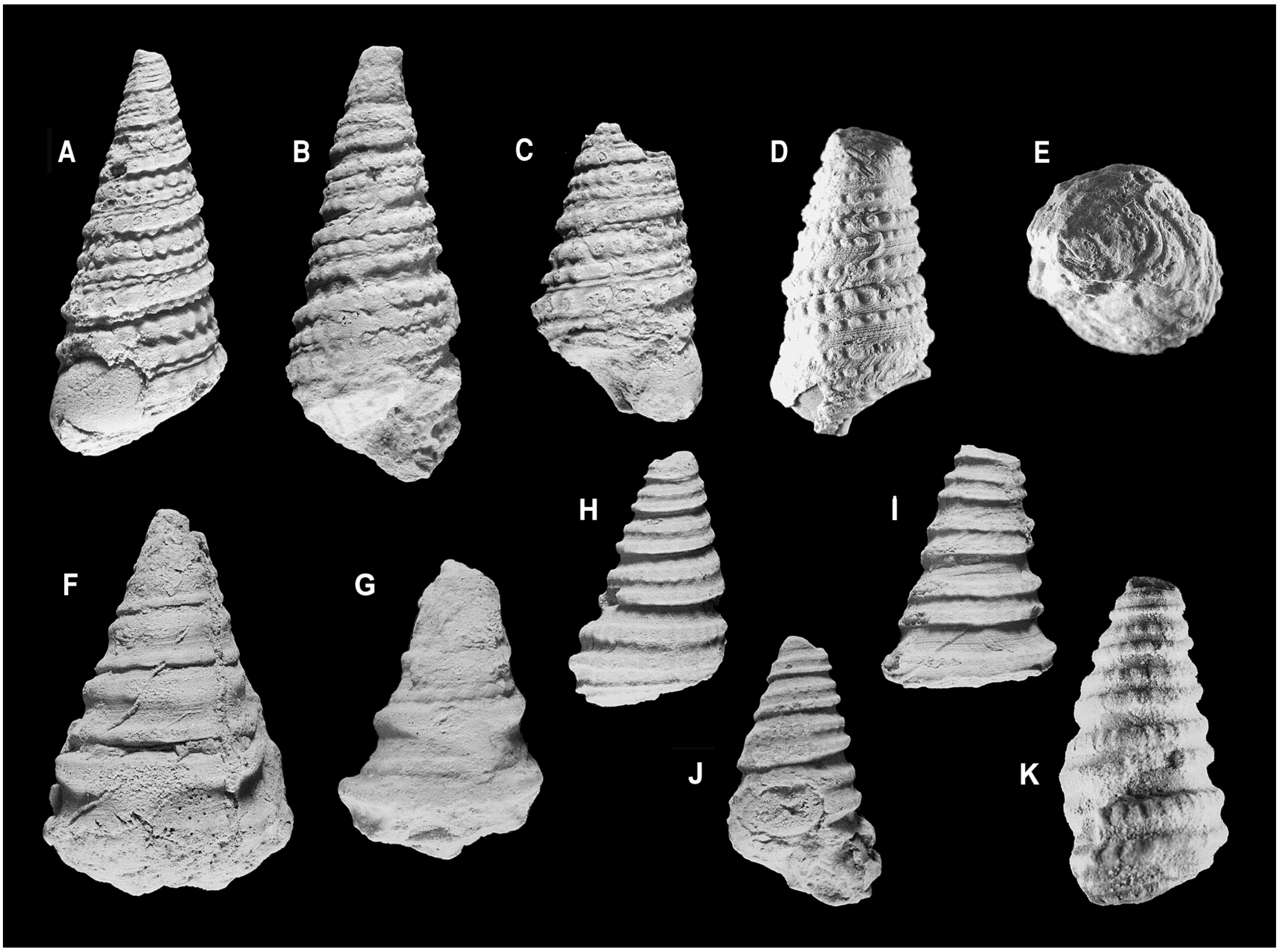


Fig. 3. **A–E**. *Cassiope kotromanensis* sp. nov. **A**, **B**. NB/67/23, lateral and apertural view, ×1.5; **C**, NB/67/28, apertural view, ×1.5; **D**, NB/67/30, lateral view, ×2; **E**, NB/67/23, basal view, ×2; **F**, **G**, *Paraglauconia lujani* (DE VERNEUIL & COLOMB, 1853). **F**, NB/D8/7, lateral view, ×1.5; **G**, NB/D9/2, lateral view, ×1.5; **H–K**, *Bicarinella bicarinata* (PCHELINTSEV, 1953). ×1.5, **H**, NB/94/89, lateral view, ×1.5; **J**, NB/94/89, apertural view, ×1.5; **I**, NB/67/21, lateral view, ×1.5; **K**, NB/94/90, lateral view, ×1.5.

*kefersteini*, having two spiral keels on its larval shell portion. They noted that the base of the teleoconch is convex and may bear spiral lines. The aperture have an oval shape.

### *Paraglauconia lujani*
(DE VERNEUIL & COLOMB, 1853)
Fig. 3F, G.

1853 *Cerithium Lujani* DE VERNEUIL & COLOMB: pl. 3, fig. 17.
? 1865 *Cassiope verneuilli* COQUAND: pl. 4, figs. 1, 2.
1865 *Cassiope Lujani* var. *crassa* COQUAND: 61, pl. 4, figs. 1, 2.
1865 *Cassiope Lujani* var. *laevigata* COQUAND: 61, pl. 4, figs. 3, 4.
1865 *Cassiope Lujani* var *nodosa* COQUAND: 62, pl. 4, fig. 5.
1868 *Vicarya lujani* (DE VERNEUIL & COLOMB) – DE VERNEUIL & LORIERE: 5-7, pl. 1, fig. 3.
1868 *Vicarya strombiformis* SCHLOTHEIM DE VERNEUIL & LORIERE: pl. 7, pl. 1, fig. 4.
1899 *Glauconia* cf. *lujani* (DE VERNEUIL) – PERON: 95-96, pl. 1. fig. 10.
1909 *Glauconia Lujani* (DE VERN.) – COSSMANN: 168, pl. 4, figs. 11–12.
1932 *Glauconia Lujani* VERN. – PETKOVIĆ & BOJIĆ: 13.
1952 *Glauconia coquandi* D'ORB. var. excavata REP. – ĆIRIĆ: 255, pl. 2, fig. 9.
1976 *Paraglauconia lujani* (VERNEUIL) – AKOPYAN: 138.
1982 *Paraglauconia lujani* (VERNEUIL) – KOLLMANN: 337, pl. 1, figs. 7–9.
1984 *Paraglauconia lujani* (DE VERNEUIL & COLOMB) – CLEEVELY *et al*.: 98, fig. 2, (non figs. 11–14).
1984 *Cassiope dorsetensis* MENNESSIER: 78, pl. 27, figs. 10, 11.
1984 *Cassiope luxani* (DE VERNEUIL) emend. VILANOVA – MENNESSIER: 78, pl. 26, figs. 18–27; pl. 27, fig. 6.
1984 *Cassiope luxani* (DE VERNEUIL) nodosa COQUAND – MENNESSIER: 78, pl. 26, figs. 27 a–b.
1984 *Cassiope luxani* (DE VERNEUIL) crassa COQUAND – MENNESSIER: 78, pl. 27, figs. 4–5.
1988 *Paraglauconia lujani* (DE VERNEUIL & COLOMB) – CLEEVELY & MORRIS: 265, text-fig. 14.

**Material.** 29 specimens from the hamlets Andrići and Rastište, localities 3, 4, 5 in Fig. 1.

**Description**. The shell is conical, up to 40 mm high, consists of four to six slightly concave whorls with grooved sutures, and has an apical angle of 26°. The sculpture consists of two main spiral ribs, which bear broad tubercles and are positioned next to the suture, one above it, the other below it. Some specimens have in addition two or three spiral lines in the centre of the whorl, while others have numerous very fine and delicate spiral lines all over the outer surface of the whorls. The growth lines are opisthocyrt, very fine, and the tangental point of their sinus is situated between the middle of the whorl and its upper third. The base carries one spiral rib and numerous fine narrow spiral lines. In longitudinal section, the inner cavities have an oval outline with a height/width ratio of 0.88.

**Remarks**. *Cassiope verneuilli* COQUAND (1865) has a more prominent apical spiral rib and is included in the synonymy, but with doubts. *Paraglauconia lujani* resembles in shape and orientation *Cassiope branneri* (HILL, 1893) from the Aptian to Early Cenomanian Comanche Formation in North America (STANTON, 1947), but is more stout and has a wider apical angle. *Paraglauconia lujani* was described but not figured by PETKOVIĆ & BOJIĆ (1932) from Aptian beds of eastern Serbia, and also *Glauconia coquandi* D'ORB. var. *excavata* described by ĆIRIĆ (1952) from Turonian deposits in central Macedonia appears to belong to this species.

**Occurrence**. Albian–Cenomanian beds in the vicinity of Andrići and Rastište hamlets.

### Genus *Bicarinella* AKOPYAN, 1976

**Type species.** *Pseudomesalia bicarinata* PCHELINTSEV, 1953, Late Cenomanian, Armenia.

**Diagnosis (according to AKOPYAN, 1976).** The shell is conical with a high spire. Whorls are slightly convex, with two major keels. They frequently bear tubercles and give the whorls an angular shape. The suture is well expressed. Ornament may also consist of additional weak spiral threads. The area between the keels in the central part of the whorls is flattened. The base is convex with a narrow umbilicus. The aperture is rounded and has a wide and deep sinus at its outer lip.

### *Bicarinella bicarinata* (PCHELINTSEV, 1953)
Fig. 3H–K.

? 1938 *Paraglauconia mediocarinata* MIKINČIĆ: 155, pl. 1, figs. 3–4.
1953 *Pseudomesalia bicarinata* PCHELINTSEV: 99, pl. 11, figs. 3–4, (non figs. 1, 2, 5, 6), pl. 12, figs. 1–5.
1974 *Pseudomesalia bicarinata* PCHELINTSEV – AKOPYAN: 234, pl. 119, figs. 2–3.
1976 *Bicarinella bicarinata* (PCHELINTSEV) – AKOPYAN: 165.
1976 *Bicarinella bicarinata bicarinata* AKOPYAN: 166, pl. 38, figs. 1–3.
1976 *Bicarinella bicarinata ornata* AKOPYAN: 167, pl. 38, figs. 5–6.
1981 *Pseudomesalia bicarinata* PCHELINTSEV – TSANKOV: 58, pl. 13, figs. 14–17.
1984 *Pseudomesalia (Bicarinella) bicarinata* PCHELINTSEV – MENNESSIER: 54, pl. 14, figs. 17–21, 35.

**Material.** 18 specimens from the right bank of the Beli Rzav River, and from the Kremići Stream, localities 1, 2, 3 and 5 in Fig. 1.

**Description.** The conical shell is up to 30 mm high and has an apical angle of 26–30°. Its whorls have flattened sides and distinct sutures. Ornament consists of two prominent spiral ribs the upper of which lies at the cetre, the second at the basal edge of the whorls. The spiral cords bear tubercles that are small on early whorls and increase in size towards the last whorl. Two or three secondary spiral threads appear between the main cords in some individuals. Growth lines are opisthocyrt and bear a shallow, widely V-shaped sinus with the tangental point between the central and the abapical third of the whorl, the point of inflexion is at the main spiral rib. Growth lines have a secondary shallow sinus near the base of the whorls. The base is convex, has a narrow umbilicus and bears two prominent spiral ribs and a few spiral threads.

**Remarks.** Our specimens are only about half the size of those individuals that have been described from other localities and listed in the synonymy. *Bicarinella bicarinata* resembles *Cassiope burnsi* from the Aptian to Early Cenomanian Comanche formation, Texas, described by STANTON (1947). *Cassiope burnsi* bears ornament with a less nodose character of the spiral cords. From Aptian beds in central Serbia, MIKINČIĆ (1938) described the species *Paraglauconia mediocarinata*, which closely resembles *B. bicarinata* in size and shape. It differs by having a delicate second sinus at the base of the shell and by the absence of an umbilicus. This species is only tentatively included in the synonymy. If future research shows that the two species are conspecific, *B. mediocarinata* would have priority over *B. bicarinata*.

**Occurrence**. Albian–Cenomanian at Mokra Gora and Uroševići.

## Discussion of the small size of the specimens

During the investigation, it became evident that the studied shells are quite small, even with same amount of whorls, much smaller than specimens cited in the synonymy. There are three possible explanations for the small size of cassiopids from the examined outcrops.

One of the possibilities is that Cassiopidae from the central part of the Tethys, during Albian and Cenomanian time did not attain the same large dimensions of the individuals which form the typical Late Cretaceous members of this family. This assumption may be supported by the fact that the here reported individuals come from beds which are older than the beds where the cited species were found. Consequently species regarded as synonyms of *Cassiope kotromanensis* were mentioned in localities of Turonian age, while here it is found in Albian–Cenomanian beds. As some other cassiopids known from older rocks have no miniature dimensions, for example, *Paraglauconia lujani* according to COQUAND (1865), FRITSCHE (1924), CLEEVELY & MORRIS (1988), this reason seems less probable (although it should not be absolutely rejected).

A second possibility for the small size of the discussed individuals may be seen in the influence of environmental factors. Living conditions in the coastal lagoons along the Tethys terranes now representing central Serbia could have been sub-optimal. They could have inhibited the proper growth of the snails. This assumption is difficult to confirm, since unfavorable factors of the environment which could have inhibited growth are not easily detected from rock facies. Also the preservation of the shells is not sufficient to compare individuals by counting their number of shell whorls. This could provide a clearer picture of the possible reasons for the smallness of the individuals. Difficulties during growth of the individuals may have come from the periodical influence of fresh water, supported by presence of charophyte stems in the deposits.

A third hypothesis explaining the small shell dimensions may come from post-mortem shell transport and size sorting. The occurrence of shell sorting during transport on the sea-bed has been described in numerous cases (BOUCOT 1953; CADÉE 1982, 1988, 1989). Water currents may have transported and sorted dead shells. During the transport, according to size and weight, sorting is performed, affecting the size frequency distribution of the reworked shells. The resulting death assemblage may have concentrated predominantly small shells. A modern case of such a secondary shell sorting in the tropical environment of the Philippines has been described by BANDEL (1991). This third explanation could be checked by several statistical methods.

## Statistical analysis

Assumptions about small size of the gastropods were checked through statistical analysis. Firstly all the specimens were measured and the size distribution was calculated, just to confirm the assumptions concerning the small size of the individuals. Subsequently statistical analysis was performed through two steps. The first included a comparison of the shell dimensions, to confirm the presence of any significant differences between shells of several species originating from the same outcrops. The second included a similar investigation conducted over the same species originating from different localities. For each specimen, appropriate dimensions were measured and parameters calculated, while principal component analysis was used for the further statistical investigations. Considering dimensions such as general shell height, width, height of last whorl, principal components were calculated, mutually correlated (to designate the most contrasted dimensions of the entered data). Principal components were sorted by the magnitude of variability, so that the first one has the highest variability, while the last one has the lowest variability.

## Size distribution in the fauna

For each specimen, the following dimensions were measured: height of the shell (H), height of the last whorl (h), shell width (W), angle of spire (?). Some parameters were indirectly calculated: height per width ratio for the whole shell (W/H), and the same ratio for the last whorl (W/h). Furthermore, sample mean and standard deviation for each parameter were calculated. The results are shown in Table 1.

The observation that the shells are notably smaller than those of the specimens cited in the synonymy was confirmed by the values presented in Table 1. In some species, the shells are nearly only half as large as the corresponding specimens from other localities.

## Relationship of different species from the same outcrops

The first investigation was performed on the specimens collected at outcrops near the hamlet Uroševići (locality 3, Fig. 1), regarding specimens of the species *Cassiope kotromanensis* and *Bicarinella bicarinata*.

Considering the data (Table 1), it is evident that *Bicarinella bicarinata* has a mean height of 22 mm, while specimens described in the literature reach up to 50 mm (AKOPYAN 1976) or even 75 mm (MENNESSIER 1984). Furthermore, *Cassiope kotromanensis* has half of the typical height of Cassiopidae (ZEKELI 1852; AKOPYAN 1976). As both species are quite small and have about equal dimensions, we assume that the shells endured moderate transport, and consequently adequate sorting due to dimension, before they finally became deposited and fossilized.

To check this assumption, the first principal components of all specimens were compared and tested. Small differences between the components for both groups was confirmed with a simple t-test 1.17, which is significantly less than 2.14, a critical value for the related number degrees of freedom.

The assemblage that had been collected in the western part of the Rastište Village (locality 5 in Fig. 1) was considered in the same manner. Here the abundant association of *Paraglauconia lujani* and *Cassiope kotromanensis* is characterized by shells which are significantly smaller than those from other localities noted in the

Table 1. Average values of the shell dimension (in mm) for the collected sample. Legend: H, height of the shell; h, height of the last whorl; W, width of the shell; α, spire angle (in degrees); W/H, width/height ratio for the whole shell; W/h, same ratio for the last whorl. The numbers in brackets represent the standard deviation for the collected sample.

| Species | H | h | W | α | W/H | W/h |
|---|---|---|---|---|---|---|
| *Cassiope kotromanensis* | 25.30<br>(6.64) | 8.49<br>(2.25) | 13.71<br>(3.41) | 31.39<br>(3.89) | 0.55<br>(0.07) | 0.34<br>(0.05) |
| *Paraglauconia lujani* | 27.65<br>(6.50) | 9.90<br>(3.28) | 16.70<br>(3.77) | 32.55<br>(4.20) | 0.62<br>(0.18) | 0.36<br>(0.09) |
| *Bicarinella bicarinata* | 22.39<br>(6.43) | 8.49<br>(2.92) | 13.22<br>(3.12) | 29.11<br>(5.21) | 0.60<br>(0.10) | 0.39<br>(0.15) |

other parts of the Tethys Ocean. As in the previous associations, *Paraglauconia lujani* is 27 mm high versus 65 mm (specimen pictured in MENNESSIER 1984), while *Cassiope kotromanensis* reaches 25 mm versus 50 mm of most Cassiopids (AKOPYAN 1976). For the two species present here, principal components were calculated and checked with the t-test. The result 1.66 is less than 2.05, the critical value for 27 degrees of freedom.

As in the previous example, there are no significant differences between shell size for the different groups. It is thus assumed that the shells from this outcrop are part of a moderately transported fossil death assemblage.

## Relationship of the same species from different outcrops

The survey was conducted with shells belonging to the same species, but which were collected at isolated outcrops. The analysis was carried out for different samples: *Cassiope kotromanensis* collected at the Rastište Village (localities 4 and 5, Fig. 1); a sample of *Bicarinella bicarinata* collected at the left bank of the Kamišna River (locality 2, Fig. 1), was compared with samples collected at the localities Uroševići (locality 3, Fig. 1) and Jokići (locality 5, Fig. 1). For each pair of samples t-tests of the principal components were performed. The results are shown in Table 2. The first column represents localities for which the t-test was calculated, the second column represents the degrees of fredom, the third column shows the calculated value of t-tests, while the last column shows the critical value for the appropriate degrees of freedom.

As becomes evident, *Cassiope kotromanensis* shows notable size differences between the assemblages collected at outcrops 4 and 5. The second listed species *Bicarinella bicarinata* shows significant differences for the shells originating from localities 2 and 3, as well as for the shells from localities 2 and 5. The other samples show no significant differences.

This contrast is visible in the principal components plot. The diagram in Fig. 4 shows the parameters of

Table 2. Principal components t-test for the same species at separate localities.

| Localities: | df | t stat | t critical |
|---|---|---|---|
| *Cassiope kotromanensis* loc. 4 vs loc. 5 | 34 | 3.282 | 2.030 |
| *Bicarinella bicarinata* loc. 2 vs loc. 3 | 9 | 3.746 | 2.262 |
| *Bicarinella bicarinata* loc. 2 vs loc. 5 | 9 | 2.539 | 2.262 |

*Cassiope kotromanensis* with larger specimen components (originating from the locality 5) predominant at the right side (black circles), and smaller ones (locality 4), at the left side of the diagram (white circles). The diagram in Fig. 5 shows the analysis of *Bicarinella bicarinata* collected at the localities 2 and 3. As in the previous diagram, the larger specimen components (locality 2) are grouped at the right side of the diagram, while the smaller ones (locality 3) are noted at the left side.

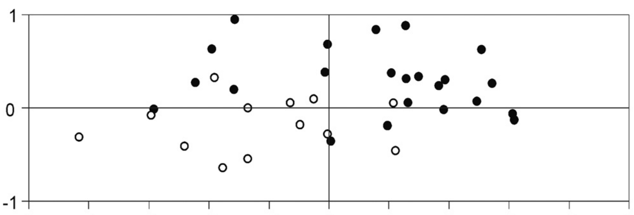


Fig. 4. Principal components diagram for *Cassiope kotromanensis*. Legend: black circles, specimens from locality 5; white circles, specimens from locality 4; horizontal line, 1st principal component; vertical line 2nd principal component.

The presented data confirm the conclusion that the studied gastropod assemblages are composed of shells

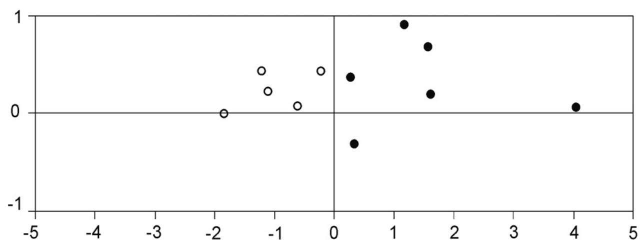


Fig. 5. Principal components diagram for *Bicarinella bicarinata*. Legend: black circles, specimens from locality 2; white circles, specimens from locality 3, horizontal line 1st principal component; vertical line 2nd principal component.

that had been transported before their fossilization. As there were no significantly damaged shells, it may be concluded that the transport was short, but prolonged enough to remove shells out of their original habitat and to perform sorting by size. The sedimentological analysis confirms this suggestion. Rock characteristics at the fossiliferous localities correspond to the facial belts 7 and 8 after the classification by WILSON (1975). The gastropod assemblages can be connected with intertidal flats, close to a shore line.

## Conclusions

Three species of Cassiopidae (Cerithioidea, Gastropoda) are described from outcrops in western Serbia. Earlier microfossil investigations (PEJOVIĆ & RADOIČIĆ 1971) indicated an Albian–Cenomanian age. According to its character, this fauna resembles associations which have been noticed from other outcrops of Tethyan sediments of the Cretaceous. The greatest similarity was recognised with the Armenian and Transcaucasian regions.

The generally smaller size of the individuals encountered in the material of this study is explained by sorting due to transportation. But also environmental factors may have had an influence on the shell size. Evolutionary factors are considered unlikely to be of greater importance.

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## Резиме


### Касиопидни гастроподи креде западне Србије

Описане су три врсте гастропода откривене у кредним седиментима западне Србије. Албско-ценомански седименти таложени су током трансгресије која је средином креде обухватила широки простор. Ове творевине налазе се између река Бели и Црни Рзав, пружајући се око 40 km у правцу северсеверозапад–југјугоисток. Оне садрже фосиле за које се сматрало да су сенонске старости (ЖУЈОВИЋ 1893; ЖИВКОВИЋ 1908; AMPFERER 1928; МИЛОВАНОВИЋ 1933). Новији радови, засновани на анализи асоцијација микрофауне указали су на стратиграфску припадност алб-ценоману (PEJOVIĆ & RADOIČIĆ

1971). У фосилним заједницама доминирају касиопидни гастроподи, а поред њих јављају се бивалвије, остракоди, дазикладацее и фораминифери. Циљ овог рада је да се опишу неке врсте гастропода и размотре њихови систематски и бигеографски односи.

Могуће је издвојити три члана локалног стратиграфског стуба. Најнижи члан чине тамносиви оолитски пешчари, слабо сортирани и слабо заобљени. Таложени су близу обале у средини високе енергије. Одговарају фацијалним појасевима 8 и 9, WILSON (1975). Средњи члан чине биокластични кречњаци. Садрже ретке фрагменте макрофауне, фекални пелет, и алге: *Bacinella sterni* RADOIČIĆ, *Nezzazatinella* cf. *picardi* (HENSON) и *Salpingoporella urladanasi* CONRAD, RADOIČIĆ & REY. У вишим деловима јављају се *Nezzazatinella* cf. *picardi* и *Hemicyclamiina sigali* (MYNC). На препаратима се уочавају бројне пукотине и фенестриране структуре испуњене финозрним материјалом. У поређењу са претходним чланом, принос материјала са копна био је мањи. Највиши члан представљен је биокластичним кречњацима који се смењују са танкослојевитим лапорцима. Садрже фрагменте љуштура мекушаца, зрна кодиацеа, оогоније харофита и алге *Hemicyclammina sigali.* У вишим деловима овог члана честе су љуштуре гастропода, спикуле сунђера и бодље ехинодермата. Седименти су депоновани у плиткој води, промењљивог салинитета, са честим приносом слатке воде са копна, иза спрудног гребена, а одговарају фацијалним појасевима 7 и 8 према WILSON-у (1975).

Гастроподи описани у раду откривни су у биокластичним кречњацима највишег члана стратиграфског стуба. Фосилоносни локалитети се налазе у Котроману, Мокрој Гори и Растишту и обележени су бројевима 1 до 5 на сл. 1. Описана је нова врста гастропода *Cassiope kotromanensis,* и врсте *Bicarinella bicarinata* и *Paraglauconia lujani* које су одраније познате на нашим локалитетима. У домаћој литератури већ су описане врсте са неким одликама примерака *Cassiope kotromanensis*, али су приписане роду *Cerithium* или роду *Glauconia.* Мора се нагласити да је нова врста врло слична појединим варијететима примерака *Glauconia coquandi* које је описао ЋИРИЋ (1952), али има различит угао завојнице, а оригинални примерци ЋИРИЋА (1952) нису били доступни за детаљнија истраживања. Родови *Paraglauconia* и *Bicarinella* такође су откривени на нашим просторима, али су описани под различитим називима и потичу са других локалитета.

Током истраживања констатовано је да су прикупљени гастроподи знатно мањи од примерака који потичу са других локалитета, ван Србије. Предпостављена су три могућа узрока ове појаве. Први је да гастроподи током алба и ценомана још увек нису достигли димензије одговарајућих припадника исте фамилије у другим, севернијим локалитетима горње креде Тетиса. Други могући узрок је да примерци нису могли да достигну одговарајућу величину услед дејства неповољних фактора средине, честим приносом слатке воде и сл. Трећи могући узрок је класификација и сортирање током транспорта љуштура обављеног после смрти организама, а пре фосилизације. На основу тога је успостављена хипотеза која је проверена статистичким методама. Резултати истраживања су са одговарајућим степеном вероватноће указали да су љуштуре транспортоване пре коначне фосилизације па је ова хипотеза прихваћена као објашњење за ограничен раст индивидуа. Фактори развоја и еволуције организама, као и услови средине, нису у потпуности одбачени али се сматрају као мање вероватни за објашњење малог раста индивидуа.

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# Pollen analyses of Pleistocene hyaena coprolites from Montenegro and Serbia

Jacqueline Argant[1] & Vesna Dimitrijević[2]

**Abstract.** The results of pollen analyses of hyaena coprolites from the Early Pleistocene cave of Trlica in northern Montenegro and the Late Pleistocene cave of Baranica in southeast Serbia are described. The Early Pleistocene *Pachycrocuta brevirostris*, and the Late Pleistocene *Crocuta spelaea* are coprolite-producing species. Although the pollen concentration was rather low, the presented analyses add considerably to the much-needed knowledge of the vegetation of the central Balkans during the Pleistocene. Pollen extracted from a coprolite from the Baranica cave indicates an open landscape with the presence of steppe taxa, which is in accordance with the recorded conditions and faunal remains. Pollen analysis of the Early Pleistocene samples from Trlica indicate fresh and temperate humid climatic conditions, as well as the co-existence of several biotopes which formed a mosaic landscape in the vicinity of the cave.

**Key words**: pollen, coprolites, Pleistocene, cave, Serbia, Montenegro.

**Апстракт.** У раду су приказани резултати анализе полена екстрахованог из копролита фосилних хијена из раног плеистоцена карстне шупљине Трлица у северној Црној Гори и касног плеистоцена пећине Бараница у југоисточној Србији. Копролити потичу од две различите врсте хијена, раноплеистоценске врсте *Pachycrocuta brevirostris*, и касноплеистоценске врсте *Crocuta spelaea*. Мада је број екстрахованих поленових зрна мали, резултати анализе полена из ових узорака дају значајан допринос познавању плеистоценске вегетације централног Балкана, за које иначе постоји врло мало података.

**Кључне речи**: полен, копролити, плеистоцен, пећина, Србија, Црна Гора.

## Introduction

Pleistocene pollen data from the central Balkans are very scanty (Janković *et al*. 1984; Nikolić 1992). The Early Holocene is somewhat better covered. Data on the history of Postglacial vegetation come from the Vlasina peat-bog in south-eastern Serbia (Černjavski, 1938) and the Jelica Mountain in western Serbia (Šercelj & Culiberg 1992). Important information about the Early Holocene vegetation comes from the Vlasac archaeological site found in the Iron Gates sector of the Danube Gorge. It is a Lepenski Vir culture site, excavated in the 1970s (Garašanin 1978; Srejović & Letica 1978). Pollen analysis has been performed on human coprolites (Carciumaru 1978), and gave a rather large number of pollen grains. Findings of coprolites at Pleistocene sites in Montenegro and Serbia gave hope about the potential of palynology in these food stuffs, and provide previously missing data concerning the vegetation.

## Localities

**Baranica.** It is a cave in eastern Serbia, situated on the right bank of the Trgoviški Timok River, approximately 5 km south-east of the town Knjaževac. It is a composite cave consisting of many narrow cave passages. There are several entrances into the cave system; one positioned 15 m above the river bed (260 m altitude) opens into an entrance chamber 5 m wide. This part of the cave is named Baranica I. The other entrance

[1] Unité Mixte de Recherche 6636, Economies, Sociétés et Environnements Préhistoriques, Institut Dolomieu, 15 rue Maurice Gignoux, F-38031 Grenoble, Cedex, France. E-mail: j.argant@wanadoo.fr

[2] Department of Palaeontology, Faculty of Mining and Geology, University of Belgrade, Kamenička 6, 11000 Belgrade, Serbia. E-mail: vesnadim@beotel.net

is located about 20 m above the first (280 m-asl), and is named Baranica II.

Archaeological excavations were first performed in 1994 in Baranica I. The site became renowned because many bones were found that "looked like" bone implements, which were later recognized in further research as hyaena-made. Nevertheless, archaeological implements were found during the continuation of the excavations between 1995 and 1997. Upper Palaeolithic artifacts were found in Baranica I (MIHAILOVIĆ *et al*. 1997) and numerous faunal remains in both Baranica I and Baranica II (DIMITRIJEVIĆ 1997, 1998).

The accumulation of faunal remains is mostly due to the scavenger activity of cave hyenas (DIMITRIJEVIĆ 2004), which produced a very rich vertebrate assemblage. The list of large mammals found gives a good representation of the fauna in the region at this period, with more taxa being found than in any other cave locality in Serbia (Table 1). The regional importance of Baranica is accentuated by the fact that it is the first locality in the region with fauna reflecting the conditions of the Last Glacial Maximum. As opposed to other excavated sites in Serbia, Baranica also shows cold fauna, including the wolverine, *Gulo gulo* and the wooly rhino, *Coelodonta antiquitatis*. It is also worth stressing the absence of warm temperate species such as the roe deer and the wild boar.

Table 1. List of the large mammals found in the caves Baranica I and II, Late Pleistocene, eastern Serbia.

| Order | Species |
|---|---|
| Lagomorpha | *Lepus* sp. |
| | *Ochotona pusilla* (PALLAS) |
| Carnivora | *Canis lupus* LINNAEUS |
| | *Vulpes vulpes* (LINNAEUS) |
| | *Ursus spelaeus* ROSSENMÜLLER |
| | *Gulo gulo* (LINNAEUS) |
| | *Martes martes* LINNAEUS |
| | *Meles meles* (LINNAEUS) |
| | *Mustela nivalis* LINNAEUS |
| | *Crocuta spelaea* (GOLDFUSS) |
| | *Panthera spelaea* (GOLDFUSS) |
| | *Panthera pardus* (LINNAEUS) |
| | *Felis silvestris* SCHREBER |
| Proboscidea | *Mammuthus primigenius* (BLUMENBACH) |
| Perissodactyla | *Coelodonta antiquitatis* (BLUMENBACH) |
| | *Equus ferus* BODDAERT |
| | *Equus hydruntinus* REGALIA |
| Artiodactyla | *Megaloceros giganteus* (BLUMENBACH) |
| | *Cervus elaphus* LINNAEUS |
| | *Bos primigenius* BOJANUS |
| | *Bison priscus* (BOJANUS) |
| | *Capra ibex* LINNAEUS |
| | *Rupicapra rupicapra* (LINNAEUS) |

Besides large mammal bones, remains of small mammals, birds, herpetofauna and fish are also found. Nineteen species of rodents have been identified (Table 2). Similar to large mammals, the small mammal remains indicate the cold conditions of the Last Glacial period, especially boreal and arctic species such as *Microtus gregalis* and *Dicrostonyx* (BOGIĆEVIĆ 2005).

Table 2. List of the rodent fauna found in the caves Baranica I and II, Late Pleistocene, eastern Serbia.

| Family | Species |
|---|---|
| Sciuridae | *Spermophilus* cf. *citellus* (LINNAEUS) |
| Castoridae | *Castor fiber* LINNAEUS |
| Dipodidae | *Sicista subtilis* (PALLAS) |
| Cricetidae | *Cricetulus migratorius* (PALLAS) |
| | *Cricetus cricetus* LINNAEUS |
| | *Mesocricetus newtoni* NEHRING |
| | *Arvicola terrestris* (LINNAEUS) |
| | *Chionomys nivalis* (MARTINS) |
| | *Microtus arvalis* (PALLAS) |
| | *Microtus agrestis* (LINNAEUS) |
| | *Microtus gregalis* (PALLAS) |
| | *Terricolla subterraneus* (DE SÉLYS-LONGCHAMPS) |
| | *Clethrionomys glareolus* (SCHREBER) |
| | *Dicrostonyx* sp. |
| | *Lagurus lagurus* (PALLAS) |
| Muridae | *Apodemus sylvaticus* (LINNAEUS) |
| Spalacidae | *Spalax leucodon* (NORDMANN) |
| Gliridae | *Dryomys nitedula* (PALLAS) |
| | *Muscardinus avellanarius* (LINNAEUS) |

**Trlica.** It is a karstic cavern which opens at 770 m-asl in Triassic limestones, located on the slope of the so-called Trlica Hill, near the city of Pljevlja in northern Montenegro. The Trlica Hill surmounts a Tertiary coal basin and the valley of the Ćehotina River. Palaeontological excavations were performed in three short campaigns (1988, 1990, and 2001). Abundant remains of mammals were found embedded in clastic deposits infilling the karstic cavern (Table 3) (DIMITRIJEVIĆ 1991, 1997, 2004; FORSTEN & DIMITRIJEVIĆ 1995; CRÉGUT & DIMITRIJEVIĆ 2006). Large herbivores, particularly ruminants, are numerous, while carnivores and rodents are each represented by a few bones and/or teeth. Several layers are distinguished in the cave profile (layers I–V), showing that the conditions were changing during deposition, although probably not during a long time span. The stratigraphic age has been correlated to the upper part of the Early Pleistocene (DIMITRIJEVIĆ 1990) and more precisely defined by *Stephanorhinus* cf. *hundsheimensis* (CODREA & DIMITRIJEVIĆ 1997), which correlates the fauna with biozones 20–22 (GUÉRIN 1980) and MQ3 (late Early Pleistocene)

Table 3. List of the mammal fauna found in the Trlica Cave, Early Pleistocene, Montenegro.

| Order | Species |
|---|---|
| Rodentia | *Dolomys dalmatinus* KORMOS |
| | *Hystrix* sp. |
| Carnivora | *Canis etruscus* MAJOR |
| | *Canis falconeri* FORSYTH MAJOR |
| | *Vulpes* sp. |
| | *Ursus etruscus* CUVIER |
| | *Gulo schloseri* KORMOS |
| | Mustelidae gen. et sp. indet. |
| | *Homotherium* cf. *crenatidens* FABRINI |
| | *Panthera* cf. *gombaszoegensis* KRETZOI |
| | *Lynx* sp. |
| | *Pachycrocuta brevirostris* (AYMARD) |
| Proboscidea | *Palaeoloxodon antiquus* (FALCONER & CAUTLEY) |
| Perissodactyla | *Stephanorhinus* cf. *hundsheimensis* (TOULA) |
| | *Equus stenonis* COCCHI |
| | *Equus* cf. *major* BOULE |
| Artiodactyla | *Alces* cf. *carnutorum* (LAUGEL) |
| | *Eucladoceros giulii* KAHLKE |
| | *Cervus elaphus* LINNAEUS |
| | *Megalovis balcanicus* CRÉGUT-BONNOUIRE & DIMITRIJEVIĆ |
| | *Soergelia intermedia* CRÉGUT-BONNOUIRE & DIMITRIJEVIĆ |
| | cf. Rupicaprinae |
| | *Bison* (*Eobison*) sp. |

(AGUSTI *et al*. 1987). The presence of *Hystrix* indicates a temperate climate.

## Samples

Two coprolites, one from the Baranica Cave, and another one from the site of Trlica were extracted for pollen analysis in 2004. The number of pollen grains was low, especially in the Trlica sample. For this reason, five more coprolites were analysed in 2005, which gave better results (Fig. 1). Their dimensions and mass are given in Table 4.

The specimen from Baranica comes from the part of the cave named Baranica II. Specimens from Trlica originate from the layers I, sublayer Ia (TRL 90/10/19, TRL 90/10/21, and TRL 90/34/7) and IV (TRL 90/80/2, TRL 90/82/2, and TRL 90/84/4).

By their shape, dimensions and texture, all specimens resemble hyena coprolites, especially those specimens from Trlica which are complete. The specimen from Baranica is a broken half, showing a compact structure and homogeneous composition on the breakage, which is essentially calcium phosphate originating from the bones consumed by this animal. It is known that pollen is incorporated into coprolites in different ways: absorbed with food (meat and stomach contents of the prey), with water, by the licking of fur or paws and, in some cases, even by ingesting vegetable matter. Taphonomic observations on fresh hyaena dung show that the pollen spectra obtained from coprolites gave relatively unbiased pictures of the landscape (SCOTT *et al*. 2003). Thus, fossil coprolites can provide available palaeoenvironmental information (LEROI-GOURHAN 1966; MOE 1983; SCOTT 1987; ARGANT 1990, 2004; CARRIÓN *et al*. 2001; YLL *et al*. 2006). As they generally correspond to a very short period of time, they should also be indicators of the season when the coprolites were produced (ARGANT 1990, 2004; TOMESCU 2006).

According to the faunal list from the two localities, these coprolites might originate from two different hyena species, Early Pleistocene *Pachycrocuta brevirostris*, and Late Pleistocene *Crocuta spelaea* (ERXLEBEN). Even if the feeding habits of these two species could slightly differ, the chemical composition and morphology of their coprolites look similar. Their life habits and territorial range should be reasonably similar to those of the recent species *Crocuta crocuta*, mostly a scavenger. Since it is considered that members of the latest species cover a territory with-

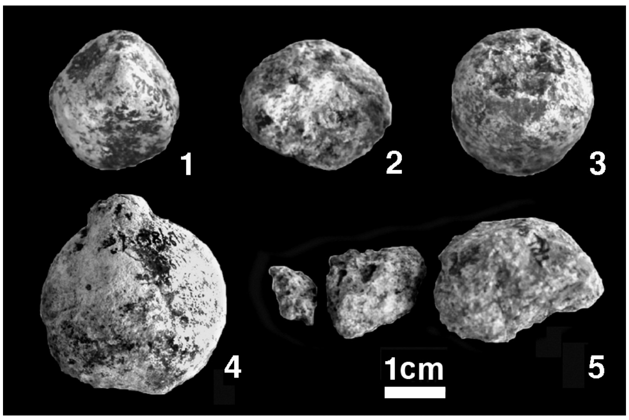


Fig. 1. Five analyzed coprolites from the Early Pleistocene of Trlica, Montenegro. **1,** TRL 90/82/2; **2,** TRL 90/34/7; **3,** TRL 90/84/4; **4,** TRL 90/80/2; **5,** TRL 90/10/19.

Table 4. Dimensions and masses of the coprolites from Trlica, Early Pleistocene, Montenegro. * measurement was impossible because the coprolite was broken

| | Length (mm) | Width (mm) | Thickness (mm) | Mass (g) |
|---|---|---|---|---|
| TRL90/8012 | 32.3 | 30.0 | 32.1 | 24.2 |
| TRL90/10119 | 27.0 | 17.2 | * | 6.7 |
| TRL90/3417 | 24.2 | 22.0 | 25.0 | 13.6 |
| TRL90/8212 | 21.2 | 20.0 | 27.1 | 13.5 |
| TRL90/8414 | 25.0 | * | * | 6.1 |

in a distance up to 4 km (ARGANT 2004), the pollen analyses from coprolites are expected to give data on climatic and edaphic conditions in the near vicinity of the sites.

## Sample preparation

The surface was first very precisely cleaned, by intensive brushing under a jet of water, in order to remove potentially polluted material and to ensure that only the content of the coprolite was treated.

The content of the coprolite was then prepared by concentration in a dense liquid, comprising the following principal stages:

• Decarbonatation with hydrochloric acid, desilicification with hydrofluoric acid (concentration 40%, cold test).

• Removal of the organic matter by heating in potassium hydroxide solution for 10 minutes.

• Concentration in a dense solution (Thoulet solution, potassium iodomercurate d = 2)

• Mounting in glycerin.

• Washing out with distilled water after each operation.

## Results of the pollen analysis, Baranica II Cave (Table 5)

The sample from the Baranica Cave came from half of the coprolite (inventory number BAR II 97/12/3).

Altogether it yielded 13 pollen grains and only 7 taxons. Trees were mostly represented by *Pinus* and *Juniperus*, both genera heliophilous and pioneers. A single deciduous tree was present: *Fraxinus*, a tree demanding moist soil and good exposure to sunlight. Its presence most probably depicting a gallery forest. Among herbs, the genus *Artemisia* was the best represented. It was accompanied by an Asteraceae of the *Carduus* type, one Poaceae and one pollen grain of Scrophulariaceae.

According to these results, it is obviously not possible to precisely reconstruct the past vegetation. Yet, some information can be given: a very open landscape with the presence of steppe taxa related to rather rigorous climatic conditions. Together with the fauna, this is in accordance with the conditions of the Last Glacial. It is not possible to be more precise because of the small number of pollen grains and the isolated character of the sample.

## Results of the pollen analysis, Trlica Cave (Table 5, Fig. 2)

Only three pollen grains were extracted out of the first sample from Trlica, (TRL 90/1021), two originating from trees, and one from grass. Nevertheless, even this small number of pollen grains showed the absence

Table 5. Content of pollen and spores from the Late Pleistocene *Crocuta spelaea* coprolite from Baranica II Cave, and Early Pleistocene *Pachycrocuta brevirostris* coprolites from the Trlica Cave. AP, arboreal pollen; NAP, nonboreal pollen.

| SAMPLE / TAXA | BAR II 97/1213 | TRL 90/1021 | TRL 8012 | TRL 8414 | TRL 3417 | TRL 8212 | TRL 10119 |
|---|---|---|---|---|---|---|---|
| *Alnus* | | | 11 | | 1 | | |
| *Quercus* | | 1 | 7 | | | | |
| *Corylus* | | 1 | 6 | | | | 1 |
| *Pinus* | 2 | | 5 | | | | |
| *Fagus* | | | 4 | | | | |
| *Abies* | | | 2 | | | | |
| *Betula* | | | 2 | | | | |
| *Carpinus* | | | 1 | | | | |
| *Buxus* | | | 1 | | | | |
| *Juniperus* | 1 | | 1 | | | | |
| *Fraxinus* | 2 | | | | | | |
| **AP** | **5** | | **40** | **0** | **1** | **0** | **1** |
| **NAP** | **8** | | **16** | **0** | **0** | **0** | **0** |
| POACEAE | 1 | | 2 | | | | |
| *Artemisia* | 3 | | | | | | |
| CYPERACEAE | | | 2 | | | | |
| RANUNCULACEAE | | 1 | | | | | |
| SCROPHULARIACEAE | 1 | | | | | | |
| Carduus type | 1 | | | | | | |
| *Plantago* | | | 1 | | | | |
| *Calluna* | | | 6 | | | | |
| *Typha latifolia* | | | 1 | | | | |
| Indeterminate | 2 | | 4 | | | | |
| **Total** | **13** | | **56** | **0** | **1** | **0** | **1** |
| Spores de *Sphagnum* | | | 18 | | | | |
| Phytoliths | | | 2 | | | | |
| Ind. Microfossils | | 3 | | | | | |
| Indet. Sporange | | 1 | | | | | |

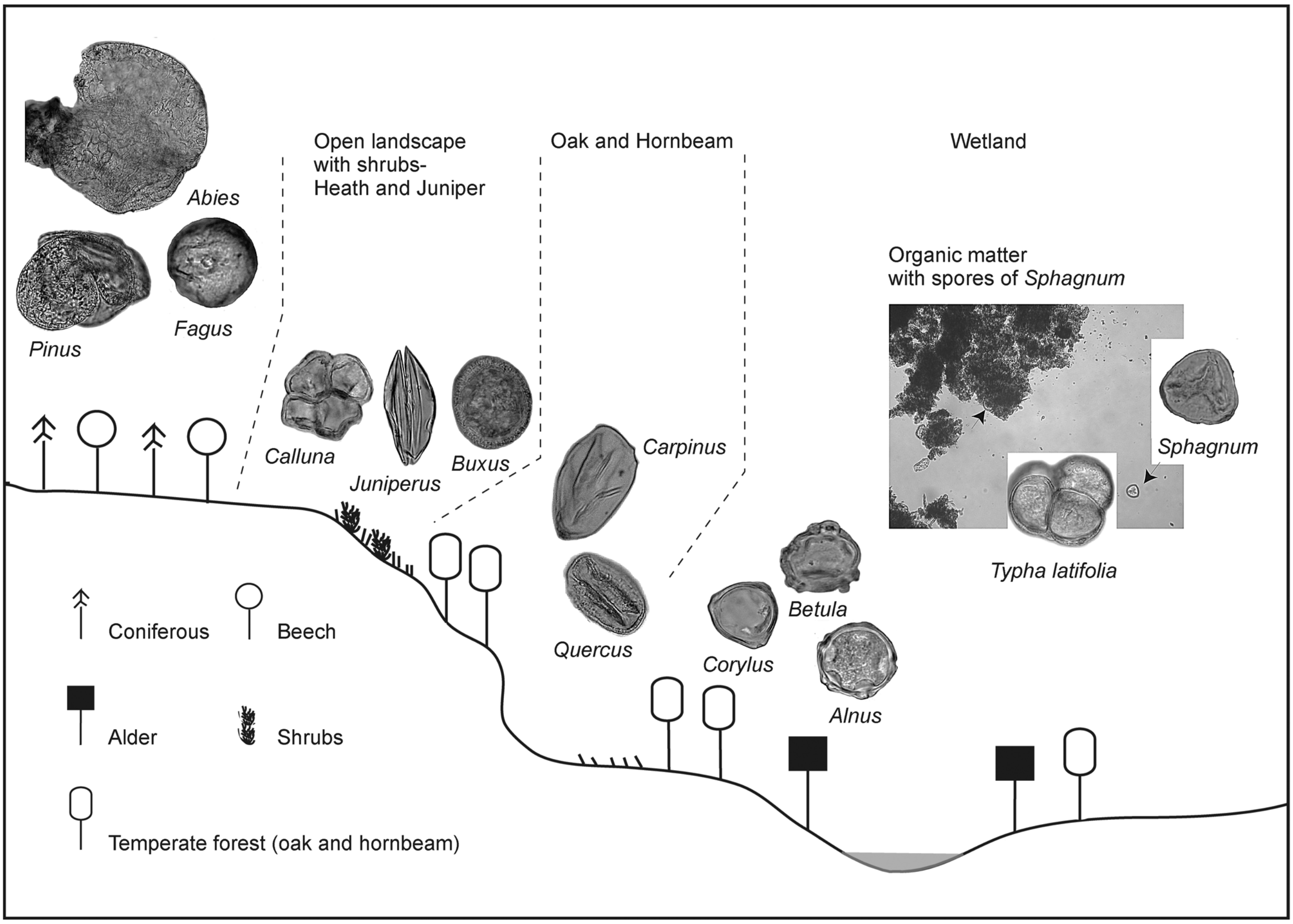


Fig. 2. Pollen extracted from the coprolite TRL 90/80/2 from Trlica, Early Pleistocene, Montenegro. Hypothetical distribution of the taxa along an imaginary profile.

of a steppe environment. *Quercus* and *Corylus* are mesothermophilous trees, demanding temperate and humid conditions.

Due to the small number of grains in this sample, five more coprolites were analysed. All of them were completely searched under the microscope.

Two coprolites were completely sterile: TRL 90/84/4 and TRL 90/82/2. Two others contained a single grain each: TRL 90/34/7 (*Alnus*) and TRL 90/10/19 (*Corylus*). Only the largest and best preserved coprolite, TRL 90/80/2 showed a relatively rich content, with a total of 56 pollen grains (Table 5).

All of the latter were very well preserved, and in some of them the cell structure is still observable. Fifteen different taxons were identified. Tree pollen grains dominated with 40 grains out of the total of 56. Although the sum of pollen grains was not sufficient to calculate percentages, they were sufficient to suggest that wooded areas existed in the animal habitat, and that they occupied an important portion of the region.

A quarter of the tree pollen grains originated from alder (*Alnus*), a tree demanding soil humidity. The animal probably visited an alder forest and, consequently a field in the vicinity of a stream and/or a swamp. This was confirmed by observing moss fibres together with 18 spores of *Sphagnum* cf. *fallax*, a species which is characteristic of swampy fields, peat bogs, alder fields or humid and sour prairies (JAHNS 1989). *Sphagnum* spores do not disperse widely; consequently in this case they could have been absorbed by an animal only at the place at which they developed. Some of them were still sealed in an organic fibrous matter (Fig. 2), which could originate only from swampy alder terrains. A humid environment where animals were coming to drink is also illustrated by a tetrad of club grass (*Typha latifolia*), a species which grows on low elevations, and, in this case, was probably not very far from the cave. Birch undoubtedly represented a part of this humid formation. Oak (*Quercus*) and hazel (*Corylus*) seem to have been quite abundant. Hornbeam (*Carpinus*) and ground box (*Buxus*) were also observed, which can grow in low humid places, but also on more arid slopes, while on higher elevations there were fir (*Abies*) and beech (*Fagus*), although, the presence of fir and beech in a valley cannot be excluded. Finally, the presence of *Juniperus*, heliophilous taxon signalling the presence of openings in the tree cover occupied also by grasses (Poaceae, plantain) and *Calluna* ( Ericacae), was also registered.

The complete pollen content from the coprolites of Trlica enables a tentative reconstruction of the environment in which the Trlica fauna existed. A summary of this reconstruction is given in Fig. 2, illustrating a possible distribution of the identified vegetation, as well as providing photographs of some of the pollen grains extracted from the coprolite TRL 90/80/2.

The reconstruction is, of course, hypothetical, and should be taken with caution. The coexistence of several biotopes is suggested, forming a mosaic landscape where trees occupied an important place. At the bottom of the valley, the humid bank of a stream or a pond was mostly occupied by alder, at the foot of which a moss (*Sphagnum*) carpet had developed. Mesothermophilous trees (oak, hornbeam, hazelnut), as well as shrubs (juniper, ground box and broom) were growing on the slopes, while at higher levels there were fir-beech forests. Throughout this area, open spaces were interspersed. The observed combination of species indicates temperate climatic conditions, fresh and humid, which enabled development of different biotopes dependent on the altitude and on edaphic conditions.

## Conclusion

The number of pollen grains extracted from the coprolites from the two cave localities, Late Pleistocene Baranica in Serbia and Early Pleistocene Trlica in Montenegro, was rather low and gave only modest possibilities for the reconstruction of the vegetation milieu of the surroundings of the two caves. Yet, for those two localities, coprolite analyses gave the only data on the vegetation. This may also be the case for other cave localities in which coprolites are found, since cave sediments are often unsuitable for fossilisation of plant remains, and pollen grains particularly. Since it is well known that important faunal remains, sometimes only available for certain regions or time spans, are often related to caves, the instances of pollen preservation in coprolites are even more valuable. Pollen is not always present in coprolites but encompassed in their mass, pollen grains are sometimes safe from digestive processes and oxygen impact and are, therefore, well preserved. When coprolites are numerous, and their stratigraphical position well-defined, they should be regarded as important for pollen sampling. On the basis of the analyses of pollen extracted from the coprolite from the Baranica Cave an open landscape with the presence of steppe taxons related to rather rigorous climatic conditions is assumed, which is in accordance with the conditions of the Last Glacial and faunal remains recorded. The pollen content from the coprolites of Trlica enabled a tentative reconstruction of the environment. Temperate climatic conditions were indicated, fresh and humid, as well as the co-existence of several biotopes which formed a mosaic landscape, depending on the altitude and edaphic conditions.

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## Резиме

### Анализа полена из фосилних копролита хијена из плеистоцена Србије и Црне Горе

Мало има података о плеистоценској вегетацији централног Балкана, док је, захваљујући анализама полена, ранохолоценска вегетација нешто боље позната. Један од примера реконструкције ранохолоценске вегетације је полен анализа из хуманог копролита са археолошког налазишта Власац. Када смо на плеистоценским налазиштима Бараница у Србији, и Трлица у Црној Гори, поред фосилних костију и зуба, открили и копролите хијена, понадали смо се да се у њима сачувао полен, јер су седименти са истих налазишта, пећински кластити, неповољни за очување полена и биљних остатака уопште.

Узорци копролита, један из горњоплеистоценских слојева пећине Бараница у Србији, и шест из доњоплеистоценских слојева Трлице у Црној Гори (табела 1), послати су у лабораторију у Француску, где су, уобичајеним лабораторијским методама, поленова зрна издвојена из копролита и направљени танки пресеци.

Узорак из Баранице садржао је свега 13 поленових зрна, односно 7 таксона (табела 2). Дрвеће је углавном представљено хелиофилним, пионирским родовима бором (*Pinus*) и клеком (*Juniperus*). Од листопадног дрвећа заступљен је само јасен (*Fraxinus*), дрво коме је потребно влажно земљиште и осветљеност, и чије је присуство вероватно у вези са близином реке. Од трава и грмља, заступљен је пелен (*Artemisia*), затим Asteraceae типа *Carduus*, и по једно зрно Poaceae, Ranunculaceae и Scrophulariaceae. На основу овако малог броја поленових зрна, није, наравно, могуће реконструисати вегетацију, али је ипак очигледно да се ради о отвореним пределима са присуством степских елемената у оштрим климатским условима. То су услови који одговарају последњем глацијалу, односно у сагласности су са одредбом старости на основу фаунистичких остатака.

У узорцима из доњоплеистоценских наслага Трлице број очуваних поленових зрна био је разнолик: у једном се налазило свега три зрна, у два по

једно зрно, два узорка су била потпуно стерилна, а из једног је издвојено 56 зрна (сл. 1; табела 1 и 2).

Поленова зрна су веома добро очувана, и на некима се виде детаљи ћелијске структуре. Одређено је 15 различитих таксона. Доминира полен дрвећа. Добар део поленових зрна дрвећа потиче од јове, дрвета коме је неопходна влага, односно непосредна близина текуће или стајаће воде за преживљавање. Овакви услови одговарају и маховини тресетници (*Sphagnum* cf. *fallax*) од које је пронађено 18 спора. Неке од спора су још увек уклопљене у фиброзну органску материју (сл. 2). На влажну средину указују и рогоз (*Typha latifolia*) и бреза (*Betula*). Прилично бројни су храст (*Quercus*) и леска (*Corylus*). Граб (*Carpinus*) и шимшир (*Buxus*) могу да расту у хумидним низијама, али и на сувљим падинама, док су на вишим деловима терена расли јела (*Abies*) и буква (*Fagus*). Најзад, присуство хелиофилног рода *Juniperus* указује на постојање и отворених простора на којима су расле траве (Poaceae) и *Calluna* (Ericacae).

Покушај реконструкције вегетације у околини Трлице приказан је на сл. 2, на којој је могући распоред индентификованих таксона илустрован сликама појединачних поленових зрна, издвојених из најбогатијег узорка TRL 90/80/2. Реконструкција је, наравно, хипотетичка, и треба је опрезно узети у обзир. Претпоставља се коегзистенција неколико биотопа у мозаичном распореду. Дрвеће игра важну улогу. У долини, влажне обале речног тока, или баре, заузима углавном јова, испод које се развија тепих тресетнице (*Sphagnum*). Мезотермофилно дрвеће (храст, граб, леска), као и грмље (клека, врес и рогоз) расли су на падинама, док су се на узвишењима простирале јелово-букове шуме, испрекидане пропланцима. Асоцијација указује на умерене климатске услове, свеже и влажне, који су омогућили развој различитих биотопа, зависно од висинских и едафских услова.

Полен није увек присутан у копролитима, али, уклопљена у масу копролита, поленова зрна понекад буду сачувана од дигестивних процеса и дејства кисеоника. Када су копролити бројни, а њихова стратиграфска припадност дефинисана, могу бити важни извор узорака за полен анализу, нарочито на оним налазиштима, на којима недостају други материјали погодни за очување полена, као што је случај са пећинским наслагама.

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# Pleistocene malacofauna of the Požarevac Danube Area (NE Serbia)

Biljana Mitrović

**Abstract.** The results of recent analyses of loess samples from the localities: Ćirikovac, Klenovnik, Novi Kostolac, Zatonje and Kisiljevo, confirm the idea that malacological associations identify biotope characteristics. Using palaeontological analyses, 25 species of gastropods were identified. Statistical analyses, tables and histograms based on ecological indices separate malacolgical associations: forest and species living mainly in woods, but also in mesophilous places and both damp and dry biotopes, steppe, open biotopes, mesophilous and hygrophilous species. Based on the current literature on the Požarevac Danube Area, the species *Vertigo pygmaea* in Ćirikovac and *Columella columella* in Klenovnik were recorded for the first time. Based on the following species: *Succinella oblonga*, *Cochlicopa lubrica*, *Granaria frumentum*, *Vallonia costata*, *Vitrea crystallina*, *Pupilla muscorum*, etc. it could be concluded that loessoid eolian sediments have their origin in the arid climate during the Pleistocene.

**Key words:** Pleistocene, gastropods, palaeoecology, loess, loessoid sediments.

**Апстракт.** Проучавањем података из узорака са лесних профила на локалитетима у Ћириковцу, Кленовнику, Новом Костолцу, Затоњи и Кисиљеву, дошла сам до резултата на основу којих се потврђује чињеница да малаколошка асоцијација одређује карактер биотопа. Палеонтолошком анализом идентификовано је 25 врста. Статистичком обрадом података, табеларно и хистограмом на основу заступљености еколошких валенци издвојене су малаколошке асоцијације: шумских и шумскомезофилних врста, степа, отворених биотопа, мезофилних и хигрофилних врста. Према досадашњим литературним подацима, на простору Пожаревачког Подунавља по први пут су пронађене врсте *Vertigo pygmaea* у Ћириковцу и *Columella columella* у Кленовнику.

На основу фауне: *Succinella oblonga*, *Cochlicopa lubrica*, *Granaria frumentum*, *Vallonia costata*, *Vitrea crystallina*, *Pupilla muscorum* и др., може се закључити да су лесоидни еолски пескови стварани у аридном климату за време плеистоцена.

**Кључне речи:** плеистоцен, гастроподи, палеоекологија, лес, лесне творевине.

## Introduction

The Požarevac Danube Area is located along the right bank of the Danube River, from the mouth of the Velika Morava River to the city of Golubac. In the geomorphologic sense, this area belongs to Morava lowland and the Mlava valley, with an average altitude of 85–110 m (Fig. 1).

The relief of the area is composed of low-level lake terraces, desiccated by fluvial erosion. Fluvial erosion has had a huge effect as is evident by the broad fluvial planes and wide river valleys. Erosion significantly reduced the Pliocene lake coverage, and moved it from the recent Danube valley further to the south, which was sometimes left in the form of fold belts (i.e., the Požarevac fold belt).

Quaternary eolian sedimentary loess and quicksand cover 97 % of the Požarevac Danube Area, being the most extensive in this geographic region. Quicksand is limited to the immediate beach areas and lies along a distance of 5–6 km from the Danube River, while loess is stretches further to the south, up to 34 km from the river. In the Požarevac Danube Area, loess sediments were, at the time of their formation, represented by one continuous cover, which was later, as a result of erosion, lowered, and broken into several separated parts:

Natural History Museum, Njegoševa 51, 11000 Belgrade, Serbia. E-mail:bmitrovic3@yahoo.com

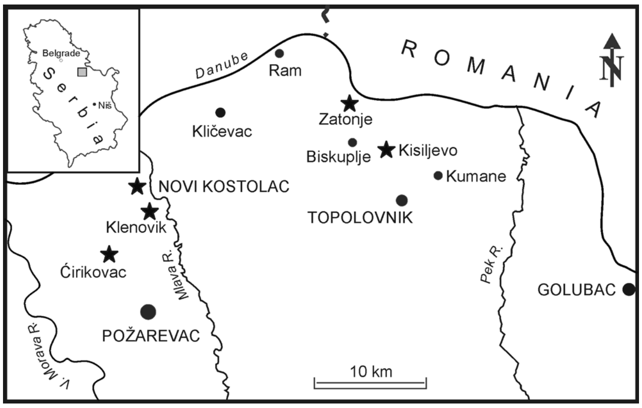


Fig. 1. Geographical position of the sites (blacks stars) with fossil macrofauna.

a) The nearest region between Velika Morava and Mlava rivers and from Požarevac to Kostolac constitutes the "Požarevac fold belt"; b.) Loess sediments between Mlava and Pek rivers follow the banks of the Danube River; from Ram to Pek River, loess outcrop at the lowest terrain between the villages Zatonja and Kisiljeva up to 100 m altitude, and to the highest terrain, where loess covers Tertiary relief from the village Topolovnik to Pek River; c.) Loess from Pek to the town of Golubac has the smallest geographic distribution and is situated at the base of loessoid sand, which according to its morphology and higher absolute altitude could not belong to the Požarevac Slope.

The Holocene is represented with the formations of lower river terraces, fluvial and slope sequences. In the Ram Danube Area (south of Ram, Topolovnik, Kumane, Biskuplje and Kličevac), eolian loessoid sands are well distributed and positioned over the Older Pleistocene sediments of the "Kličevac Formation". The loessoid sediments of the Smederevo–Ram Danube Area are often changed into deluvial formations, composed of gravel which indicates repeated sedimentation through rinsing processes.

Literature on this subject is numerous and includes: ŽUJOVIĆ (1889, 1893), CVIJIĆ (1924), STEVANOVIĆ (1949), MARKOVIĆ-MARJANOVIĆ (1951), MILOJEVIĆ (1960), MILAKOVIĆ (1973), MALEŠEVIĆ *et al*., (1980), RAKIĆ (1980), DIMITRIJEVIĆ & KNEŽEVIĆ (1988), STEVANOVIĆ *et al.* (1992), etc.

## Material and methods

Quaternary malacofauna was collected from sediments in two ways: as individual specimens (visible to the naked eye) and in bulk samples of 3 kg. The specimens visible to the naked eye were collected individually.

During the mechanical processing and extraction of individual fossils from the loess sediments, hand tools, such as trowels, knives and brushes, were used. The taxonomical determination of the "naturally prepared fossils" was done depending on the degree of preservation, on the genus or species level. The extracted fossil snails with preserved sculpture were studied and prepared again in the laboratory. The restoration of the broken shell fragments was made by glue and polish. Employing table lenses, the extremely fragile and tiny specimens were "quickly" transferred in order to preserve the shell specimens. In order to perform the identification of macrofauna with stronger shells, when it was necessary to determine the elements of oral aperture, regularity and structure, these specimens were washed with 3% $H_2O_2$.

The fossil material was identified under binocular lenses, using the comparative collection of fossil and recent molluscs from the Collection of Natural History Museum, Belgrade, collected by PETAR PAVLOVIĆ, as well as foreign literature (BROHMER *et al*. 1962; GROSSU 1956, 1993; FRANK 2004; LOŽEK 1964; KERNEY *et al*. 1983, 1999; ŠILEJKO 1984; KROLOPP & SÜMEGI 1993, 2000; SOÓS 1943, 1959; and PFLEGER 2000).

During the preparation of the histogram, ecological valences for species were used according to LOŽEK (1964). In the text, the percent representation is shown in parentheses after the name of the species. The statistic processing of the results is shown Table 1 and in the histogram in Fig. 7. The material was inventoried and labeled under the Inventory number K 6306-6402 and kept in the collection of the Natural History Museum, Belgrade.

## Results and discussion

### Ćirikovac

According to the Basic Geological Map (MALEŠEVIĆ *et al*. 1980), on the "Kostolac (Požarevac) fold belt", between Požarevac and Ćirkovac, deluvial-proluvial sediments (dpr) lie discordantly over the Pontian sediments – "Kličevac Formation". The major components of the "dpr" are gravels, sand and silty-sands up to 10 m thick, while in the base is loessoid sandy-clayey-silts, 5 m thick (Fig. 2), in which a diverse land fauna of the Upper Pleistocene was identified: *Pupilla sterri* (VOITH), *Chondrula tridens* (MÜLLER) and *Granaria frumentum* (DRAPARNAUD); species of open habitats: *Pupilla muscorum* (LINNÉ), *Vertigo pygmaea* (DRAPARNAUD) and *Vallonia pulchella* (MÜLLER); the mesophilous species *Trochulus hispidus* (LINNÉ) and hygrophilous species: *Sucinella oblonga* (DRAPARNAUD) and *Catinella* cf. *arenaria* (BOUCHARD-CHANTEREAUX) (Pl. 1, Fig. 7). The top level of this profile is composed of fossil soil, 0.5 m in thickness. From the loessoid sands, the only fossil-bearing layer, the warmth-loving *Trochulus striolatus* (PFEIFFER) (Pl. 1, Fig. 9) was recorded as the only representative of forest-mesophilous species (24%). It inhabited

Table 1. Survey of Quaternary malacofauna with a column of percentage distribution on different localities, of the Požarevac Danube area. Explanation of symbols according to Ložek (1964). **1W,** forest associated species; **2W(M),** species living mainly in woods, but also in mesophilous places and both damp and dry biotopess; **4S,** steppe dry sunny places; **5O,** species living in open places without arboreous vegetation; **7M,** mesophilous species which sometimes, can live in damp or dry places; **7Wf,** mesic rupestral and scree-forest species; **8H,** humidity requiring, cold resistant species; **No,** number of the specimens.

| Paleoeco. character. | Molluscan records | L o c a t i o n s | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Čirikovac | | Klenovnik | | Novi Kostolac | | Zatonje | | Kisiljevo | |
| | | No. | % | No. | % | No. | % | No. | % | No. | % |
| 1W | *Discus ruderatus* (Férussac) | | | 9 | 6.25 | 8 | 3.69 | | | 1 | 0.21 |
| | *Cochlodina laminata* (Montagu) | | | 1 | 0.7 | | | 5 | 5.21 | 1 | 0.21 |
| | *Aegopinella nitens* (Michaud) | | | 10 | 6.94 | 8 | 3.69 | 1 | 1.04 | 51 | 11.36 |
| 2W(M) | *Vitrea crystallina* (Müller) | | | 4 | 2.78 | 4 | 1.84 | 15 | 15.63 | | |
| | *Triochulus striolatus* (Pfeiffer) | 39 | 24.84 | 19 | 13.20 | 18 | 8.3 | | | 117 | 26.06 |
| | *Arianta arbustorum* (Linné) | | | | | 5 | 2.3 | | | 2 | 0.44 |
| | *Fruticicola fruticum* (Müller) | | | | | | | 1 | 1.04 | 21 | 4.68 |
| 4S | *Pupilla sterri* (Voith) | 1 | 0.64 | | | 2 | 0.92 | | | | |
| | *Chondrula tridens* (Müller) | 52 | 33.12 | 43 | 29.86 | 55 | 25.35 | 3 | 3.13 | 10 | 2.23 |
| | *Granaria frumentum* (Draparnaud) | 12 | 7.64 | 14 | 9.72 | 14 | 6.45 | 27 | 28.13 | 71 | 15.82 |
| | *Cecilioides acicula* (Müller) | | | | | | | | | 2 | 0.44 |
| 5O | *Pupilla muscorum* (Linné) | 10 | 6.37 | 6 | 4.17 | 19 | 8.75 | 8 | 8.33 | 7 | 1.56 |
| | *Vertigo pygmaea* (Draparnaud) | 3 | 1.91 | | | | | | | | |
| | *Vertigo alpestris* Alder | | | | | | | 2 | 2.08 | | |
| | *Columella columella* (Martens) | | | 1 | 0.7 | | | | | | |
| | *Vallonia costata* (Müller) | | | 2 | 1.39 | 25 | 11.52 | 2 | 2.08 | 24 | 5.35 |
| | *Vallonia pulchella* (Müller) | 8 | 5.1 | 5 | 3.47 | | | | | | |
| | *Catinella* cf. *arenaria* (Bouchard-Chantereaux) | 3 | 1.91 | | | | | | | | |
| 7M | *Euconulus fulvus* (Müller) | | | 3 | 2.08 | | | 3 | 3.13 | | |
| | *Punctum pygmauem* (Draparnaud) | | | 5 | 3.47 | 10 | 4.61 | 8 | 8.33 | 4 | 0.89 |
| | *Trichulus hispidus* (Linné) | 26 | 16.56 | 11 | 7.64 | 17 | 7.83 | 1 | 1.04 | 71 | 15.82 |
| | *Cochlicopa lubrica* (Müller) | | | 5 | 3.47 | 7 | 3.23 | | | 43 | 9.58 |
| 7Wf | *Clausilia dubia* Draparnaud | | | 4 | 2.78 | 11 | 5.07 | 3 | 3.13 | | |
| | *Orcula dolium* (Draparnaud) | | | 2 | 1.39 | 8 | 3.69 | 6 | 6.25 | 17 | 3.79 |
| 8H | *Succinella oblonga* (Draparnaud) | 3 | 1.91 | | | 6 | 2.76 | 11 | 11.45 | 7 | 1.56 |
| | | 157 | 100 | 144 | 100 | 217 | 100 | 96 | 100 | 449 | 100 |

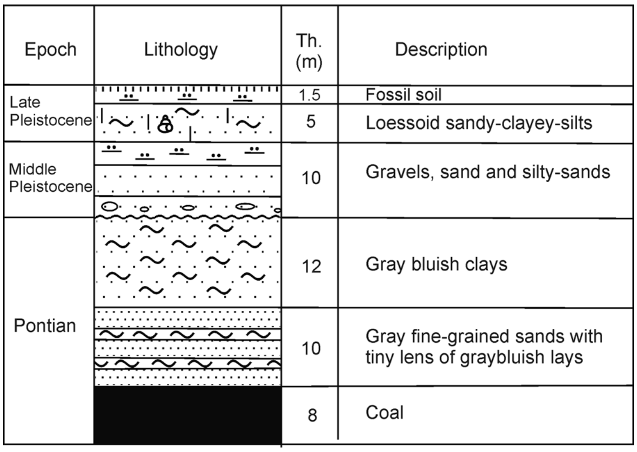


Fig. 2. Detailed view of the upper part of the section from Ćirikovac.

moist forest habitats and high grasses, along the ecotone boundary belt between forest and grasslands.

A colder climate is indicated by steppe fauna (41.4%): *Pupilla sterri* (0.64%), *Chondrula tridens* (33%) and *Granaria frumentum* (7%), while species inhabiting open biotopes: *Pupilla. muscorum* (6%), *Vertigo pygmaea* (2%), *Vallonia pulchella* (5%) and mesophilous *Trochulus hispidus* (16%) were weakly represented.

One of the most common representatives of the genus *Vertigo*, *Vertigo pygmaea,* (Pl. 1, Fig. 5) was recorded only at the locality of Ćirikovac. It occurs in association with species inhabiting open habitats, as well as those living in forests. In the Late Pleistocene, *V. pygmaea* became more common in the sediments originating in cooler and moister periods (Krolopp & Sümegi 1993). From the genus *Vertigo*, *V. pygmaea* is one of a few typical of loess formations (Krolopp & Sümegi 2000).

## Klenovnik

A profile of the Pleistocene sediments was discovered close to Klenovnik on the road to Kostolac, after the right turn towards the school. These sediments lie over Pontian gray coarse-grained quartz sands, 2.5 m thick. The profile (Fig. 3) shows brown silty sands (1.0 m thick), overlaid by reddish sandy clays (1.5 m thick) and light brown silty sands a (2.5 m thick). The exposed profile is covered with silty sands with a low humus content, 0.5 m thick.

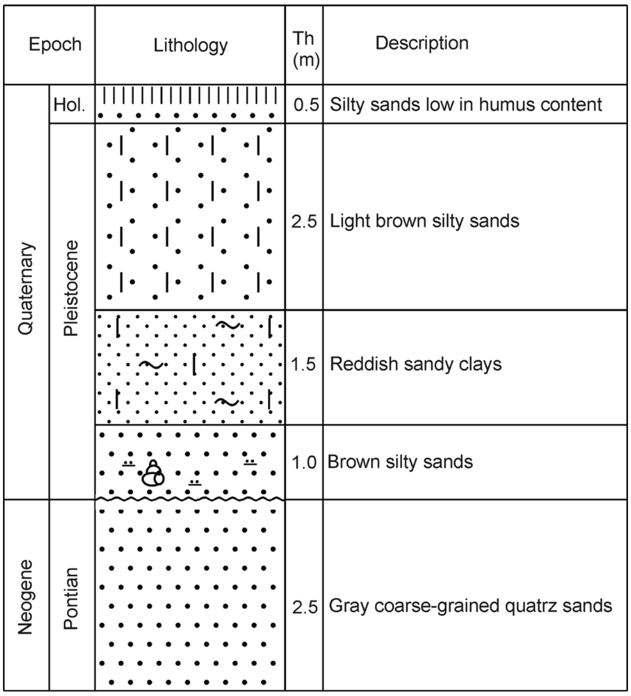


Fig. 3. Detailed view of the upper part of the section from Klenovnik.

In the silty sands, a diverse gastropod fauna composed of species confined to certain habitats was discovered. The forest species were few in numbers: *Discus ruderatus* (FÉRUSSAC) (6.25 %), *Cochlodina laminata* (MONTAGU) (0.7%) and *Aegopinella nitens* (MICHAUD) (6.94%). The mesophilous species of forest biotopes: *Vitrea crystallina* (MÜLLER) (2.78%) and *Trochulus striolatus* (13.20%) belong to species living in conditions of mesic forests. The forest-steppe zone was replaced by steppe, with the characteristic species *Chondrula tridens* (29.86%) and *Granaria frumentum* (9.72%). The species of open spaces, inhabiting biotopes ranging from wetland meadows to steppe: *Pupilla muscorum* (4.16%), *Columella columella* (MARTENS) (0.7%) (Pl. 1, Fig. 3), *Vallonia costata* (MÜLLER) (1.38%), *Vallonia pulchella* (MÜLLER) (3.47%), were replaced by mesophilous species: *Euconulus fulvus* (MÜLLER) (2.08%), *Punctum pygmaeum* (DRAPARNAUD) (3.47%) (Pl. 1, Fig. 10), *Trochulus hispidus* (7.64%), *Cochlicopa lubrica* (MÜLLER) (3.47%), and species of screen forests and rocks: *Clausilia dubia* DRAPARNAUD (2.78%), *Orcula dolium* (DRAPARNAUD) (1.38%).

In the region of the Požarevac Danube Area, the species *Columella columella* was recorded only at this locality. It is a species typical of loess formations, indicating the existence of specific cold tundra areas in Upper Würm, but was also present in the more hygrophilous parts of the steppe (SÜMEGI & RUDNER 2001). It commonly appears in association with other characteristic loess species, such as *Sucinella oblonga*, *Vallonia tenuilabris*, etc.

In these sediments, land fauna of a steppe association was best represented (39.58%), a certain indication that they were formed by wind-blown particles being laid upon the already formed accumulative plain. Such a cover of aeolian dust is connected with the last glaciation or Würm in a broader sense.

## Novi Kostolac

In the vicinity of the coal pit Novi Kostolac, at the surficial pit Drmno, Pontian sediments (Fig. 4) are represented with fine to coarse gravels bound with clay 2 m thick, yellowish, slightly silty sands 1 m thick. Overlying these sediments are sandy loessoid silty sands 5 m thick with a rich association of Pleistocene molluscs: Forest species include *Discus ruderatus* (3.69%) and *Aegopinella nitens* (3.69%). Mesophilous species of a forest biotope are: *Vitrea crystallina* (1.84%), *Trochulus striolatus* (8.3%) and *Arianta arbustorum* (LINNÉ) (2.3%) (Pl. 1, Fig. 12). The following interval of cold winters and a fairly dry vegetation period during the summers caused the appearance of the most common steppe species *Chondrula tridens* (25%), *Granaria frumentum* (6.45%) and *Pupilla sterri* (0.92%) of interstadial stage. The mesophilous species: *Pupilla muscorum* (8.75%) and *Vallonia costata* (11.5%) were especially important in areas characterized by open

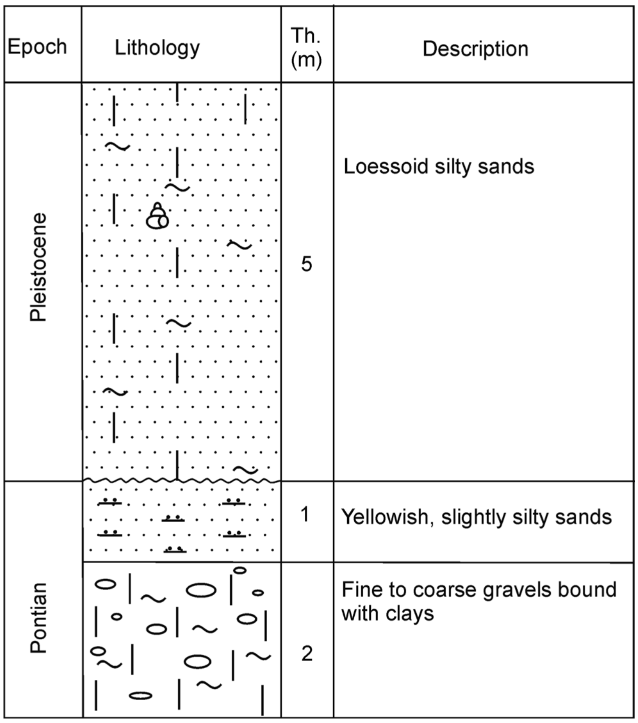


Fig. 4. Detailed view of the upper part of the section from Novi Kostolac.

steppe biotopes. The species *Vallonia costata* is highly tolerant, a so-called species of "transition zones" between open and woodland habitats (KROLOPP 1995). The mesophilous species: *Punctum pygmaeum* (4.6%), *Trochulus hispidus* (7.83%), *Cochlicopa lubrica* (3.2%) replaced the species of screen forest biotopes: *Clausilia dubia* (5%), *Orcula dolium* (3.69%).

The humidity from tree leaves or from moist soil was suitable for life of hygrophilous species, such as *Sucinella oblonga* (2.76%). According to the malacological results from the analyzed locality, the appearance together of warmth-loving, cold-loving and mesophilous fauna is obvious evidence that the loess series was deposited during several phases of stadial and interstadial.

## Zatonje

At the road Ram–Biskuplje, on the right bank of the Danube, at the exit from the village of Zatonje, a profile of sandy sediments, about 12 m thick occurs, which consist of eight determined layers (Fig. 5). The thickest, fifth layer included the fauna of steppe biotopes: *Chondrula tridens* (31.3%), *Granaria frumentum* (28.13%). The species *Sucinella oblonga* (11.45 %) in most of the European loesses is typical snail assemblages of loess steppe. Three ecological groups were present, mesophilous species: *Euconulus fulvus* (3.13%) (Pl. 1, Fig. 8), *Punctum pygmaeum* (8.33%), *Trochulus hispidus* (1.04%); species of open biotopes: *Pupilla muscorum* (8.33%), *Vertigo alpestris* ALDER (2.08%) (Pl. 1, Fig. 2), *Vallonia costata* (2.08%) and species inhabiting forest detritus and rocks: *Clausilia dubia* (3.13%) and *Orcula dolium* (6.25%).

In the gray, fine-grained quartz sands with small lenses of sandy silts (Fig. 5), the fauna of a forest biocoenosis was also recorded: *Cochlodina laminata* (5.21%), *Aegopinella nitens* (1.04%), as well as that of mesic forest biotopes: species *Vitrea crystallina* (15.63%) (Pl. 1, Fig. 11) and *Fruticicola fruticum* (MÜLLER) (1.04%). The species *Vertigo alpestris* was recorded for the first time at the open profile of the locality Zatonje. It is characteristic only for the Upper Pleistocene (Würm), including loess (but it is not typical) (KROLOPP & SÜMEGI 2000). This petrophilous species may be locally an indicator of forest and shrub habitats, during cold and moist climatic periods. According to the collected fauna, the hypothesis of MARKOVIĆ-MARJANOVIĆ (1951) on a multi-phase nature of land loess is supported. Additional proof are the limestone rock plates 1 cm thick, which appear serially in the water wells of the village Zatonje at a depth of 21 m. The other layers are not fossil-bearing.

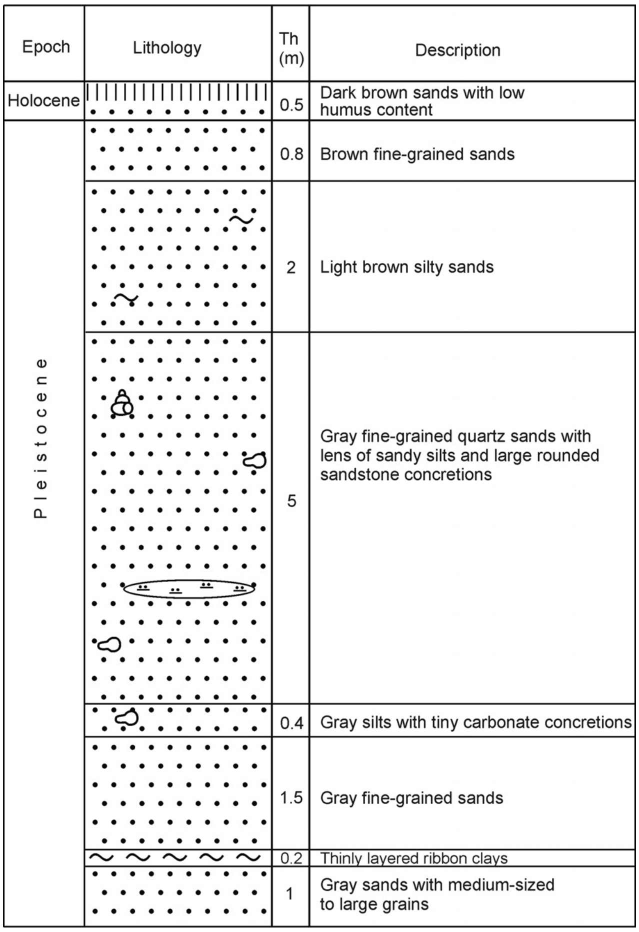


Fig. 5. Detailed view of the upper part of the section from Zatonje.

## Kisiljevo

Between the villages Kisiljevo and Biskuplje, discordantly over Miocene sediments, lay the Lower Pleistocene deluvial folds of the "Kličevac Formation", composed of gravel, sands, silts and tufa (RAKIĆ 1980). In the broader area of the village Kisiljevo toward Topolovnik, the sands are joined in inundation layers by various silts, which are, especially at the surface, of alluvial character and transformed into a loessoid or fluvial horizon 5 m thick (Fig. 6). It contains Holocene malacofauna of a forest biotope: *Discus ruderatus* (0.21%), *Cochlodina laminata* (0.21%), *Aegopinella nitens* (11.36%) (Pl. 1, Fig. 4); and mesophilous fauna *Trochulus striolatus* (26.06%), *Arianta arbustorum* (0.44%), *Fruticicola fruticum* (4.68%). This fauna was included in the formation of a biocenosis belonging to the forest-steppe type, which later became less diverse and turned into some kind of steppe. The species: *Chondrula tridens* (2.23%), *Granaria frumentum* (15.82%) (Pl. 1, Fig. 1) and *Cecilioides acicula* (0.44%) showed that the steppe conditions were maintained for some time. The species *Pupilla muscorum* (1.56%) and *Vallonia costata* (5.35%) confirm the existence of a common feature of steppe adaptations and life in open terrains. The mesophilous species are *Punctum pygmaeum* (0.89%), *Trochulus hispidus* (15.82%) and *Cochlicopa lubrica* (9.58%), while *Orcula dolium* (3.79%) (Pl. 1, Fig. 6) and *Sucinella* *oblonga* (1.56%) represented transitional forms of these and neighbouring associations.

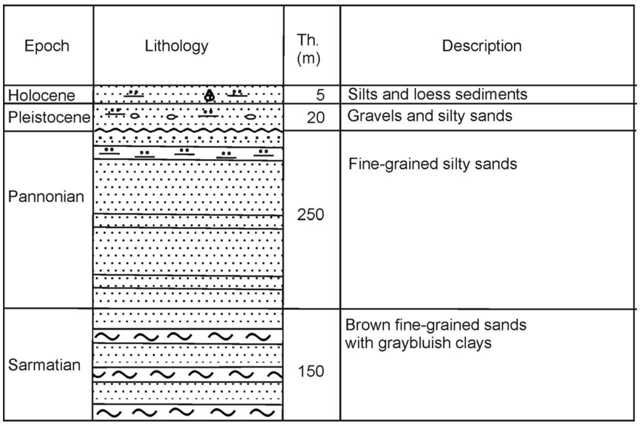


Fig. 6. Detailed view of the upper part of the section from Kisiljevo.

## Conclusions

By analyzing the abundances of malacofauna from loess sediments of the Požarevac Danube Area, several biotopes were recognized (Fig. 7): forest, open areas within forest biotopes, steppe, open biotopes, forest-mesophilous areas and moist biotopes.

and arid winters and humid summers; the succession of "cold-loving forms" and "warm-loving forms" indicate that the loess was deposited in three Würm stadials, while the basal part was deposited during the Ris–Würm interglacial. The majority of these dry, grass, steppes represented the biogeography area of the Pannonian–Dakian steppe, suggesting diluvium origin (MATVEJEV 1961).

The open biotope consists of places of moist meadows and steppe. It is hypothesised that the S and SE winds in the southern parts, enabled the development of open biotopes for many species represented with 11.76%.

The mesophilous species were continually distributed along all of the studied profiles, they are represented with 24.92 %, and could live in fallen leaves and in relatively moist meadows.

According to some hypotheses (RAKIĆ 1977), the ecological conditions with more humid environment formed during the deposition of the oldest horizon, matching the penultimate phase of glaciations. Although the terrestrial fauna of gastropods had the widest distribution, it does not necessarily mean that the sediment was formed on land, because terrestrial forms could also indicate open grassland areas in the vicinity of water or moist ground. The presence of hygrophilous species (2.54%) may indicate that this loess was also occasionally flooded, but still not long enough to develop water fauna.

During the Riss–Würm interglacial, an analogous type of Balkan–Middle European ecological conditions

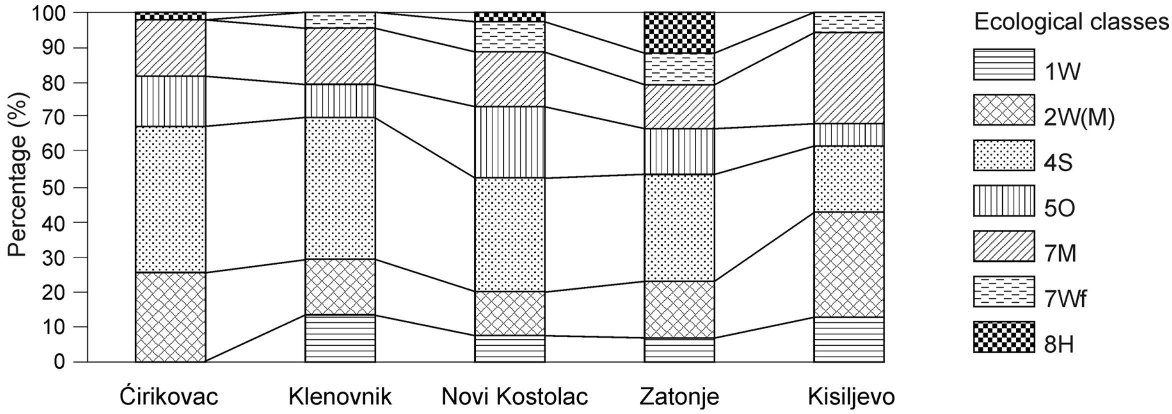


Fig. 7. Percentrage distribution of the terrestrial gastropod fauna on the basis of ecological groups.

Forest and forest-mesophilous species are abundant with 32%; the most common species is *Trochulus striolatus* (Ćirikovac, Klenovnik, Novi Kostolac and Kisiljevo). The "warmth-loving forms" also belong to this group, and they appear mostly in the relatively warmer phases of the late Würm.

Steppe fauna is abundant with 28.78%, with species *Chondrula tridens* and *Granaria frumentum* present at all localities. The steppe species lived in intrazonal biotopes (forest valleys, flooded forests along rivers, etc.), while some of them are representatives of mesophilous groups. The steppe climate was characterized by cold

was occasionally widely distributed in Europe. In the regional sense, the sediments of the "Kličevac Formation" of the Požarevac Danube Area can partially be correlated with similar sediments of the "Srem Formation" at the slopes of Fruška Gora Mountain and the "Zagajička Formation" in Southern Banat (RAKIĆ *et al*. 1998).

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## Резиме

## Плеистоценска малакофауна Пожаревачког Подунавља (СИ Србија)

Проучавањем заступљености малакофауне на лесним профилима Пожаревачког Подунавља, установљено је неколико биотопа: шуме, отворени простори у шумским биотопима, степе, отворени терени, шуме мезофилног типа и влажни биотопи.

Шумске и шумскомезофилне врсте су заступљене 32%, овој групи припадају "топлољубиве форме", које се јављају у релативно топлијим фазама касног вирма. Најзаступљенија врста је *Trichia striolata* (Ћириковац, Кленовник, Нови Костолац и Кисиљево).

Степска фауна присутна је са 28.78%, а најзаступљеније су врсте *Chondrula tridens* и *Granaria frumentum* су заступљене на свим локалитетима. Степске врсте живе у интразоналним биотопима (шумским увалама, плављеним шумама дуж река и др.) а неке су и чланови мезофилних група. Степску климу одликују хладно-суве зиме и жарка лета, смена заједница хладнољубиве и топлољубиве фауне. Састав гастроподске фауне указује да је лесна серија формирана за време Рис-вирмског интерглацијала и у три вирмска глацијала. Већи део ових исушених, травнатих степа, сматра се да представља биогеографско подручје подпровинције панонско-дакијских степа, што указује да су степе "дилувијалне старости" (МАТВЕЈЕВ, 1961).

Отворене биотопе чине влажне ливаде и степе. Претпоставља се да је утицај Ј и ЈИ ветрова у јужним деловима степе, омогућио развој отворених станишта за 11.76% присутних врста.

Мезофилне врсте континуирано се појављују у свим истраживаним профилима са укупно 24.92%, могу живети и у опалом лишћу и на умерено влажним ливадама.

Постоје предпоставке (РАКИЋ 1977) да су се еколошке карактеристике које указују на влажнију средину, одиграле за време депоновања најстаријег хоризонта, што би одговарало претпоследњој фази глацијације. Иако је заступљена углавном сувоземна фауна мекушаца тј. гастропода, то не мора да значи да је седимент стваран на сувом. Копнене форме указују на отворене травнате пределе, који су били у близини воде, односно влажног тла. Присуством хигрофилних врста (2.54%) може се претпоставити да су се више пута формирале баре, али ипак недовољно дуго да би се развила водена фауна.

За време рис-вирмске интерглацијације, аналоги тип балканско-средње-европских еколошких услова био је повремено широко заступљен у Европи. У регионалном погледу седименти "Кличевачке serijом" Пожаревачког подунавља, делимично се могу корелисати са сличним наслагама "Сремске серије" на падинама Фрушке Горе, и "Загајичком серијом" у Јужном Банату (РАКИЋ 1998).

PLATE 1

Fig. 1. *Granaria frumentum* (DRAPARNAUD). Kisiljevo; × 8.

Fig. 2. *Vertigo alpestris* ALDER. Zatonje; × 13.

Figs. 3a, b. *Columella columella* (MARTENS). Klenovnik; × 13.

Fig. 4. *Aegopinella nitens* (MICHAUD). Kisiljevo; × 4.

Figs. 5a, b. *Vertigo pygmaea* (DRAPARNAUD). Ćirikovac; × 26.

Fig. 6. *Orcula dolium* (DRAPARNAUD). Kisiljevo; × 8.

Fig. 7. *Catinella* cf. *arenaria* (BOUCHARD-CHANTEREAUX). Ćirikovac; × 8.

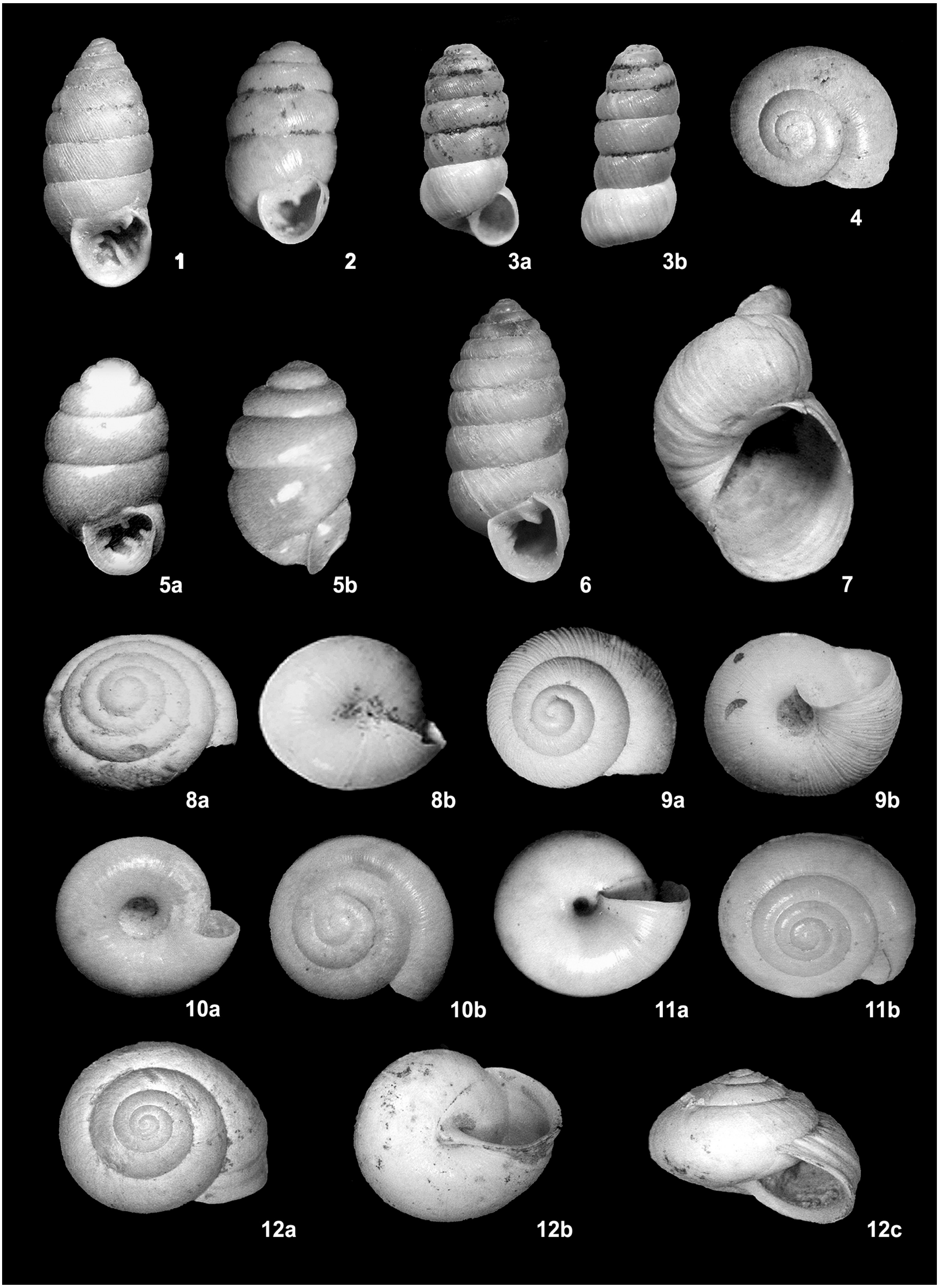
Figs. 8a, b. *Euconulus fulvus* (MÜLLER). Zatonje; × 13.

Figs. 9a, b. *Trochulus striolatus* (PFEIFFER). Ćirikovac; × 4.

Figs. 10a, b. *Punctum pygmaeum* (DRAPARNAUD). Klenovnik; × 27.

Fig. 11. *Vitrea crystallina* (MÜLLER). Zatonje; × 13.

Figs. 12a, b, c. *Arianta arbustorum* (LINNÉ). Novi Kostolac; × 3.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# Thermomineral water of Nikoličevo Spa (eastern Serbia)

Petar Dokmanović, Veselin Dragišić & Slavko Špadijer

**Abstract**. New monitoring results (2000–2002) of the thermomineral water outflow and quality regime of the Nikoličevo Spa (eastern Serbia) show that, during 30 years, a scaling process occurred and decreased the well outflow by app. 80%, as a consequence of well deterioration and reservoir depletion. Consequently (slower water movement), the water temperature increased by 1,5–2° C. Stabile values of the outflow and water quality parameters, registered during new monitoring, show an insignificant influence of the annual meteorological cycle on the outflow and quality regime. According to its chemical composition, the water is sodium-bicarbonate- fluoride, oligomineral and isothermal and a wide spectrum of applications is available. The limit for an efficient exploitation and application of the water is the current low outflow rate, so the drilling of new wells is recommended.

**Key words**: thermomineral water, Nikoličevo Spa, scaling, annual outflow regime, quality.

**Апстракт**. Резултати новог (2000.–2002. год.) мониторинга режима истицања и квалитета термоминералне воде Николичевске бање (Источна Србија) показују да је, током периода од 30 година, издашност бунара опала за око 80 %, највероватније као последица "старења" бунара и делимичне исцрпљености термалног резервоара. Последично (због успореније водозамене), температура вода повишена је за 1,5–2° С. Стабилне величине издашности и параметара квалитета вода, регистроване током нових испитивања, указују да не постоји осетан утицај годишњег метеоролошког циклуса на режим издашности и квалитета. Према хемијском саставу вода Николичевске бање се сврстава у натријум-хидрокарбонатне флуоридне олигоминералне изотерме, са широким спектром могућности коришћења. Лимит за ефикасно коришћење ове воде представља тренутна издашност, па треба приступити изради нових бунара.

**Кључне речи**: термоминерална вода, Николичевска бања, пад издашности, годишњи режим издашности, квалитет.

## Introduction

There is a natural occurrence of thermomineral water in the village Nikoličevo, in eastern Serbia, within the "Timok eruptive region", app. 7–8 km north–east of the town of Zaječar. The thermomineral waters of the Timok region have been known and used for spa treatments since the Roman times. Another 4 occurrences of thermomineral waters are known in the region: Brestovac Spa, Gamzigrad Spa, Šarbanovac Spa and Sumrakovac Spa, all of them being related to the deep faults of a NW–SE general strike. In the seventies of the 20$^{th}$ century, an extraordinary outflow and quality of thermomineral water of the Nikoličevo Spa were stated by drilling holes. Unfortunately, during almost thirty years, there was no real (economic) interest in this hydrogeological phenomenon. During the period 2000–2002 a certain scope of explorations was realized: monitoring of the annual outflow and quality regime in order to define exploitable water reserves.

## Geology

The geological structure of the Nikoličevo Zone is comprised of Barremian–Aptian carbonate forms, flysh, volcanoclastic and volcanic rocks of Upper Cretaceous age and younger Miocene and Quaternary deposits (Fig. 1). The Barremian–Aptian ($K_1^{3,4}$) limestones are developed according to the "Urgonian facies" type, which

Department of Hydrogeology, Faculty of Mining and Geology, University of Belgrade, Djušina 7, 11000 Belgrade, Serbia. E-mail: dokmani@eunet.yu

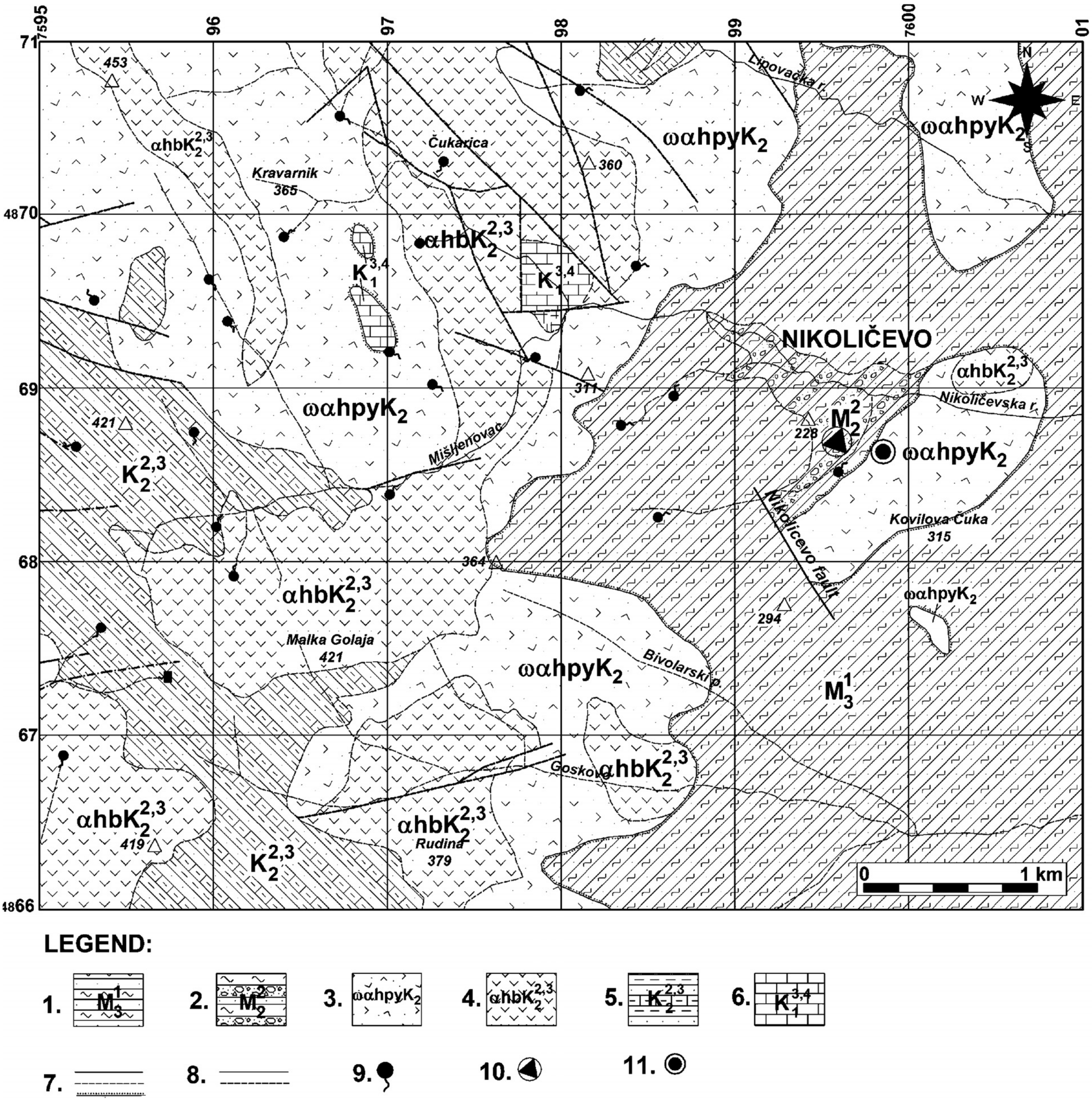


Fig. 1 Hydrogeological map of the Nikoličevo wider zone (after VESELINOVIĆ 1967, simplified). Legend: 1. Miocene sandstones and sandy clays (Intergranular aquifer); 2. Miocene conglomerate, clays, and sands (Intergranular aquifer); 3. Turonian– –Senonian volcanoclastites-agglomerate, breccias, tuff and sandstone (Fissured aquifer); 4. Turonian–Senonian andesites (Fissured aquifer); 5. Turonian–Senonian sandstones, marlstones, marl carbonates (Minor fissured aquifer); 6. Barremian–Aptian limestones (Karst aquifer); 7. Geological contacts; 8. Faults; 9. Spring; 10. Group of thermomineral springs; 11. Group of (B1 and B2) wells.

are supposed to be the outermost northern outcrops of the complex Tupižnica–Knjaževac synclinal. Within the vast and, as to geologic structure, compound Turonian–Senonian volcano-sedimentary complex, there can be singled out: flysch ($K_2^{2,3}$) sediments (sandstone, marlstone, marl carbonate) lying transgressively over Urgonian carbonates; volcanoclastites ($\omega\alpha hpyK_2^{2,3}$) represented by agglomerate, breccias, tuff, sandstone and tuff; andesite ($\alpha hbK_2^{2,3}$ and $\alpha pyK_2^{2,3}$), with a prevailing presence of hornblende. Miocene sediments lie transgressively over the volcano-sedimentary complex, representing the outermost western parts of the Zaječar basin. They are represented by conglomerate, clays, and sands ($M_2^2$), namely sandstone, sandy clays and conglomerate ($M_3^1$). The spreading of Quaternary sediments is completely confined.

The terrain belongs to the Carpathian thrust of the Carpathian-Balkan and within its frame to the Dobrodol–Grlica structural zone. Generally, in the Timok eruptive region, there have been singled out the following fault systems: longitudinal (NNW–SSE), transversal (NE–SW, rarely NNE–SSE) and diagonal fault of E–W strike.

Photogeologic analyze of the Timok region ruptures showed that the oldest fault trends (NN–SSE, NW–SE) were generated by the form and position of the old Hercynian Pluton-Tanda massif, in the eastern rim, and the Homolje–Kučaj massif, in the west. To this group also belongs the Nikoličevo fault (Fig. 1), along which there has been some vertical displacement; thus Miocene sediments are at the same level as older fractured and blocks-divided Cretaceous sediments. Such defined geological relations represented a predisposition for the deep circulation of groundwater, its heating and mineralization.

## Hydrogeology

The following types of water-bearing formations can be singled out (Fig. 1):

1. Confined intergranular aquifer, within Miocene sediments.

2. Fissured aquifer in volcanic and volcano-clastic rocks, where can be distinguished:

a) The part above the erosive basis – low water bearing, gravitational water flow

b) The part below the local erosive basis – within fractured zones with more favourable water bearing (locally) and ascendant and descendent flow.

3. Upper Cretaceous marls and sandstones represent an aquitard or minor fissured aquifer, with local and limited water bearing.

4. Karst aquifer, within Lower Cretaceous limestones represents mainly a semi-open hydrogeological structure. Limestones in deeper parts are recrystallised, while groundwater (with higher temperature, t > 20° C) flows through faults and fissures.

## Thermomineral water occurrences

Several authors has dealt with the thermomineral water in Nikoličevo. ŽIVKOVIĆ (1893) was the first who mentioned "fairly hot, sulphurous water" in Nikoličevo and later LEKO (1922) who stated that there were three hot water springs of which "the main one had a flow rate of app. 3 l/min, with a water temperature of 34° C". MILOJEVIĆ (1973) noted that "in August 1964 three main springs had a total outflow of 0.45 l/s with temperatures 26–31° C". The greatest research contribution was made by Milojević: two boreholes (wells) were drilled near the existing springs. Well $B_1$ was carried out in February 1972 and $B_2$, in May 1972. The occurrences (inflows) of thermomineral water along the boreholes profiles were (MILOJEVIĆ 1973):

$B_1$ well:
– at 16 m – Q = 0.1l/s, t = 28° C
– at 30 m – Q = 0.2l/s, t = 29° C
– at 106 m – Q = 33 l/s, t = 33.80° C

$B_2$ well:
– at 72 m – Q = 0.2 l/s, t = 29° C
– at 157.3 m – Q = 4.4l/s, t = 34.3° C

Water tapping was from fractured andesites and limestones, at the depths of 100–160 m (Figs. 2, 3), without an intake screen (open hole).

All thermomineral water occurrences (springs and well outflows) in Nikoličevo are situated within a radius of app. 100 m. Their total outflow (May 1972) was 17.5 l/s, whereby 16.9 l/s was from the wells, without pumping. The range of the temperatures was 19–34.9° C, whereby the well waters were characterized by higher temperatures (Tab. 1).

Table 1. Thermomineral water occurrences and flow rates – 17 May 1972 (after MILOJEVIĆ 1973).

| Occurrences | Q (l/s) | t° C |
|---|---|---|
| Well B1 | 12.37 | 34.9 |
| Tapped spring 1 | 0.02 | 24.8 |
| Tapped spring 2 | 0.12 | 26.2 |
| Untapped spring 1 | 0.22 | 28 |
| Untapped spring 2 | 0.1 | 25 |
| Untapped spring 3 | 0.1 | 27 |
| Untapped spring 4 | 0.1 | 24 |
| Untapped spring 5 | 0.02 | 19 |
| Untapped spring 6 | 0.01 | 19.5 |
| Untapped spring 7 | 0.0 | 20 |
| Well B2 | 4.4 | 34.3 |

It is obvious that the initial $B_1$ flow rate of 33 l/s (February 1972) was reduced to 12,37 l/s (May 1972), as a consequence of: 1. the hydraulic influence (participation) of $B_2$ outflow of 4.4 l/s, and 2. an usual scalling with time, as a consequence of the accomodation of a piesometric level in the well radius.

## Flow rate scaling

During the period August 2000 – February 2002, flow rates and water temperature measurements were carried out. It was established that the flow rate of the $B_1$ well oscillated within 2.22–2.53 l/s, while the flow rate of the $B_2$ well oscillated within 0.63–0.71 l/s, the total flow rate was 2.9–3.2 l/s (Fig. 4). This means that during 28 years (1972–2000), the total flow rate of the wells was very reduced, by more than 80 %.

Probably, the main reasons for the scaling are:

1. Well deterioration;

2. Depletion of the thermal water reservoir

Well deterioration processes could be:

– Physical (mechanical) causes-rock collapse in the intake unscreened hole parts of the wells or intensive deposition of particles carried from the aquifer in the

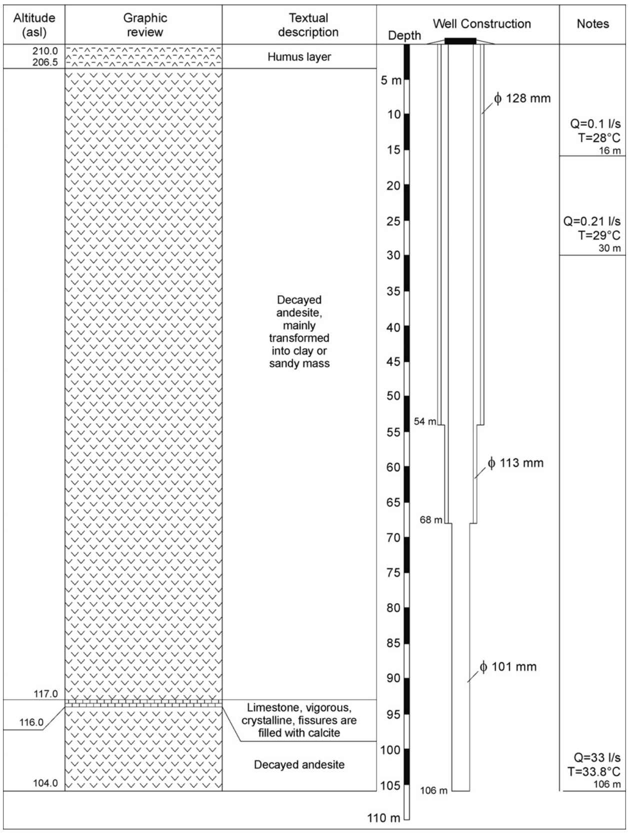


Fig. 2. Lithological profile and construction of well B-1 (after MILOJEVIĆ, 1973, simplified).

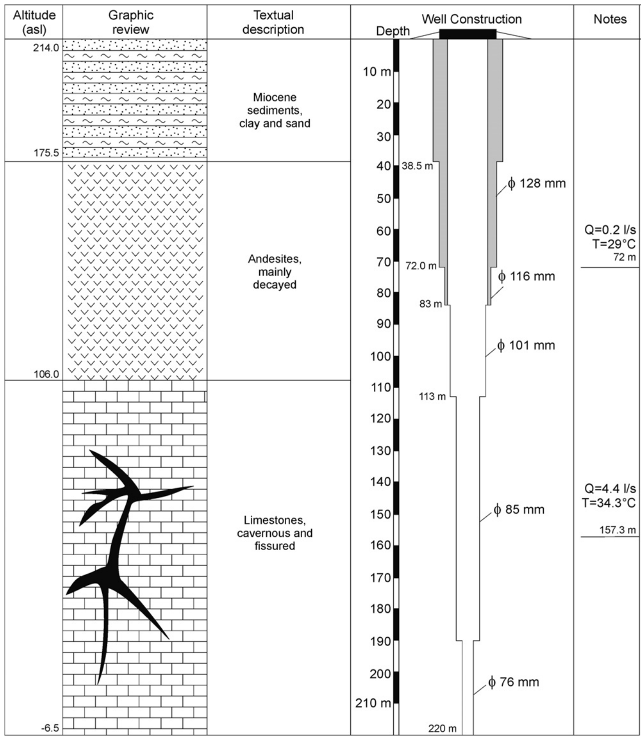


Fig. 3. Lithological profile and construction of well B-2 (after MILOJEVIĆ, 1973, simplified).

intake parts. Both of the mentioned causes are possible, because of the profiles properties (Figs 2, 3): decayed andesites (well $B_1$) or cavernous limestones (well $B_2$).

– Chemical incrustation of the intake parts and well casings and, also, of the transit aquifer zones, next to the holes. Generally, lowering of hydrostatic pressure (by groundwater tapping) and, also, changes of groundwaer velocity upsets the chemical, especially carbonate and iron equilibrium of groundwater, so incrustation occurs. The process is more rapid in the small intake spaces (drill diameters 76–101 mm, Figs 2, 3) and the manifestation of scaling is more noticable.

Reservoir depletion could be the consequences of a continual free (uncontrolled) long term outflow of wells.

## Water quality

The water temperatures were also measured during the period August 2000 – February 2002: 35.5–36.6° C for the $B_1$ well, and 36.2–37.0° C for the $B_2$ well. (Fig. 4). The temperatures were higher by 0.6–2.7° C than the ones in May 1972 (Tab. 1).

According to the chemical composition (Tab. 2), thermomineral waters of the Nikoličevo spa are sodium carbonate ones, with the total mineralization fluctuating between 466 and 650 mg/l, low iron and manganese concentrations, pH value from 6.7 to 8.3, and the presence of undissolved $H_2S$ gas. One of the essential features of the water is a higher fluoride (F) concentration (2.79–3.8 g/l). It should be stated that differences between the chemical components (Tab. 2) arise, partly, as a result of the analytical methods of different chemical laboratories. The most noticeable difference is the one between the concentration of $H_2S$ gas (Tab. 2) in 1972 (4.5–5.1 mg/l) and in 1995 (0.28–0.38 g/l), but

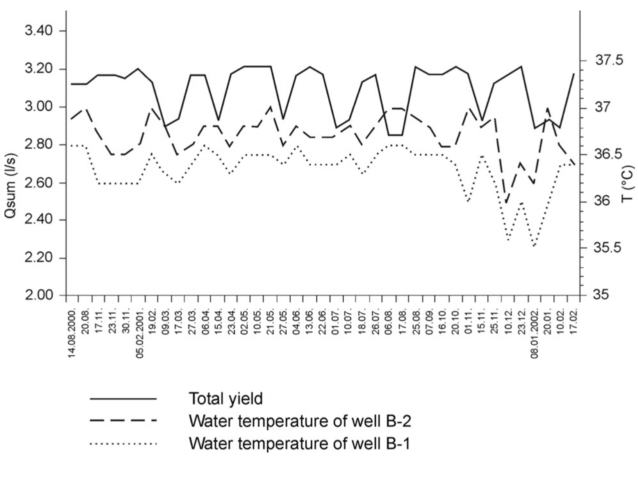


Fig. 4. Flow rates and water temperatures of the wells B-1 and B-2 (August 2000 – February 2002).

Table 2. Chronological survey of some chemical components of the thermomineral water.

| Date<br>Well | Total miner. (mg/l) | Dry residue (mg/l) | Na+K (mg/l) | $HCO_3$ (mg/l) | Fe (mg/l) | Mn (mg/l) | $H_2S$ (mg/l) | F (mg/l) | pH |
|---|---|---|---|---|---|---|---|---|---|
| 1972 (1) | | | | | | | | | |
| B-1 | 541.2 | 487,7 | 147 | - | 0.3 | 0.0 | - | - | 7.0 |
| 1972 (2) | | | | | | | | | |
| B-1 | - | 500 | 147.5 | 366 | | | 4.25 | | 7.6 |
| B-2 | - | 490 | 147.5 | 366 | - | - | 5.1 | - | 7.6 |
| 1995 | | | | | | | | | |
| B-1 | 650 | - | 134.2 | 328.8 | 0.17 | <0.01 | 0.28 | 3.8 | 7.5 |
| B-2 | 650 | - | 131.7 | 325.5 | 0.13 | <0.01 | 0.38 | 3.6 | 7.6 |
| 1997. | | | | | | | | | |
| B-1 | - | 519 | - | - | - | - | - | - | 8.12 |
| B-2 | - | 510 | - | - | - | - | - | - | 8.04 |
| 11.09.'00 | | | | | | | | | |
| B-1 | 503.66 | | 143.5 | 372.0 | 0.01 | 0.0 | - | - | 7.95 |
| B-2 | 502.82 | | 138.1 | 378.6 | 0.03 | 0.0 | - | | 7.98 |
| 08.06.'01 | | | | | | | | | |
| B-1 | 490.35 | | 155.2 | 426.9 | 0.01 | 0.0 | - | - | 6.94 |
| B-2 | 455.67 | | 138.2 | 369.4 | 0.02 | 0.0 | - | - | 7.49 |
| 07.09.'01 | | | | | | | | | |
| B-1 | 498.07 | | 147.6 | 391.6 | 0.01 | 0.0 | - | - | 7.30 |
| B-2 | 489.96 | | 138.6 | 378.6 | 0.01 | 0.0 | - | - | 6.88 |
| 16.10.'01 | | | | | | | | | |
| B-1 | 466.80 | | 140.6 | 391.6 | 0.01 | 0.0 | - | - | 7.35 |
| B-2 | 461.77 | | 126.2 | 391.6 | 0.01 | 0.0 | - | - | 6.70 |
| 09.11.'01 | | | | | | | | | |
| B-1 | - | | - | - | <0.05 | <0.025 | - | - | 8.30 |
| B-2 | - | | - | - | <0.05 | <0.025 | - | - | 8.30 |
| 10.01.'02 | | | | | | | | | |
| B-1 | - | | - | - | <0.05 | <0.025 | - | - | 7.90 |
| B-2 | - | | - | - | <0.05 | <0.025 | - | - | 8.00 |
| 26.02.'02 | | | | | | | | | |
| B-1 | - | | - | - | - | <0.025 | - | - | 7.70 |
| B-2 | - | | - | - | - | <0.025 | - | - | 7.90 |
| 06.09.'02 | | | | | | | | | |
| B-1 | - | 400 | - | - | 0.03 | <0.01 | - | 2.82 | 7.50 |
| B-2 | - | 400 | - | - | 0.06 | 0.01 | - | 2.79 | 7.70 |

the availlable results of only two gas analyses are insuficient for a proper interpretation.

On the basis of the hydrochemical results, the water belongs to the category of sodium carbonate, fluoride, isothermal, oligomineral ones, suitable for balneotherapy, drinking (limited, because of fluorine concentration) and recreation purposes.

An analysis of gas composition show the nitrogen type and vadose origin of the water (DIMITRIJEVIĆ 1975).

## Conclusions

Thermomineral water of Nikoličevo Spa was tapped by two wells, at a depth of 100 to 160 m. A karst-fissured aquifer was formed within Cretaceous andesites and limestones. Thermal character, as well as certain chemical properties, result from circulation of the groundwater deep in the Nikoličevo fault zone.

During the period 1972–2000, scaling occured and the flow rate decreased by more than 80 %, from the initial 17 l/s to 3 l/s, as a consequence of the deterioration of the wells and reservoir depletion. The reduced flow rate and, consequently, slower groundwater movement, resulted in the water temperature rising by 0.6–2.7° C .

The annual regime (August 2000 – February 2002) of the wells, flow rates and the water temperature were assessed as quite stable, without significant influence of the annual meteorological cycle.

The chemical composition and water temperature enable manifold utilization, especially in the domain of balneology and recreation, but the current low flow rate is limiting.

The depth of the intake zones and the existence of overlaying confining beds, as an insulator from (potential) surface pollution, are the favourable aquifer vulnerability factors.

In order to use and sustain this natural resource, the following should be done:

• TV, calliper, temperature and/or flow-velocity logging of the holes, if possible (because of the small diameter), in order to identify the inflow and incrustation zones in the holes and causes of the deterioration.

• Drill a new well or wells, next to the location of the existing one(s), of suitable constructions, primarily of larger drill diameters. Construction and position of the intake parts will depend on the results of wells logging. As to the location $B_1$, it should include greater depth from 160–170 m as well. This will provide considerably larger flow rate(s) than the current one(s).

• Proper sanitation (dysfunction) of the existing holes, because of low production, as well as sanitary protection of the resource.

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## Резиме

## Термоминерална вода Николичевске бање (источна Србија)

Природни извори термоминералних вода, слабе издашности, налазе се у селу Николичеву, у источној Србији, у оквиру тзв. "Тимочке еруптивне области", на сса. 7–8 km североисточно од Зајечара. Термоминералне воде егзистују у оквиру комплексне карстно-пукотинске издани, формиране у оквиру доњокредних кречњака и горњокредних вулкано-кластичних стена, а предиспозицију за њихово формирање (дубоку циркулацију) чине раседи правца пружања ССЗ–ЈЈИ.

Двема истражним бушотинама из 1972. године, дубина 106 и 220 m, констатоване су изванредне квантитативне и квалитативне карактетистике: сумарна издашност од сса. 17 l/s (самоизливом) и температура вода од 34–35° С. Режимским осматрањима спроведеним у периоду август 2000. – фебруар 2002. године, установљено је да је, услед процеса старења бунара и, вероватно, делимичне исцрпљености "резервоара" термалних вода, издашност опала за сса. 80 % и износи 2,9–3,2 l/s, док је температура вода, због успореније водозамене (мањег истицања) повишена на 35,5–37° С. Стабилне величине издашности и температуре, мерене у периоду 2000. – 2002. год., указују да не постоји осетан утицај метеоролошког циклуса на режим вода.

Према хемијском саставу, који се за наведени 30-годишњи период може оценити као стабилан, воде се сврставају у натријум-хидрокарбонатне флуоридне олигоминералне изотерме, са широким спектром могућности коришћења. У циљу ефикаснијег коришћења овог изванредног ресурса, потребно је санирати постојеће и израдити нове водозахвате одговарајућих конструктивних карактеристика.

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Material being described must be registered as part of a formal collection housed in some recognised Institution so that it is accessible and available for study by other workers.

Paper should be arranged as follows: title, name and surname (in full) of author or authors, abstract, key words, adresses (foot note on the 1st page) with a mention of the parent organisation and e-mail address, text, acknowledgements, references, summary, figures, tables, and plate captions.

**The title of the paper** should be short, but expressing the principal aim of the paper.

**The abstract** must be concise, not more than 200–250 words, and should be informative, stating the results presented in the article rather than describing its contents. Inclusion of references in the abstract is not recommended.

After the abstract, list 5–8 **keywords** which describe the subject matter of the work. They should be arranged from general to more specific ones.

The **text** should be written as clear and understandable as possible. Use up to threee levels of headings. Their hierarchy should be indicated in the left-hand margin of the text. Italics are used only for the name of genera and species, or if a word is italicized in the original title. References should be cited in the text as follows: DAMBORANEA (2002) or (DANBORANEA 2002) for a single author; FÜRSICH & HEINZE (1998) or (FÜRSICH & HEINZE 1998), for two authors; RICCARDI *et al*. (1991) or (RICCARDI *et al*. 1991) for multiple-author works.

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AGER, D.V. 1963. *Principles of Paleoecology*. 318 pp. McGraw-Hill, New York.

OWEN, E.F. 1962. The brachiopod genus *Cyclothyris*. *Bulletin of the British Museum (Natural History)*, *Geology*, 7 (2): 2–63.

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**Acknowledgments** should be as short and concise as possible.

A **summary** (up to 15% of the paper) is published in Serbian and should contain the essence of all new data and the conclusions.

**Illustrations** can be submitted as conventional hard-copies or in electronic form. The preferred formats for graphics are TIF, EPS, CDR (600 dpi) and for photographs and plates TIF (600 dpi). All original drawings and photographs should be in the form of glossy prints of profesional quality. The illustrations should have a width of 8.4, 12 or 17.5 cm, the final limit is the size of type area (17.5 × 24.5). Lines and letters must be suitable for reduction. It is also recommended to send copies reduced to the size for publication; after reduction, the smallest lettering should be not less then 1 mm and not greater than 4 mm in height. The aproxiamte position of figures and tables should be indicated in the manuscript margin. Do not incorporate illustrations in the text of the paper. Figure, table and plate captions should be listed on separate sheets. The author's name and figure number should be indicated at the foot of the illustration. The figure numbers can be writen by hand on a paper copy of the plate or on a transparent overlay, not on the plate itself. The cost of printing colour figures must be paid in full by the author.

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All **correspondence**, enquires and manuscript submissions should be directed to the Editor-in-Chief of *Geološki anali Balkanskoga poluostrva*.

Prof. Dr. Vladan Radulović
Institute of Regional Geology and Paleontology
Faculty of Mining and Geology
University of Belgrade
Kamenička 6, 11000 Belgrade
Serbia
E-mail: vrad@eunet.yu – only for correspondence

ГЕОЛОШКИ АНАЛИ БАЛКАНСКОГА ПОЛУОСТРВА
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